TMSA: participatory sensing based on mobile phones in urban spaces

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Abstract. A design for a novel mobile sensing system, called Temperature Measurement System Architecture (TMSA), that uses people as mobile sensing nodes in a network to capture spatiotemporal properties of pedestrians in urban environments is presented in this paper. In this dynamic, microservices approach, real-time data and an open-source IoT platform are combined to provide weather conditions based on information generated by a fleet of mobile sensing platforms. TMSA also offers several advantages over traditional methods using participatory sensing or more recently crowd-sourced data from mobile devices, as it provides a framework in which citizens can bring to light data relevant to urban planning services or learn human behaviour patterns, aiming to change users' attitudes or behaviors through social influence. In this paper, we motivate the need for and demonstrate the potential of such a sensing paradigm, which supports a host of new research and application developments, and illustrate this with a practical urban sensing example.

Keywords: Pedestrian-oriented applications · Participatory Sensing · Crowdsourcing · Open-source IoT platform

1 Introduction

The recent development of telecommunication networks is producing an unprecedented wealth of information and, as a consequence, an increasing interest in analyzing such data both from telecoms and from other stakeholders' points of view. In particular, mobile phones with a rich set of embedded sensors, such as an accelerometer, digital compass, gyroscope, Global Positioning System (GPS), microphone, and camera, generate datasets that offer access to insights into urban dynamics and human activities at an unprecedented scale and level of detail.

Collectively, these sensors give rise to a new area of research called mobile phone sensing. They are relevant in a wide variety of domains, such as social networks [1], environmental monitoring [20], healthcare [17], and transportation [21] because of a number of important technological advances. First, the availability of cheap embedded sensors is changing the landscape of possible applications (e.g. sharing the user's real-time activity with friends on social networks such as Facebook, or keeping track of a person's carbon footprint). Second, to sensing, smartphones come with computing and communication resources that offer a low barrier of entry for third-party programmers (e.g., undergraduates with little phone programming experience are developing applications). In addition, the mobile computing cloud enables developers to offload mobile services to back-end servers, providing unprecedented scale and additional resources for computing on collections of large-scale sensor data and supporting advanced features.

The omnipresence of mobile phones thanks to its massive adoption by users across the globe enables the collection and analysis of data far beyond the scale of what was previously possible. Several observations can now be made thanks to the possibility of crowdsourcing using smartphones. Since 94.01% of the population has mobile network coverage in 138 countries [13] and it is expected to reach more than one billion people by 2022, there is a huge potential for obtaining real-time air temperature maps from smartphones. This will enable a new era of participatory engagement by global population, where the data required is in part willingly provided by citizens via smartphone apps. Although it raises complex societal issues that must be addressed as we face this new era, it also provides an unprecedented opportunity for the citizens of a community to play an active role in the betterment of their community, not only in terms of reporting critical environmental and transportation data, but also in mitigating the very challenges their own data identifies. It will be a cooperative and informed effort, with information technology enabling societal transformation, to address the growing challenges our cities face in the coming decades [19]. Therefore, crowdsourcing opens the door to a new paradigm for monitoring the urban landscape known as participatory sensing.

Participatory sensing applications represent a great opportunity for research and real-world applications. In [12], CarTel is a system that uses mobile phones carried in vehicles to collect information about traffic, the quality of en-route WiFi access points, and potholes on the road. Other applications of participatory sensing include the collection and sharing of information about urban air and noise pollution [9], or consumer pricing information in offline markets [11]. Additionally, they also changed living conditions and influenced lifestyles and behaviours. In indoor activities, energy demand planning [2] will become more challenging, given the projected climate change and its variability. In order to assess the resource implications of policy interventions and to design and operate efficient urban infrastructures, such as energy systems, greater spatial and temporal resolutions are required in the underlying resources that demand data. Besides, they accommodate pedestrian traffic and outdoor activities, and greatly contribute to urban liveability and vitality. Therefore, outdoor spaces that provide a pleasurable thermal comfort experience for pedestrians effectively improve their quality of life [3].

An Internet of Things (IoT) framework can be proposed to support citizens in making decisions about daily activities by a notification system based on a faster access to air temperature data. But data accuracy can be improved by creating an application that promotes participatory sensing. In this tool, the individuals and communities using mobile phones, online social networking and cloud services collect and analyze systematic data. This technology convergence and analytical innovation can have an impact on many aspects of our daily lives and community knowledge can help determine our actions. Since our work is currently focusing on these approaches, this paper will present a blueprint that we have created for air temperature screening that we call Temperature Measurement System Architecture (TMSA).

The rest of this document is structured as follows: Section 2 introduces different use cases from the participatory sensing domain which depict the usage of mobile devices from different points of view. Then, based on a state of the art analysis we propose the TMSA that gathers real-time data to allow citizens to acess air temperature (and other parameters of weather conditions), and explain how it can influence users' attitudes or behaviors. Section 3 investigates existing IoT building blocks by means of protocols, components, platforms, and ecosystem approaches in the form of a state of the art analysis. Additionally, TMSA infrastructure proposes concrete technologies for the corresponding building blocks of the cloud architecture and their data flow between each. Finally, Section 4 concludes this document with a discussion on the resulting architecture specification and its compatibility with the other work packages as well as an outlook on future work within TMSA.

2 Background

To make the best use of currently available literature, we reviewed and herein present an analysis of participatory sensing applications studies with the goal of better understanding the variables that affect daily human activities. Besides, real time monitoring is an emerging technology in both mobile technologies, such as tablets and smartphones, and plays an important role in society. Some studies prove the challenges and limitations to implement non-invasive methods with this kind of sensors. Offering a simple method for mobile sensing could increase the acceptance to monitor and achieve satisfactory results.

2.1 Participatory Sensing via Mobile Devices

With an increasing number of rich embedded sensors, like accelerometer and GPS, a smartphone becomes a pervasive people-centric sensing platform for inferring user's daily activities and social contexts [14]. Additionally, as we mentioned, the number of users with access to mobile technology has increased rapidly around the globe. Besides, data sensing techniques are becoming widely used in various applications including forecasting systems, for example, in [5], the potential of participatory sensing strategies to transform experiences, perceptions, attitudes, and daily routine activities in 15 households equipped with wood-burning stoves in the city of Temuco, Chile. In our previous work [16], crowdsensing data establishes an easy connection between citizens and technology innovation hub to acquire detailed data on human movements. Based or not on empirical observation we can gather air temperature data with the support of people via their mobile phones.

In this work, participatory sensing is aligned with five key principles that spread across areas of design, organizational development, and community action research [18]. It includes:

- Active Citizens: where users work in partnership and contribute to the common good;

- Building Capacities: understanding that sustainable transformation requires a certain amount of trust, which is built through communication and a culture of participation;
- Building Infrastructure and Enabling Platforms: the purposeful devising of structures and platforms support participation, with a focus on sustainability, long-term action and impact;
- Intervention at a Community Scale: harnessing the collective power of the community and using a community-centred approach and community-driven solutions, so that communities become the catalyst of interventions for large-scale and transformative change;
- Enhancing Imagination and Hope: supporting and enhancing the ability for communities to imagine new possibilities, and building a shared vision based on seeing the future in a new light and collectively working towards shared objectives.

In fact, participatory sensing is a method or an approach to extract any kind of data from the communities which can be used for their own benefit and solve global challenges at a local level. The main sensing paradigm of our study enables monitoring air temperature from mobile phones and, besides, other weather parameters using external sensor networks. Using information collected by pedestrians, the resulting system produces more accurate reports than systems that do not rely on multiple input sources.

2.2 Challenges of Mobile Phone Sensor Technology

Table 1. Limitations and issues in temperature-measuring apps (adapted from [15]).

Context	*Restriction*	*Description*
Hardware	Collection of sensor data across mobile platforms and devices	– Participants not charging or turning off their phones – Unavailability of any network connections, hampering data transfer to servers
	Data collection influences data completeness and differ between operating systems	– Collection of sensor data is easier to support on Android than iOS – More apps are available for Android than for iOS – iOS has greater restrictions on accessing system data and background activity
	Battery life in mobile phones	– App collecting sensor data can consume a significant amount of a battery
	Some smartphones are not equipped with a temperature sensor	– Battery temperature sensor can be used to measure temperature
Software	Engagement and retention of users	– User-centered design approach is considered an integral part of any temperature screening app development
	Codesign of temperature screening apps should involve stakeholders	– Increases the likelihood that the app will be perceived as attractive, usable, and helpful by the target population
	Confidential handling and use of data, as well as privacy and anonymity	– Temperature screening data is highly sensitive because of the potential negative implications of unwanted disclosure
	Security and privacy differ by users	– Android and iOS users differ in terms of age, gender and in their awareness of app security and privacy risks

Despite the potential of mobile phone sensor technology in air temperature research and the fact that participatory sensing can be useful in developing temperature-measuring apps they pose several key challenges, both at hardware and software level to temperature-measuring apps. If an app collecting sensor data is too resource-intensive, a user's motivation to continue using it decreases [7]. An optimized data collection should therefore be aligned with the expectations of users regarding battery consumption. Other technical and issue restrictions are mentioned in Table 1.

Bigger challenges are confidential handling and use of data, as well as privacy and anonymity (of user data) within apps. Indeed, measuring a person's body temperature is, in theory, to be considered a processing of personal data. This may, for example, be different in cases where the temperature is measured for a few seconds, without there being any direct or indirect link whatsoever to (other) personal data. In that case, the measurement could fall outside the definition of "processing" as defined in the General Data Protection Regulation (GDPR) [8]. Additionally, systems making use of predictive analysis techniques not only collect data but also create information about body temperature status, for example, through identification of risk markers. Therefore, social impact needs to be considered beyond individual privacy concerns.

2.3 Effects of air temperature in daily human activities

The air temperature along with other weather condition parameters (rainfall and wind speed), has effects on people's everyday activities [4]. People's daily activities can be inferred, such as place visited, the time this took place, the duration of the visit, based on the GPS location traces of their mobile phones. Based on the collected information, it is possible to estimate, for example, if people are more likely to stay longer at beach, food outlets, and at retail or shopping areas when the weather is very cold or when conditions are calm (non-windy). When compared with people's regular activity information, we can probably research, for instance, how it noticeably affects people's movements and activities at different times of the day. Or we can observe the effect of air temperature, rainfall and wind speed in different geographical areas. Therefore, besides noting how mobile phone data can be used to investigate the influence of environmental factors on daily activities, this work sheds new light on the influence of atmospheric temperature on human behavior.

2.4 Temperature Measurement in Mobile Sensing

Many researchers and engineers have been working on real time and remote monitoring systems to measure temperature. In [10], the author shows an example to illustrate the dependency of air temperature sensor readings on storing positions on the body: front or back trouser pocket, chest pocket, and around the neck (hanging). This work uses the Wet-Bulb Globe Temperature (WBGT) as the benchmark for environmental thermal conditions that reflect the probability of heatstroke, because it consists of three important factors: air temperature, air humidity, and radiant heat [23]. On the other hand, in [22], the authors present a design for a new mobile sensing system (AMSense) that uses vehicles as mobile sensing nodes in a network to capture spatiotemporal properties of pedestrians and cyclists in urban environments.

Given that previous projects indirectly depend on the mobile phone sensing, none of them is able to calculate air temperature. Alternatively, Nguyen Hai Chau, in [6], shows that temperature readings of smartphone batteries can be used to estimate air temperature. In this paper, two statistical models that allow each smartphone to predict the temperature in or out of human clothes' pockets were built. The formulae of models given in Eq. 1 and Eq. 2:

$$T_{air} = T_{battery-out-of-pocket} x 0.903 + 1.074 \quad (1)$$

and

$$T_{air} = T_{battery-in-pocket} x 1.877 - 35.1, \quad (2)$$

where T_{air} is the estimated air temperature, $T_{battery-out-of-pocket}$ and $T_{battery-in-pocket}$ the temperatures of a smartphone battery given smartphone context is out of pocket or in pocket, respectively.

Furthermore, smartphones are often carried close to the body, e.g. in pockets of coats, trousers and in people's hands. Therefore, Nguyen Hai Chaur developed a new approach of using two linear regression models to estimate air temperature based on the temperature of an idle smartphone battery given their in-pocket or out-of-pocket positions. Lab test results show that the new approach is better than an existing one in mean absolute error and coefficient of determination metrics. Advantages of the new approach include the simplicity of implementation on smartphones and the ability to create maps of temperature distribution. However, this approach needs to be field-tested on more smartphone models to achieve its robustness.

3 Experimental Study Case

This article surveys the new ideas and techniques related to the use of telecommunication data for urban sensing. We outline the data that can be collected from telecommunication networks as well as their strengths and weaknesses with a particular focus on urban sensing. Moreover, the data contributed from multiple participants can be combined to build a spatio-temporal view of the phenomenon of interest and also to extract important community statistics. Therefore, in the IoT architecture proposed, participatory sensing can achieve a level of coverage in both space and time for observing events of interest in urban spaces.

3.1 Methodology

This chapter presents a state of the art for the building blocks of the IoT system proposed like communication, microservices, data visualization, and device management. For each aspect, we provide a general description on the purpose, requirements, and challenges.

Communication Protocols The most important protocols for this study are Representational State Transfer (REST) and Message Queue Telemetry Transport (MQTT). REST denotes an architectural style for distributed hypermedia and web service systems. Additionally, it defines a generic interface to resources (referenced by an Uniform Resource Identifier (URI)), consisting of methods like GET for requesting and

POST for creating resource representations. Within the World Wide Web (WWW), client applications, like browsers or mobile apps, may invoke these methods, typically via the Hypertext Transfer Protocol (HTTP) where JavaScript Object Notation (JSON) are widely used to encode the transmitted representation.

In its turn, MQTT is a publish-subscribe messaging protocol. The protocol is based on TCP/IP and is designed for small devices with limited network connection. It comprises the publish/subscribe pattern with a broker, which is responsible for receiving messages and sending them to interested parties. The content is identified by a topic. When publishing content, the publisher can choose whether the content should be retained by the server or not. If retained, each subscriber will receive the latest published value directly when subscribing.

Micro-services Integration A client implementation is provided by the Eclipse Ditto project. It provides a platform to realize the digital twin metaphor and is a framework designed to build IoT applications with an Edge component. The Ditto package is completed with a web front end which allows the developer or administrator to remotely log in and which developers can use to provide a web facing aspect to their own application's configuration needs. It also provides functionality to realize higher level REST API to access devices (i.e. Device as a Service); include notification of state changes and provide metadata-based support to search and select digital twins (i.e. Digital Twin Management).

To integrate between Eclipse Ditto and Firebase a message broker especially dedicated to MQTT is needed. It's the Eclipse Paho MQTT project. Besides, Paho supports clients for various languages, it provides another open-source client implementation: MQTT-Sensors Network (MQTT-SN). In general, developers have to consider security for MQTT themselves. The result is a working system that has been running on 2 microservices, hosted in a Docker Desktop (application for MacOS and Windows machines to build and share containerized applications), via mobile communication or Wi-Fi access points.

Data Processing Components The increase of device density produces a lot of data and creates new challenges for the Internet infrastructure. In order to solve this problem, we propose a infrastructure called cloud computing services, often called simply "the cloud", which can be categorized into three types—Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS)—to relieve this pressure off Big Data. For example, the first service that provides an infrastructure like Servers, Operating Systems, Virtual Machines, Networks, and Storage on a rent basis is used by AmazonWeb Service and Microsoft Azure. Another service is used in developing, testing and maintaining software for Apprenda and Red Hat OpenShift. PaaS is the same as IaaS but also provides additional tools like DBMS and BI service. And lastly, SaaS allows users to connect to applications through the Internet on a subscription basis. Google Applications, Salesforce use it. In this context, the development platform called Firebase can be useful. Because several features are supported, such as encryption, authentication, and cloud data storage, it is ideal for access control, storage and efficient sharing in real-time. Another advantage is it uses the HTTPs communication protocol that supports bidirectional communications encryption between a client and server. Therefore, in our architecture we will use SaaS, a private fragment for storage on smartphone and a public fragment to disperse on Cloud as privacy policy, using Firebase mainly as a Big Data Sharing centre.

3.2 System Design

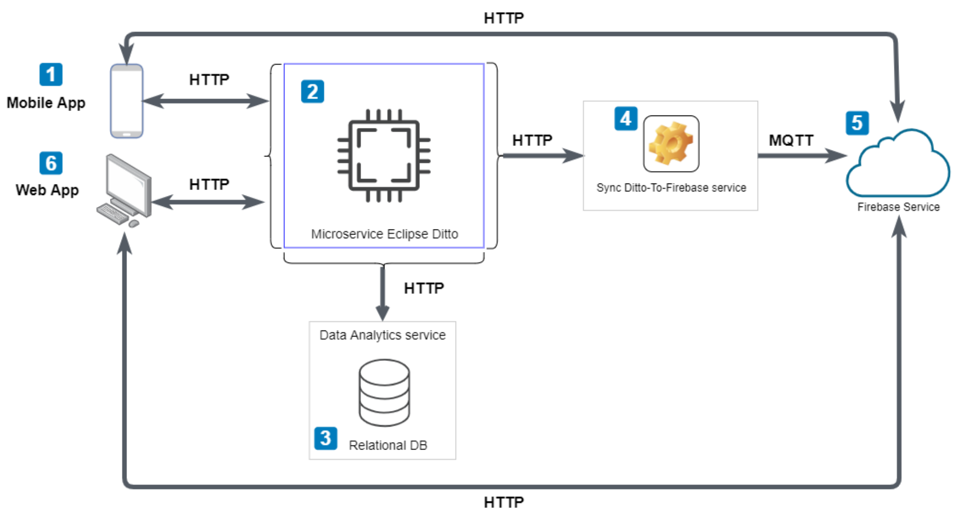

Fig. 1. Architecture proposal for pedestrian-oriented applications.

Fig. 1 shows how the IoT Platform architecture works. The design of this architecture includes a secured management and distribution of mobile phone data as well as the integration of external services and applications. Firstly, (1) mobile phone will detect air temperature using literature's previously described approaches (Eq. 1 and Eq. 2) and get the data. Then the data will be sent to (2) Eclipse Ditto via machine-to-machine (M2M)/"Internet of Things" (IoT) connectivity. Then (3) Eclipse Ditto will save the data to a data analytics service like a relational database. From there, using mobile phone, we can manage client connections to remote systems like social networking services (e.g, Facebook and Twitter) and to exchange Ditto Protocol messages. If the remote system is unable to send messages in the necessary format, there is the option to configure custom payload mapping logic to adapt to almost any message format and encoding. To connect and synchronize Ditto data to the cloud, we added the (4) Sync Ditto-To-Firebase service. (5) Firebase works as a cloud-based machine-to-machine integration platform. The cloud-based philosophy of scalability is at the core of the proposed IoT infrastructure. Additionally, the system records and displays the data. Thereafter (6) the user can get the results from a mobile phone app or web app.

This IoT Platform architecture being based on an IoT Cloud Platform is expected to scale both horizontally to support the large number of heterogeneity devices connected and vertically to address the variety of IoT solutions. However, an IoT architecture comprises core building blocks that are applied across different domains and regardless of the use case or connected Things. Depending on the applicable reference architecture, such building blocks differ in naming and granularity level. Therefore, the IoT schema above shows typically core features for the Eclipse open source software stack for an IoT Cloud Platform with facilities for device management, data storage and management, visualization, analytics, and stream processing.

4 Conclusion and Future Work

Recent advancements in IoT have drawn attention of researchers and developers worldwide. IoT developers and researchers are working together to extend the technology on a large scale and several stakeholders have benefited from the application of smartphone-based sensing. However, multiple gaps remain between this vision and the present state of the art. In particular, additional research is needed to address major issues such as air temperature measurement efficacy, integration of newer analytic approaches including artificial intelligence (AI), privacy issues, and implementation of sensing into actual mobile phones. Moreover, there are a set of options for how device-to-platform connection is made and it depends on the environment and constraints of the device. This is, if the device is outside and moving around we use cellular connectivity; in indoor environments, Ethernet or Wi-Fi connectivity is a better option. And finally, in gateways and edge compute, in some cases the devices can't connect directly to the central cloud platform or other platforms in intermediate layers and instead require the use of an IoT gateway to bridge the gap between local environment and platform. This gateway is required when using Wireless technologies like Bluetooth and LPWAN, since those don't provide any direct connection to the network or the Cloud. IoT is not only providing services but also generates a huge amount of data. For that reason, the importance of big data analytics is also discussed and can provide accurate decisions that could be used to develop an improved IoT system.

In this survey article, we address the mentioned issues and challenges that must be taken into account to develop applications to measure air temperature based on our IoT architecture. Therefore, due to its reliability and feasibility the proposed layered architecture is useful to many kinds of applications. In future work, we intend to build new model applications based on this proposed IoT architecture. The main goal is to predict our way of living in an era impacted by the viral effects of IoT application (Human-Computer Interaction and Machine-to-Machine connections) and, for example, could be used to foster business process management in the IoT era.

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