Smart Wearable Sensors: Analysis of a Real Case Study

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***Abstract*—Wearable devices are constantly expanding in number and functionalities within both the IT market and the fashion market. Smart watches have become very popular and have moved from a tool only showing information related to the smartphone to a device able to monitor and display a vast plethora of data, including data related to the owner's health (e.g., hearth rate, body temperature, steps per day, etc.). This huge amount of data that wearables in the world can generate could be further elaborated to become even more useful. Yet, designing effective solutions to collect, store and elaborate sensors data is a challenging task. To this aim, in this paper, we present a framework to model a wearable sensors network in a simple and flexible in order to adapt to different scenarios.**

***Index Terms*—IoT, Wearable, Sensor, Testbed, Measurements, Arduino**

I. INTRODUCTION

Wearable technology have recently become very popular, flooding the IT and fashion market with devices that can be worn or included in dresses and accessories. Their success is not just based on a fashion trend; rather, smartwatches, glasses and bracelets offer the user a lot of useful functionalities as well as the possibility to collect and elaborate a vast plethora of information regarding the owner (i.e., number of steps, hearth rate, level of stress, GPS position, etc.) and the environment (i.e., sound, light, altitude, etc.) [1]–[6].

The main advantage of using wearable devices instead of smartphones to support these applications is represented by their ability to stay naturally on the owners' body without requiring attention and handling: e.g., wearables do not need to be hold in your hand, a position control sensor for Alzheimer patients could be hidden in a bracelet, etc.

Applications of wearable technology includes of course rehabilitation [7], fitness/welness [8], elderly monitoring [9] and military's capabilities [10]. Even more interesting, sensed data from different devices belonging to different users may be aggregated to generate new information, sometimes with a positive impact on our society [11]–[15]. Indeed, the widespread popularity of wearable technology can lead to the generation of a huge amount of data that must then be efficiently gathered, stored, and further elaborated, thus requiring innovative solutions to this aim [16], [17].

The main objective of this paper is the proposal and discussion of an architecture that allows various wearable sensors to collect and transmit data to a central unit thanks to a wireless connection. To this aim, we consider the representative case study of a small wireless weather station collecting various data such as temperature, atmospheric pressure, UV rays, and GPS positions. The system could be employed at beach resorts, winter sport resorts, or even in a city. Through it, a user can be continuously updated with the weather conditions, useful tips, advertising or other data that can vary from use case to use case. Our system considers heterogeneous nodes (e.g., sensors, smartphones, server) and different possible wireless connectivity (e.g., bluetooth, Wi-Fi).

The paper is organized as follows. In Section II we overview background information and related work. Section III presents our envisioned system architecture and Section IV reports on some test we performed to assess it. Finally, in Section V conclusions are drawn.

II. BACKGROUND AND RELATED WORK

From the technology standpoint, the pervasive coverage of mobile sensing technology and the ubiquity of network connectivity are key factors that have boosted our capability to acquire and monitor data regarding the environment we are immersed in. The people-centric sensing paradigm has been around for some years and a significant research effort has been devoted to its development, ranging from algorithms and techniques proposed to measure specific environmental properties to hierarchical system architectures and communication paradigms [18].

Mentioning few representative examples, in [19] the authors describe an application that determines pollution exposure indexes for people carrying mobile devices. A microblogging service is discussed in [20]; it uses mobile devices to record multimedia content in-situ and shares this content in real-time. Aram *et al.* [21] propose a system for data acquisition using smartphones and specialized sensors. In particular, they show how it is possible to acquire temperature and humidity values using low cost sensors and how these data could be forwarded through Bluetooth connectivity to a smartphone. In this way, it is possible to monitor conditions about a room or a particular environment, and alert when specific unhealthy conditions are reached.

PRISM [22] is a framework that supports the participatory data acquisition of environmental data using off-the-shelf mobile device. This framework provides both an infrastructural component that orchestrates the mobile nodes participating in the data acquisition process, and a mobile component to be used with the smartphones that automatically collects data from the environment.

Unfortunately, fashion and sensing technology have started to merge only recently (e.g., smartwatches and activity tracker wristbands) thus providing a small set of very specific applications which are limited with respect to the unveiled potential. As we plan to demonstrate, any cloth/accessory could evolve to become an interconnected and data providing object able to foster new and innovative services. Of course, this passes through the ability to convert our wearables into desirable techno-fashion items with hidden sensing systems participating in a general software/communication architecture for the creation of new 2.0 services.

III. SYSTEM ARCHITECTURE

In this section we present a possible solution for the architecture of the system, which is depicted in Figure 1. The goal is to provide a *simple* and *flexible* architecture for the overall system suitable for the case study presented in Section I.

Our network is composed by a set of nodes, which can be different for equipment, functionalities and encumbrances. The more important node of this kind of network is the *server*, which collects, stores and elaborates the retrieved data. The simplest nodes are the *sensors*, i.e., UV ray sensors, GPS sensors or temperature and humidity sensors mounted on a little board, which collect data about the environment and send them to the server for further elaboration. The transport protocol could be TCP or UDP depending on the tradeoff between reliability and complexity required by the considered application [23].

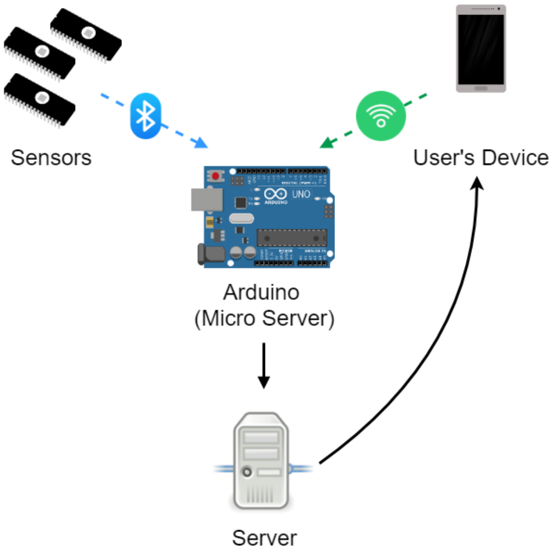


Fig. 1: General architecture of the system.

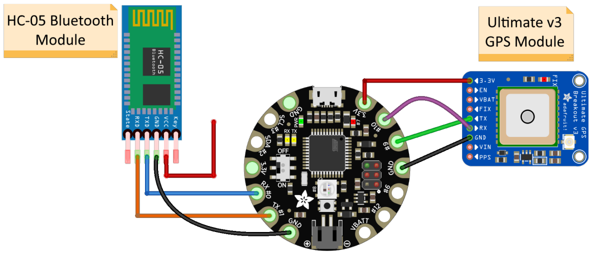


Fig. 2: A Bluetooth module and a GPS sensor mounted on a Adafruit Flora b.

To avoid bottleneck, initial elaboration of data can be performed also by other components of the network with limited resources. An example of this kind of elaboration is *data filtering* and it is applied to GPS data which, as we will discuss in Section IV, contain errors due to communication problems with the satellites.

Figure 1 shows our testbed configuration. We adopted an Arduino Uno Rev. 3 equipped with Bluetooth HC-05 and Wi-Fi ESP8266 modules for this components. Sensors are mounted on Arduino LilyPad Main Board and Adafruit Flora, which are specifically designed as wearable devices that can be applied to clothes. A Bluetooth HC-05 module is used for the communication. The sensors that have been selected are:

- the Si1145 sensor for the UV rays,

- BME 280 sensor for pressure, temperature and humidity and
- the Flora Wearable Ultimate GPS module for the location tracking.

Figure 2 shows a Bluetooth module and a GPS sensor mounted on a Adafruit Flora board: the holes all around the board can be used to connect other components (in this case, the bluetooth and the GPS module) but also to sew the board inside clothes, bags, etc.

Another important node of this network is the smartphone, that can be used both to acquire data, e.g., GPS position, luminosity, etc., but also to display data on the screen. In our case study, smartphones can be used to retrieve weather forecast from a weather station which collects data about humidity, UV ray and temperature via a sensors networks and elaborates forecast. Moreover, they can be used to alert parents if their child (with a GPS sensor in her/his cap) goes too far away, to receive alert about UV level and advertise daily's offers at the beach resort. In summary, the smartphones is responsible for the interaction with the users.

IV. PRELIMINARY RESULTS

We performed a set of tests to evaluate whether the system is able to collect data and whether the retrieved data are correct. For this reason, we have performed various measurements of the environment parameters of each component described in Section III.

Data are collected using the BME280 sensor for temperature, humidity and pressure, the Si1145 sensor for the UV level and the Ultimate V3 GPS Module for the GPS tracking. For each environmental parameter, we performed 50 measurements with a 10 s time lapse. The obtained results are presented in Figure 3: each graph shows the collected data for each parameter (i.e., temperature in Figure 3a, pressure in Figure 3b, humidity in Figure 3c and UV level in Figure 3d), the mean values and the standard deviation to evidence how much data vary during the measurements.

The first and second charts (respectively, Figure 3a and Figure 3b) reports the data collected by the BME280 sensor for temperature and pressure. The good performance of the sensor is demonstrated by the limited variations among the collected data. Data about humidity present wider oscillations, but still limited and lower than one percentage point (see Figure 3c).

Similar, even sensor Si1145 for the collection of the UV level performs well, with a smooth increase of the UV level and a limited standard deviation. Figure 3d reports the retrieved values. The Si1145 sensor detects and measures light both in the visible and infrared spectrum and, based on this, it elaborates an estimation of the UV level.

The GPS data have been collected using the Ultimate v3 GPS Module and the tests have been performed in different locations to simulate heterogeneous real scenarios. In particular, we recorded the GPS position far from obstacles and sources of interference such as trees and buildings. Each test is composed by 100 position measurements.

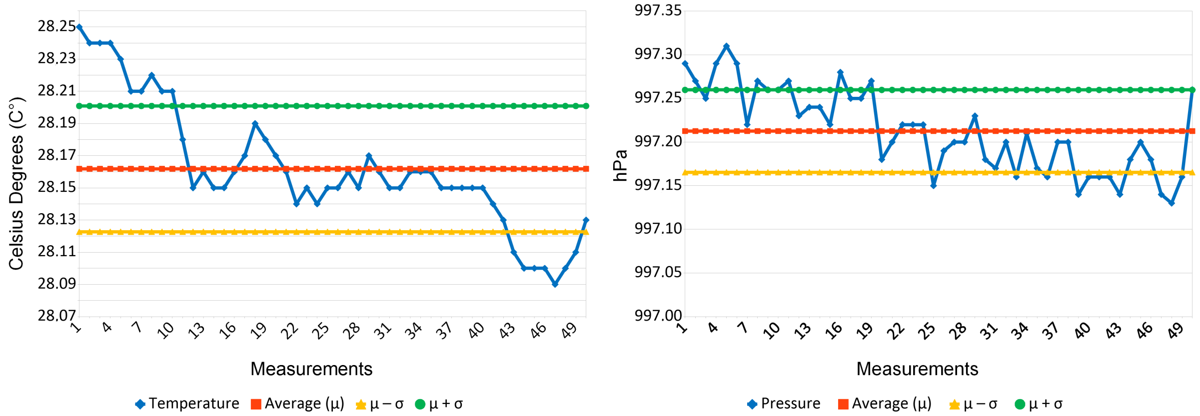
Unfortunately, retrieved data showed that this sensor is not fully reliable, since the GPS module introduced a high quantity of errors in the measurement during our test. This is a common situation for the wearable sensors which are usually hardware components built to minimize not only the size of the hardware itself, but also the energy consumption and cost. This leads to a lower precision of the devices.

We have hence implemented an algorithm to detect and correct the errors before sending data to the servers. In our system, the preliminary elaboration to filter the results is performed by the Arduino Uno board. An example of a typical situation of incorrect data that we encountered during our experiments can be observed in Table I: we can see two measurements made within a 10 s time interval between them that represent a movement of more than 120 km. This is clearly impossible, since this movement would require an exaggeratedly high speed of the users. Therefore, this clearly represents an error introduced by the GPS module. The Arduino board is then in charge to apply some filters to clean the data. The filters utilized in our measurements check the validity of the speed required by the movement. This simple, preliminary, elaboration allows also to lower the computational load of the centralized servers and to avoid to transmit useless data.

We have filtered collected data, respectively, in absence of obstacles and in presence of trees. As we can see, the average error is 1.93 m (with a standard deviation of 0.843) in an open area and grows to 6.66 m (with a standard deviation of 0.884) in presence of trees. In both cases, the values are acceptable for our use case, as a distance of about 7 m is acceptable for kids' surveillance.

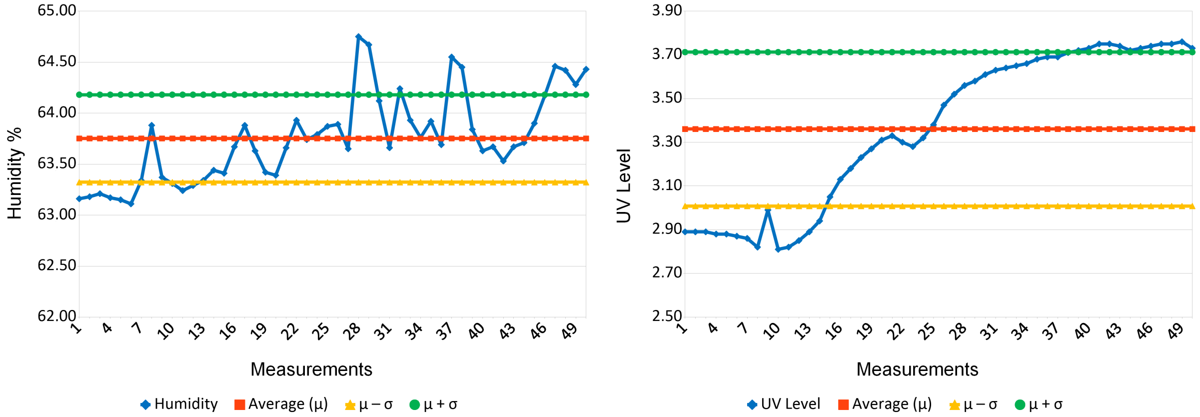
V. CONCLUSION

In this paper we have presented an architecture that allows various wearable sensors to collect and transmit data to a central unit thanks to wireless connectivity. We have considered the representative case study of a small wireless weather station collecting various data



(a) Temperature (BME280 sensor)

(b) Pressure (BME280 sensor)



(c) Humidity (BME280 sensor)

(d) UV Level (Si1145 sensor)

Fig. 3: Measurements performed by the BME280 and Si1145 sensors.

Localization Error of the GPS Module				
Date	**Time**	**Real Position**	**Detected Position**	**Error (m)**
04/06/17	18:25:40	(45.892815,12.082536)	(45.89283,12.082583)	5.11
04/06/17	18:25:50	(45.89283,10.415869)	(45.89283,12.082583)	128983.9

TABLE I: Localization error between the real position of the GPS module and the detected one.

such as temperature, atmospheric pressure, UV rays, and GPS positions. Such system could be employed at beach resorts, winter sport resorts, or even in a city to continuously update the user with the weather conditions, useful tips, advertisement or other data, depending on the considered use case. Our system considers heterogeneous nodes (e.g., sensors, smartphones, server) and different possible wireless connectivity (e.g., bluetooth, Wi-Fi). It is hence flexible enough to adapt to a wide range of use cases that shares similar base requirements.

Preliminary but encouraging results have been gathered through a real testbed to assess the performance of the system.

As future work, we are going to extend our work in several directions. First of all, we plan to expand the tests on our system including a comprehensive evaluation of energy consumption [24], [25] and of the impact of the nodes/servers' placement [26]. Furthermore, we have overlooked so far privacy, security and trustworthiness aspects; these have to be taken into account in future developments [27]–[29]. Finally, we plan to enhance our system with the possibility for the users to personalize the information received and the output layout [30].

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