IoT and Data Visualization to Enhance Hyperlocal Data in a Smart Campus Context

Lorenzo Monti
University of Bologna, Italy
lorenzo.monti20@unibo.it

Catia Prandi
University of Bologna, Italy
M-ITI/LARSyS, Portugal
catia.prandi2@unibo.it

Silvia Mirri
University of Bologna, Italy
silvia.mirri@unibo.it

ABSTRACT

Internet of Thing and data visualization have been exploited in several contexts to put into effect intelligent environments. What we argue in this paper is that these emerging areas, and related technologies, have a real potential to be explored to benefit communities, answering to their needs and interests and let their members be active participants. To prove our reflections, we designed and developed i) an infrastructure made of sensors to collect real-time data, and ii) a rich web-based application to interact with data in a specific scenario: a University campus. To complement our system, we plan to give the students' community the possibility to contribute to the whole system, not only with ideas (e.g., participatory design and user-driven innovation) and data (e.g., crowdsourcing and crowdsensing) but also with sensors to plug-in into the infrastructure and visualization add-ons to represent the gathered data.

CCS CONCEPTS

• **Human-centered computing** → *Information visualization*; • **Information systems** → *Sensor networks*;

KEYWORDS

Intelligent environment, IoT, Smart Campus, Community-based system, Hyperlocal data

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1 INTRODUCTION

We live in a data-centric world where data influence and drive our daily decisions, producing new insights and knowledge [19, 20, 24]. This scenario is made possible by exploiting Internet of Things (IoT) technologies and sensors that are becoming more and more inexpensive and easily accessible, enabling the collection of huge amounts of data [3, 10, 49]. Interesting enough is that such a scenario was already hypothesized in 1991, when Mark Weiser describes the emerging of a "*physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network*" [47]. He, with his pioneer vision, basically introduced the concept of ubiquitous computing smart environment, where embedded sensors and computing devices let users understand the environment and provide services based on the collected data [14, 17].

With the advances in different fields of Computer Science, such as Human-computer interaction, Artificial Intelligence and Pervasive/Ubiquitous computing, nowadays smart environments are becoming more and more *intelligent*, letting emerging a new area [8, 42]. In fact, the term *intelligent environment* has been increasingly used to describe a physical environment where innovative and pervasive information and communication technologies enable people to experience and interact with space and generated data [9].

In such intelligent environments, the role of users can become relevant [33], moving from passive beneficiaries of services to active participants [40], data explorers [41] and contributors [31], also by means of their activities on social media [44, 45]. This scenario can be easily pictured thinking to a specified community of interest, where users have common needs and interests [18]. This is the context where the concept of hyperlocal data emerged as crucial for empowering a community. Such term expresses the information generated inside a specifically geolocation community, that can be used to better inform the community and improve the users' experience in interacting with spaces [29].

To inform such a community about the hyperlocal collected data, making them participates, the interaction with data is fundamental [40, 41]. There are different ways to let users interact with data, one is exploiting data visualization methodologies, providing information is a visual way [12, 37].

In this paper, we present our approach in creating an intelligent environment targets to the need of a specific community. As a real-world case study, we designed and preliminary deployed an *intelligent campus*, exploiting IoT and low-cost sensors, as well as data visualization, to let University students enjoy and interact with data collected around them. In doing that, we want to exploit an altruistic approach, where students together with smart sensors and pervasive technologies can contribute to improving the campus livability. A few examples of altruistic IoT approaches have been recently presented in literature [4, 32]. With this work, we go a step further, i) augmenting a University campus with low-cost smart technologies and sensors, ii) deploying displays in public settings to let users interact with the hyperlocal data, being informed about

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specific phenomena in a spatial-temporal dimension, and iii) including the community as active participants in exploring and in benefiting from the intelligent environment and produced data.

The remainder of this paper is organized as follows. First, we present related works to emphasize how our approach is different from previous ones. Then, we describe the system design, presenting the sensors used and the system architecture. In Section 4 we detail the rich web-based application we design to let the community to interact with data, through public displays deployed in the smart campus. Finally, we conclude the paper with a discussion on how to empower students exploiting our platform and next planned steps.

2 RELATED WORK

In this section, we briefly introduce some work related to the concept of "smart campus" and to projects putting it into practice, together with some work presenting interesting cases based on the collection and the provision of pollutant data in urban scenarios.

The idea of "smart campus" is at the basis of several works [2, 22, 36]. However, it is not clear what designing and building a "smart campus" means in practice. It is worth mentioning that currently there is no common and shared definition of smart campus, even if some researchers, who have worked on this topic, conveyed the definition on the basis of different approaches [35]. Three main different groups of such approaches can be identified: technology driven, smart city concept adoption, and based on the development of an organization or business process [46].

Taking into account the technological approach, a smart campus results from the development of a digital campus [26], by exploiting IoT service providers and and cloud computing [13]. The idea behind this approach is transforming common objects which can be traditionally found in a university environment into a unique intelligent campus environment [11]. On the other side, the smart city concept adoption is based on the assumption that a smart campus shows several similarities with a smart city. By using the same paradigm, a smart campus should adopt modern technology to support different users (students, researchers and professors, employees, visitors, etc.) [28]. Summing up, a smart campus can be intended as a small and self-contained city, taking into account the number of functions, users, activities, and connections [36].

Finally, according to the third group of approaches, a smart campus is developed through the effective use of resources [6], by providing services to environmental communities [2], reducing costs and improving the quality of life (inside and outside the campus) [15]. In this sense, collecting data about environmental aspects can play a fundamental role and can be improved by the adoption of the first two concepts too.

Several studies are based on the investigation of low-cost sensors devoted to detect and monitor environmental data, such as information that can be used to estimate and evaluate air quality. In general, proposed systems for environmental monitoring mainly follow two different approaches. A first approach is based on building a network of sensors devoted to monitoring indoor and outdoor air quality. Studies based on this approach analyze the architecture of the network of sensors [16], taking into account different problems, such as consistency and sensitivity of a sensor to its micro-environment local conditions [34]. The second approach is based on the use of mobile sensors with the aim of monitoring air quality in different parts of a city concurrently and continuously [7]. Such an approach can be applied in different ways, ranging from the use of mobile sensors unit [5], to the use of sensors for smart phones [21] or for wearable devices [23].

One of the most commonly used approaches to data collection, given mobile low-cost sensors, is crowdsensing, which can be exploited in a very efficient way in different contexts [39], that can be exploited together with the crowdsourcing paradigm [38, 43]. Woodruff et al. [48], in the Common Sense project, developed a website that shows a unique aggregated evaluation of the pollutants measured by a set of sensors owned by the members of a community. Data coming from such sensors have been normalized over time to the EPA's Air Quality Index. All of the views on the site use color encodings and descriptors to communicate data and results because usually citizens have no confidence with raw pollutant concentrations.

Ziftci et al. [50] developed Citisense, a system that allows users to collect air quality data via portable sensors and to get real-time feedbacks about pollution with an Android application or view summary information in a map. Kuznetsov et al. [25] proposed a modular system of low-cost and networked sensors that measure environmental factors such as air pollution, radiation, water quality or noise. Aberer et al. [1] presented OpenSense, an open platform to monitor air pollution using wireless and mobile sensors by adopting complex utility driven approaches. They installed these sensors on vehicles of public transports, such as buses and trams. Hasenfratz et al. [21] built GasMobile, a prototype system for participatory air pollution monitoring. They used a small, low-cost, and on-the-shelf sensor with the aim of monitoring the ozone concentration. An Android application has been provided in order to let the user exploit and browse the real-time collected data.

3 THE SYSTEM DESIGN

In this Section we present the system design of our platform by detailing the entire architecture composed of different layers:

(i) the IoT and sensors layer that includes environmental sensors stations [4], dB noise monitoring sensors, peripheral 3D cameras;
(ii) the database layer that is represented by all the repositories where data and content are stored, in particular, our internal database, the database where real-time sensed data are saved and external open data collections used to integrate our data with official information exposed by the University;
(iii) the data visualization and presentation layer that allows the community to interact with the monitored data in order to increase users' context-awareness;
(iv) the web-server layer that is able to host the web application, to answer to the client's requests, to retrieval information from the databases, and to enable the communication between the different layers.

In the following subsections, we will present each level in details. Figure 1 presents the sensors, database, and web-server layers, showing how the three levels are connected to each other.

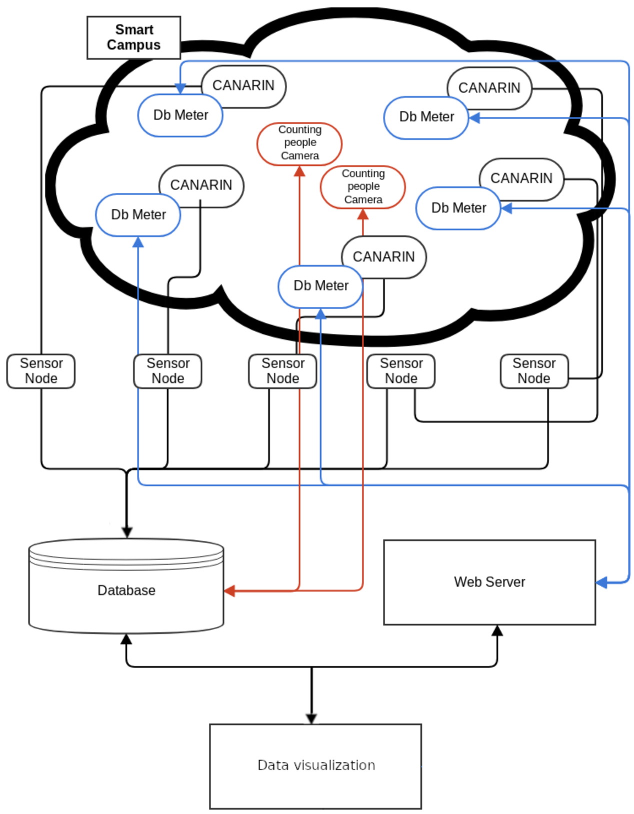

Figure 1: Our Smart campus architecture.

3.1 Sensors layer

We have considered the campus as a whole, collecting both outdoor data, such as atmospheric and environmental noise monitoring, and indoor data to sense, for instance, the number of people in classrooms and laboratories.

The environmental sensors. Focusing on the collection of the environmental data, we relied on Canarin II [4], designed and developed thanks to the collaboration among the Macao Polytechnic Institute, the Asian Institute of Technology, and the Pierre and Marie Curie Sorbonne University. This sensor station is equipped with different sensors:

- environments sensors to sense air contaminants, gathering formaldehyde, PM 1.0, PM 2.5 and PM 10 values;
- temperature;
- relative humidity;
- air pressure.

The communication between the station and our web server are possible thanks to a Wi-Fi module that allows each device to act as a node in our infrastructure.

At the moment, we placed these sensor stations outside the building, in strategic positions facing different pollution sources and urban and natural conditions.

To collect data about the indoor condition, we are exploiting CO2 sensors that have been placed in every classroom and laboratory to monitor the quality of air, in order to activate a heating, ventilation, and air conditioning (HVAC) system when needed.

The noise sensor. Concerning the noise monitoring and measurement, after an analysis of accurate and low-cost microphones, we opted for a USB condenser microphone named *"Mini Akiro"* which has an omnidirectional pattern, a signal-to-noise ratio 85 dB and a frequency response from 100 Hz to 16,000 Hz. This sensor provides us with an interface for monitoring, collecting, storing and then analyzing the surrounding sound signals. To compute the signals caught by the microphone we used a Raspberry Pi 2 model B, a powerful, versatile and low-cost single-board computer. Furthermore, we used an AWUS036NHA Alfa USB Wi-Fi module for enabling the communication with the web server using the wireless network managed by the University of Bologna (i.e., ALMAWIFI).

The signals captured by the sensor are then computed by the Raspberry Pi before be stored in the database. To do that, we exploited a Python package called SoundMeter[1] that returns a RMS (Root Mean Square) value every 30 seconds. This value is then converted in Decibel thanks to the following sound pressure level (SPL) formula:

$$SPL = 20 * \log_{10}(\frac{P}{P0})(dB), \tag{1}$$

where P is the instantaneous sound pressure of the sound signal and $P0$ is the reference sound pressure of 20 µPa.

The infrared 3D camera. Considering in particular the indoor campus data, we focused our attention on how much the classrooms and the laboratories are exploited with respect to their actual capacity. In this sense, in order to count the number of people in an area, we took advantage of an Intel RealSense D415 Depth camera [2]. This camera is USB-powered and consists of an infrared projector, a pair of depth sensors and with a RGB Sensor which has a resolution and a frame rate equal to 1920 x 1080 at 30 fps. The RealSense technologies provide a suite of depth and tracking technologies, that makes possible to count the number of people in a given area. To avoid privacy issues, we store in our database, every 10 minutes, only the number of people in a given timestamp obtained from the frames analysis. To let this possible, we plugged-in (via USB) the camera to a Raspberry Pi that analyzed the collected frame sequences with a computer vision algorithm and returns the room occupancy as an integer number.

At this stage, we are using two RealSense cameras in one classroom and a laboratory, which a different layout. In the future, we plan to provide different premises with a people counting technologies to cover all the point of interests (PoIs) for the students community, including all the classrooms and laboratory as well as library and study rooms.

[1] https://pypi.org/project/soundmeter/
[2] https://www.intel.com/content/www/us/en/architecture-and-technology/realsense-overview.html

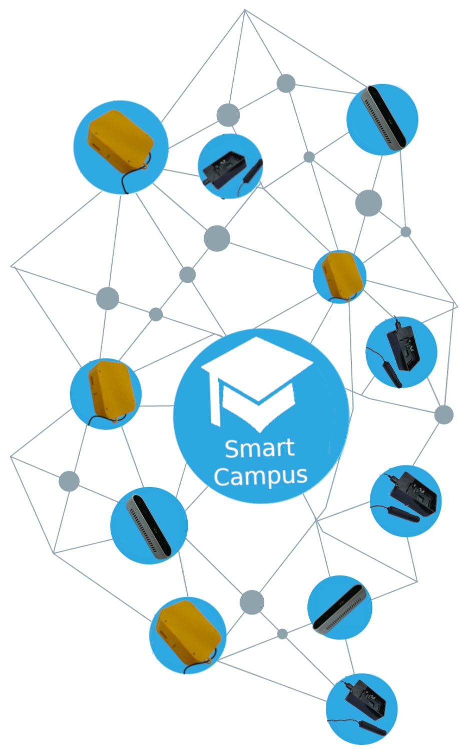

Figure 2: Sensors used in our architecture.

3.2 The database layer

Thanks to the database layer, the data collected real-time by the sensors can be stored and queried, and made available to the web-based application. In details, the sensed data are stored in a mySQL[3] database every 30 seconds/one minute, depending on the sensor typology and purpose. For example, air quality and noise data are saved every 30 seconds, while camera data every 1 minute. Considering the environmental sensors stations, each entry stored in the database is represented by the raw sensed data, the timestamp, and the georeferenced coordinates.

In addition to the databases for the real-time sensed data, we are also exploiting an open data collection [4] of information related to the University community, and in particular, relevant for the students. This dataset is made freely accessible by the University of Bologna and includes a variety of data, ranging from the lessons timetable to a collection of georeferenced point of interests. To interact with the open data, we used *ckan*[5], an open-source DMS (data management system).

The use of different sources of information allows us to provide the community with data covering different aspects of the University life on a campus. For this reason, we designed and implemented the system to be able to easily be configured to integrate external data repositories.

[3]https://www.mysql.com/
[4]https://dati.unibo.it/
[5]https://github.com/ckan/ckan

3.3 The web-server layer

As a web server we exploited the one source Nginx[6], that can also be used as a reverse proxy, load balancer, and HTTP cache.

The web server is responsible to receive the clients requests, querying the database layer and answering with the aggregated data, which are displayed by the presentation layer.

We implemented the web service using Node.js[7] and Express[8].

To manage real-time sensed data visualization we exploited some libraries, such as Socket.IO[9] that enables real-time, bidirectional and event-based communication between the browser and the server.

3.4 The presentation layer

The presentation layer allows the community to interact with the data. We implemented a rich-web base application using web technologies, including HTML5 and CSS3, JavaScript and so on.

The map-based interface is based on a open source project[10][27].

We developed a customized version, as detailed in Section 4.

4 THE RICH WEB-BASED INTERFACE

We designed and developed a rich web-based interface to let students, and, more in general, the University community to interact with data and become more aware of the data generated by the campus, as a whole system.

The rich web-based interface can be explored by the campus community thanks to two public touchscreen displays (32" capacitive professional monitor), freely enjoyable at the two entrances of the main building.

The interface is composed mainly of three main components corresponding to three interaction modes:

- a map-based interaction;
- a search-based interaction;
- the sensed data visualization and interaction.

The map-based interaction. The map-based interaction enables the user to select a specific level in the SVG map. After selecting a level (floor), it is possible to visualize all the point of interests present and interact with them. In particular, such categories are: classrooms, laboratories, professors' offices, courses lessons, and sensors. Moreover, in all the SVG maps is possible to visualize the facilities, such as toilets, stairs and elevators. Once selected the point of interest (PoI), the information collected about it are popped-up in a panel at the bottom of the screen, and the location is highlighted in the map with an animated marker.

The search-based interaction. The search-based interaction enables users to access the information exploiting a search function to filter content by keywords. In this way, it is possible to easily access to information without knowing the actual position of the PoIs. The system provides a list of all the PoIs including the searched keyword. Selecting a specific PoI from the list, the application displays the right floor where the PoI is located, with a market to highlight the

[6]https://www.nginx.com/
[7]https://nodejs.org/en/
[8]https://expressjs.com/
[9]https://socket.io/
[10]Code available at: https://github.com/codrops/Interactive3DMallMap/

Figure 3: The interactive representation of the three levels of the smart campus

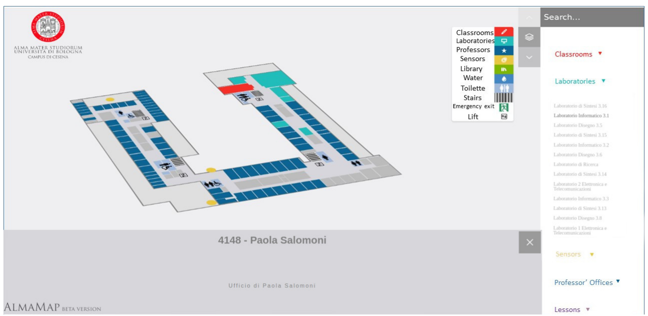

Figure 4: A zoom on one level of the smart campus

actual location. Figure 4 presents an example of interaction where the user is searching for a laboratory.

The sensed data interaction. Besides the information about PoI such as classrooms, laboratories, professors' office, libraries, and so on, we exploited data visualization techniques to represent in an intuitive way data gathered by the sensors that compose our smart infrastructure. The interface presents the real-time data, with values refreshed every minute, as well as historical data, with the possibility to interact with the timeline. This allows users to become aware of environmental conditions (both indoor and outdoor) concerning the University campus. In Figure 5 is possible to see an example of visualization of data about sensed data from the air quality station, in particular, current and historical humidity and temperature values.

5 DISCUSSION AND FUTURE WORKS

In this paper, we present an infrastructure made of different sensors, designed and deployed in a new university campus of the University of Bologna, in order to gather data about different environmental conditions, concerning both indoor and outdoor phenomena. The infrastructure is now composed of air quality sensors stations (PM 1.0, PM 2.5, PM 10, CO_2), noise monitoring sensors, and 3D camera for people counting. Moreover, we augmented the smart campus with a rich web-based application that exploits data visualization techniques to display hyperlocal information. In details, the interface allows users to interact with spatio-temporal data of interests of the University community, in the specific campus context.

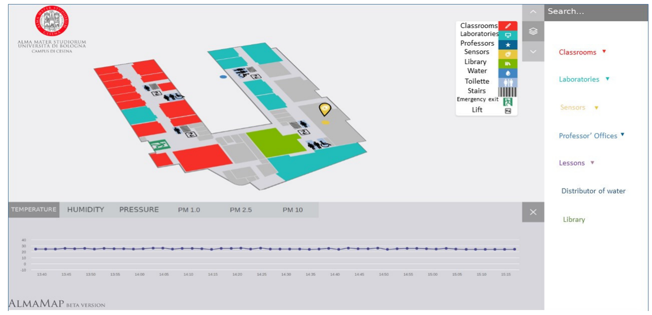

Figure 5: The visualization of the outdoor environmental data

The platform, in this way designed, can be investigated to became an altruistic tool to facilitate the participation of the community and to increase the potential of hyperlocal data, with the final goal to benefit the campus community. In fact, considering, in particular, our case study, we implemented the system in a university campus that hosts the Computer science and Engineering Department, the Electronic Engineering Department and the Department of Architecture and Design. Therefore, students living the campus are developing all the skills needed not only to suggest services based on their needs but also to actively participate in the design, implementation and development of such services, from the IoT and sensors hardware (that can be plugged-in into our infrastructure), to the data visualization software, in accordance with the architectural constraints. To achieve this scenario, we plan to make available as open data the sensed information, together with the definition of how to implement data visualization modules that can just be added to our presentation layer as add-ons. We will also make available the rich based-application as a mobile application that will let users personalize the visualization [30], enabling/disabling the interactive add-ons and the sensors data flow, and test their services.

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