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Crowd Sensing for Urban Security in Smart Cities

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Abstract: Upcoming cities must undoubtedly reason upon the knowledge they have acquired through data gathered by sensorization. Those who do that will be at the forefront, closing to become Smart Cities. To achieve this goal, we must evolve from an Internet of Things to an Internet of People, defined as an ecosystem where everyone and everything can sense the other and the world, and act upon such data and knowledge, aiming to enhance people's quality of life. Considering the Vulnerable Road Users' (VRUs) problem, this work provides a proof of concept on crowd sensing for urban security in Smart Cities, confirming that our concept is viable and has practical potential. The goal is to sense the density of people at certain points of interest for VRUs, such as pedestrian crossings or busier roads, by detecting Wi-Fi probe requests with a Smart Scanner. Such information can be relevant to many applications, allowing, for example, the promotion of better safety measures on crowed spots, enhance crowd control and assemble interesting insights on traffic characteristics. To complement this work, and considering that smart clothing will certainly play an important role in promoting the citizen sensor and the smart cities' approach to VRUs' safety, a case study will be presented and discussed in which their clothing is equipped with a Bluetooth Low Energy transmitter. This allows such users to be recognized on the road, which may help avoid dangerous situations. The proof of concept was a success, with the developed software showing promising results at an extremely low price.

Keywords: Smart Cities, Crowd Sensing, Internet of People, Ambient Intelligence, Vulnerable Road Users, Smart Clothing
Categories: D.0, I.2.1, I.2.m, K.4.0

1 Introduction

During these last years, many significant technological advancements have been observed by the human being, namely in terms of road safety [Anaya 15] [Duenkler 13]. Indeed, considering that by 2050 about 70% of the world's population is expected to live in cities [UN 14], there is a move to revolutionize one's thinking about big metropolises. There are many areas underlying such domain, being health care, crime prevention and road safety some of the most notable. Hence, the way to address Smart Cities will focus on a multitude of aspects and will demand huge efforts. On the one hand, there is no definitive definition for such term, but a broad range of similar perspectives and respective backgrounds. In our vision, a Smart City must have the *ability to reason upon the knowledge acquired through data gathered by sensorization, with focus on improving the quality of life at urban centres, considering sustainability and safety principles*. Here, sustainability is to be understood under social, economic and ecological grounds [Fernandes 17a]. Side by side with Smart Cities stands the Internet of Things (IoT). In fact, objects such as clothing, food packing or shoes will be endowed with some level of internet-addressable features, offering context awareness and communication capabilities. On the other hand, as the name implies, IoT focuses on the thing. Now is the time to complete the puzzle with a missing piece, the human being. In essence, the merging of people with the IoT would enable the creation of the Internet of People (IoP), which consists of a dynamic global network, an ecosystem, where things and people communicate and understand each other; where everyone and everything can sense the other and the world, and act on such knowledge and information, aiming to improve people's quality of life. In order to bring people to the IoP and make them an active, reactive and proactive element, it is necessary to promote the citizen sensor, which consists in providing people with sensing capacities [Fernandes 17b]. In addition, significant importance should also be given to Ambient Intelligence (AmI) for the promotion of Smart Cities. AmI consists of sensors and actuators incorporated into an environment, which then becomes sensitive and responsive to the presence and needs of a human being in a non-intrusive way [Silva 13]. In fact, a Smart City should invoke large scale AmI by creating several distinct sensorization levels in cities, as shown in Figure 1. At a first level, one can find public APIs that can be used to extract relevant information such as road conditions and the weather. On a second level there are the devices that can be worn by people in their daily routine, being these crucial enablers of the citizen sensor. The third and final level comprises the city in itself and the methods for extracting actionable data from the environment in where one lives and stands.

In turn, road safety has become a major concern not only for car manufacturers, but also for governments. At its core, it is a very comprehensive and broad topic, ranging from measuring traffic congestion to increasing the safety of motorcyclists or pedestrians. On the road, one can find actors that differ in a number of characteristics, attributes and idiosyncrasies. However, some problems are still to be unscrambled, namely those that have a strong impact on actors outside the vehicle. Those are known as Vulnerable Road Users (VRUs) and have been defined as being non-motorized actors, such as pedestrians, cyclist as well as motorcyclists [CEP 10]. Their vulnerability may arise from several directions such as the lack of external protection, age, physical and mobility impairments, or visual and/or hearing disabilities. In our previous studies, we concluded that research into the VRU problem has focused on vehicles and drivers, foregoing relevant information about the VRU. Current studies considered the VRU as a passive element, as a flat thing, without emotions, physical characteristics or differentiated behaviour. The focus was on informing the non-vulnerable users. What is different in our approach to the VRU problem is that the focus is on bringing people into this global ecosystem known as the IoP, taking into account the characteristics of the VRUs, along with their physical and emotional state, allowing, for example, the creation of awareness for an unpredictable behaviour.

This work emerged from the need to strengthen the foundations of the IoP and, thus, empower Smart Cities. With the VRU problem in mind and focusing on the second and third levels for data collection in Smart Cities (Figure 1), this study aims to present a proof of concept on a Smart City's approach to crowd sensing, validating that our concept is feasible and has practical potential. In essence, the goal is to have a measure of the density of people at a particular point of interest for VRUs, such as pedestrian crossings or busier roads. Such information may be relevant to a number of applications, allowing one to promote greater and better security measures on crowed spots, enhance crowd control and urban planning, assemble interesting insights on how visited a specific point of interest is, its traffic characteristics, among others. Two different experiments will be made. The first one will use a Smart Scanner developed from a second generation ESP8266 ESP-12E NodeMCU Amica board, a low-power Arduino type board, with an extremely low retail price, which runs on ESP8266 Wi-Fi module, to sense a point of interest for Wi-Fi probe requests. A probe request is a frame sent by a client station (e.g., smartphone or laptop) requesting information from a specific Access Point (AP) or all APs in a given area. If properly sensed, it may give a measure of people's density of a given area and even their trajectories. To complement the proof of concept, the second experiment will focus on Smart Clothing, which will undoubtedly play an important role in the promotion of the citizen sensor and Smart Cities. Designed primarily for runners and cyclists, the focus will be on equipping VRUs' clothes with a Bluetooth Low Energy (BLE) transmitter to understand how such users can be detected on the street, thus avoiding potentially dangerous situations for such VRUs. An Android application was also developed for this purpose. The remaining of this paper will be structured as follows, viz. The next section will analyse the literature in regard to the topics being covered in this work, followed by a section that endorses and validates the used materials and methods. The fourth section will discuss the achieved results. Finally, conclusions are drawn and future work is outlined.

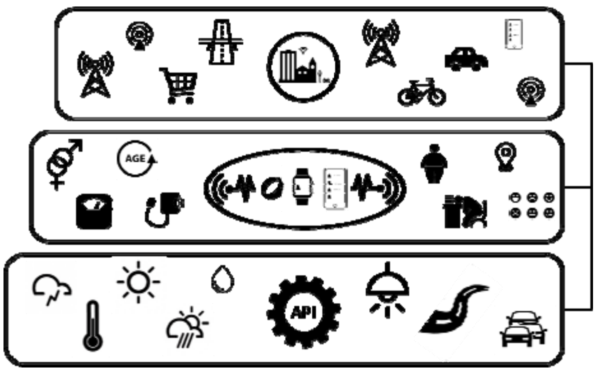

Figure 1: The scale levels for data collection and Ambient Intelligence.

2 Literature Review

A literature review was performed to understand how are researchers currently addressing the problems being studied in this work. Hence, this review focused on two different domains, viz. On one hand, how are researchers addressing the problematic of VRUs to increase road safety. On the other hand, how is crowd sensing being bind within a Smart City.

2.1 Road Safety and Vulnerable Road Users

Road safety is a very comprehensive topic, ranging from measuring traffic congestion or improving road pavements to increase the safety of motorcyclists or pedestrians. Some studies have already begun to develop systems that use IoT concepts to increase road safety. Some focus on improving safety by enabling Vehicular Ad Hoc Networks (VANETs), using cars as nodes of a mobile network [Khekare 13] [Barba 12]. Others focused mainly on Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication [Milanes 12] [Anaya 14]. On the other hand, some studies have already shifted their attention to Pedestrian-to-Vehicle (P2V) communication [Cho 14] [Liu 10] and the VRU problem, being the majority a purely theoretical approach and with no impact on our world. In [Cho 14], the authors propose a P2V communication system that targets children and the elderly and focuses on conflict zones. In this study, communication happens between vehicles and infrastructures, and only later between infrastructures and pedestrians. There is no direct communication between people and things. In [Anaya 15], the authors feature a new Advanced Driver Assistance Systems (ADAS) to prevent accidents involving motorcyclists and cyclists. To achieve such goal, a VRU detection system was developed, where vehicles and motorcyclists were equipped with their own communication unit. The last actor, the cyclists, were equipped with an on-board sensor known as iBeacon. However, they focused on informing the non-vulnerable driver of the presence and location of the VRU through a unidirectional information flow. Other studies, such as [Liebner 13], took a different approach, focusing on the benefits that smartphones could bring to the VRU, where it was evaluated the accuracy and transmission latencies for smartphone-to-car communications. It was demonstrated that the performance of the smartphone's GPS was severely affected if the smartphone was, for example, in the breast pocket of a jacket.

In all these studies, the focus is on informing the non-vulnerable user, the driver, about the presence and location of the VRU through a unidirectional flow of information. In fact, this can be considered as the main conclusion of our literature review [Fernandes 17a]. The main emphasis is on vehicles and drivers, foregoing relevant information about the VRU, who is being considered as a flat thing, as a passive actor, without differentiated emotions, behaviours or personality. In contrast, our intention is to enable the IoP, making people and things communicate and understand each other; making people an active, reactive and proactive actor and, therefore, consider their own emotions, physical and sociological characteristics to improve their safety as VRUs. It became clear that the VRU in itself is being ignored, as well as the use of the IoP to address the VRU problem. Indeed, in [Fernandes 17b] we had the opportunity to postulate a set of properties we envisage as essential for a successful implementation of the IoP. Among those properties, it is the novelty of integrating the Citizen Sensor as an active, reactive and proactive actor that enables the IoP. Under this setting, wearable devices, which empower citizens with sensing capabilities, will allow people to join the IoP and, thus, expedite the appearance of new approaches and solutions to the VRU problem.

Although the academic community has been producing important advances in the road safety domain, the vast contribution of the industry to the technological progress of our world is undeniable. In fact, given the great attention that has been paid to road safety, there are a significant number of projects funded and supported by companies and/or institutes that aim to promote industry development, improve people's quality-of-life and foster the social good. Therefore, we are required to study and analyse those that are related to the topics covered in our work and, so, emphasis has been put on research projects on the VRU problem, IoT, Big Data and the Social Good [Fernandes 18]. Bearing in mind the difficulty to unveil such projects and the fact that many of them are not open to the public, eighteen were considered for review, many of which had different approaches to the problems under study. These projects include *Telefónica's Big Data for Social Good* [Oliver 14] and *BYTE* [Byte 14], which focus the use of big data to promote social welfare in areas such as crime prevention, propagation of pandemics and flood detection. It is interesting to note the tremendous benefits of using anonymized network data and massive mobile data to create more robust and accurate solutions, seizing the opportunities that Big Data brings to maximize social benefits [Fernandes 18]. On the other hand, older projects such as *SMART RRS* [Smart 08], *Ko-TAG* [Duenkler 13], *SAVE-U* [Save 04] and *ARTRAC* [Artrac 14] were important to the advance of state of the art radar, camera and video-based sensors, which are now available in almost every car. Recent projects such as *XCYCLE* [Xcycle 15], *HIGHTS* [Hights 15], *MAVEN* [Maven 16] and *TT* [TT 17] use smartphones, high-precision location technologies and infrastructure-based wireless communication technologies to increase road safety and improve current in-vehicle detection system. Others like *TIMON* [Timon 15], *TEAM* [Team 12] and *VICINITY* [Vicinity 16] are focused on developing frameworks for collaborative networks and future automated vehicles and their challenges. Indeed, the goal of all these projects is to foster the social good and promote road safety by expanding the existing knowledge of sensors and collaborative networks. However, the main conclusion from the academic review remains valid, viz. Excessive attention is given to the non-vulnerable user, foregoing vital information about the VRU. A detailed and more deeper review may be found in [Fernandes 17a] and in [Fernandes 18], where more data is shared, including bibliographic search strategies, dates, graphics and others.

2.2 Crowd Sensing

Some studies have already engaged on employing different means for tracking and counting people at specific places. Indeed, the main focus is on tracking and counting people instead of sensing and considering them as active actors. Some studies have focused on methods that force people to carry specific devices or on employing invasive technologies like cameras. However, the acceptance of such methods is low due to development and deployment costs, inefficiency in some scenarios and privacy issues. On the other hand, non-invasive methods would be easier to implement and to be accepted by the community, even if less accurate. In [Musa 12], the authors aim to track user's smartphones using Wi-Fi monitors, being focused on trajectory/path. The authors' system uses common AP hardware to both collect and deliver detections, requiring a central server for intelligence purposes. The proposed tracking system consists of one or more Wi-Fi monitors placed at specific locations and a central server where Wi-Fi observations are analysed. Wi-Fi monitors are built from standard Wi-Fi access point hardware, namely the Ubiquity PicoStation 2, which retails for around $70. Even though this price is not prohibitive, it is substantially high when compared to the board used in our work, which retails for around $2.90 and already includes a Wi-Fi module. On the other hand, for internet access the monitors have to be equipped with a cellular modem, incurring in a significant monthly cost, which can be prohibitive for long-term or large-scale deployments. In addition, there is no estimation of crowd density being only focused in tracking people. In [Weppner 13] the authors used a technique for estimating crowd density using a mobile phone to scan the environment for bluetooth devices. Their approach requires users to be moving through the environment with their smartphones scanning for devices with discoverable bluetooth enabled. Moreover, the authors derive the basis for their technique on very wrong assumptions, i.e., "many people have the Bluetooth transceivers of their mobile phone in the discoverable mode as default setting". Fortunately, one can easily notice that the number of people that understand the risks of keeping the bluetooth services enabled is increasing substantially. Obviously, some people may keep such services on every day, but they are not a representative sample of the population. Therefore, the use of standalone bluetooth scanning will provide extremely inaccurate results for crowd sensing. On the other hand, we are witnessing to the exponential use by people of smartwatches, smartbands and even smart clothing, all of which hold bluetooth connectivity. The inclusion of studies focusing on the detection of such devices would allow one to produce robust models for crowd sensing. As an example, in the work presented in [Schauer 14], both Wi-Fi APs and bluetooth beacons are used to determine the reliability of the estimation of people. In particular, attention is devoted to Wi-Fi technology with active and passive scanning of not only MAC addresses but also RSSI (Received Signal Strength Indicator). The study was conducted at a major boarding airport in Germany and boarding passes were used as validators for the assessment of each strategy. Considerations about users' devices, bluetooth and Wi-Fi policies are also shown to have influences in the number of captured devices. In general, bluetooth is considered to underestimate the number of people while Wi-Fi tends to overestimate. The authors suggest an hybrid approach for more accurate results. One study that leverages Wi-Fi technology to count the total number of people walking inside a building is the one performed by [Depatla 17]. Their approach is based on Wi-Fi transceivers, receivers and Wi-Fi RSSI measurements. The first one transmits wireless signals that interact with walking people and static objects and are then received by the receiver. The fluctuation in RSSI values between transceiver and receiver may indicate the presence of people, animals or objects, in the area between the two devices. One is constantly transmitting wireless signals, while the other measures the emitted signals and records the RSSI. Both wireless cards need to be interfaced with a computer, having the authors used a Raspberry Pi. Even though this is a very interesting approach to the problem under study, there are some obvious drawbacks. The authors employed tests with very few people inside the area of interest, leaving doubts about the accuracy of the system with a real crowd. Moreover, the cost of this solution may be significant if one aims to cover a meaningful area, requiring several transmitters, receivers and computers. In addition, new studies would have to be conducted if one changes any variable, such as the distance between devices or they relative position to each other, as the model would have to learn to identify new RSSI fluctuations as people. Differently, in [Wang 17] the authors provide an application scenario for the use of Wi-Fi probe-based detection of user occupancy. In this case, the estimation is demonstrated as an input for modelling user occupancy and optimize HVAC (Heating, Ventilation, and Air Conditioning) control. Though the approach is interesting, the aim of this research is to create occupancy models using Dynamic Markov Time-Window Inference from occupancy estimation. The passive scan used in the approach is not detailed but it is based on a simple detection of devices. Enhanced Wi-Fi and Bluetooth strategies can be used to improve use occupancy estimation, but they are not in the scope of this article. Another approach may be seen in [Oransirikul 14], where the authors, with a non-invasive and non-participatory mechanism, aimed to measure bus passenger loads by detecting the periodic network probing activity from Wi-Fi devices built into smartphones. The authors experimented two methods for data collection. The first one relied on Bluetooth device detection, but poor results enforced the second method, the one relying in Wi-Fi probing detection. The authors' approach was to use the wireless network interface controller of a Linux computer (Atheros AR9285 wireless network interface of a Hewlett-Packard Pro- Book 4320s laptop running Ubuntu) placed in monitor model and *airodump-ng* for packet capture during a sixty-minute period at a bus stop on a busy afternoon and during a ten-minute ride aboard a bus. Indeed, the use of a computer and the need for someone to operate the device within a bus and at a bus stop significantly reduces the practicability and feasibility of the system while, at the same time, increases costs. Another interesting study that aimed to make the bridge between Smart Cities and monitoring and tracking systems is the one presented in [Fernandez 17]. Here, the authors present a system to track the movement of people and vehicles, monitoring the radioelectric space by catching Wi-Fi and Bluetooth signals. The system collects people's and vehicles mobility data and is able to track them with a grid of devices that are connected to a central server, allowing the construction of traffic flow models or mobility graphs. The devices that compose the system are based on a single-board Raspberry Pi 1 including two USB cards and have a cost of 100$ each. Even though the authors claim these devices are low-cost and significantly cheaper than usual monitoring systems, their price is still substantially high (several devices of 100$ each) when compared to our solution of 2.90$ ESP8266 NodeMCU boards. A positive aspect of this work relates to the anonymization of data for privacy purposes, even though most devices already employ MAC randomization when probing Access Points. Moreover, there is no reference to the software used for device detection neither if it is using proprietary technology or if new software was developed, as in our case where we produced and released two open-source software programs under a MIT license. Finally, the system's architecture consists of many parts and modules such as one to act as a gateway between the devices and the server or other that implements a set of services for accessing the devices from outside. In our case, the ESP8266 NodeMCU board running our open-source software can detect the devices, handle and treat data, detect and discard new/old sightings, communicate the sightings to the cloud (since it has the capability to work, simultaneously, as an Access Point and as a Station), and receive pre-defined commands.

3 Materials and Methods

For this work, there was a clear concern with the cost of the solution to ensure the feasibility of its deployment within a city. Moreover, advocating for open-source software, we decided to publish all the software we produced under a MIT and Apache 2.0 license in GitHub.

3.1 Crowd Sensing Smart Scanner

Taking advantage of the huge potential of small Wi-Fi integrated boards, the authors decided to use a second generation ESP8266 ESP-12E NodeMCU Amica board (Figure 2). The NodeMCU is a low-power Arduino type board which runs on ESP8266 Wi-Fi module. It is suitable for the IoT and can facilitate the bridge towards Smart Cities, removing the need for wired communication and processing. Besides the reduced cost of 2.4€, or $2.90, per board, it also has an impressive set of characteristics that should be highlighted. It has Wi-Fi capability, eliminating any need for wired communication, 4 MB of flash memory, which proved to be more than enough for this work, a micro-USB interface, a built-in antenna, open-source support, small dimensions (4.8x2.4x0.5cm), low weight (109g), and other features that make it a desirable hardware for future Smart Cities.

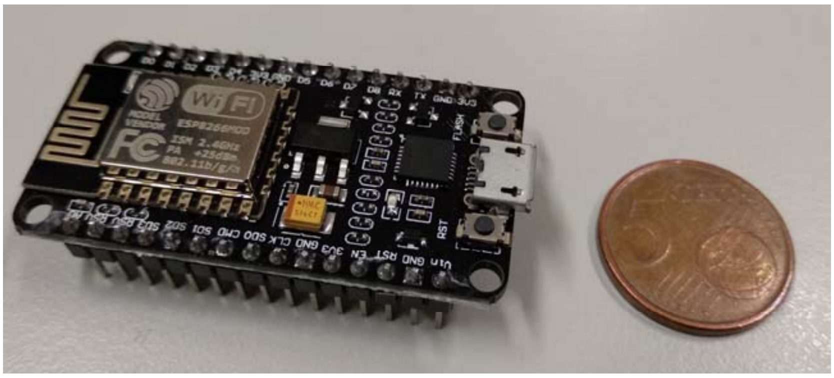

Figure 2: A second generation ESP8266 ESP-12E NodeMCU Amica board.

1) Arduino IDE

The Arduino Integrated Development Environment (IDE), the one used in this work, is a cross-platform application written in Java that makes it very easy to develop code and upload it to the board, providing basic one-click mechanisms to compile and upload sketches to an Arduino type board. Sketch is the name given to a program developed with this IDE, which should be written in the languages C/C++. The open-source nature of the Arduino project has facilitated the release of many free software libraries that other developers may use. In fact, in our system we use two external libraries, entitled as ESP8266WiFi and FirebaseArduino. Programming in the Arduino IDE requires the developer to define, at least, two functions: setup() and loop(). The former one is called once when a sketch starts after powering up or reset, being used to initialize variables, input and output pin modes, and other libraries needed in the developed sketch. The latter is repeatedly executed in the main program until the board is powered off or reset. In addition, this board contains a Light-Emitting Diode (LED), which is a convenient feature for many tests and for beginners in Arduino programming.

2) The software - Crowd Sensing

This open source software consists of a sketch, developed in the Arduino IDE, to detect Wi-Fi probe requests issued by people's smartphone. With this, one is empowering the citizen sensor on a non-invasive manner. The software was released in GitHub (https://github.com/brunofmf/Crowd-Sensing) under a MIT license. It makes use of, essentially, two libraries: ESP8266WiFi.h, which provides specific Wi-Fi routines for connecting to the network, and FirebaseArduino.h, which one may use to call the Firebase API from the ESP8266 Arduino core. As mentioned earlier, there are two mandatory functions. On the *setup*() one we set the data rate in bits per second (baud) for serial data transmission; we setup the Wi-Fi mode of the board as *WIFI_AP_STA*, meaning the board will work, simultaneously, as an Access Point and as a STAtion; we start both modes with the required authentication credentials and, if the station connection is successful, initialize the Firebase connection; we setup the timer for handling data collection and the transmission of information to the Firebase database; and we register the handlers that are called every time a connection/disconnection is made and every time a probe request is received by the board. On the *loop*() function is where the board waits for user interaction. It accepts commands like *Stop*/*Restart*, *Count*, *Start*/*Stop_Timer* and *Clear*, among others. This allows an administrator to enforce additional behaviour from the board, which, by default, starts with the handlers and services enabled. More functions make part of this sketch, being the most important the *onProbeRequestCaptureData*(), which captures the probe request, assesses whether it is in the presence of a new sighting and decides to save/discard the MAC, RSSI and timestamp of the event; and the *sendDataFirebase*(), which is responsible to build a JSON object with the sightings and send the information to the Firebase database. The developed sketch is ready to use (plug and play), with more information and details being provided on the corresponding GitHub page.

3) Range Measurement Experiment

The board comes with a built-in antenna but there is no safe and clear value for its range. However, as we want to measure and sense people in a particular area of interest, it would be important to know the exact area covered by a single board. Therefore, to answer this question we were required to make a simple experiment to discover the range of the board in an outdoor scenario. The procedure was to start the board and run the above sketch. Then, a person would periodically connect and disconnect to the board, while moving away from the board in a straight line. Thus, the board would collect the RSSIs, which would decrease to the point where one would be unable to connect and no RSSI would be received by the board. Then, a straight line was drawn and the distance between the board and the place where the signal was lost calculated. After performing this process a few times in several directions, it was clear that the board had a range of, approximately, 27 metres on straight line, covering an area of, approximately, 2290 square metres (Figure 3). It is important to note that in indoor scenarios the range may be slightly smaller due to unavoidable interferences. However, such scenarios do not pose a point of interest to VRUs and, subsequently, to this work, so no values were computed for such scenarios.

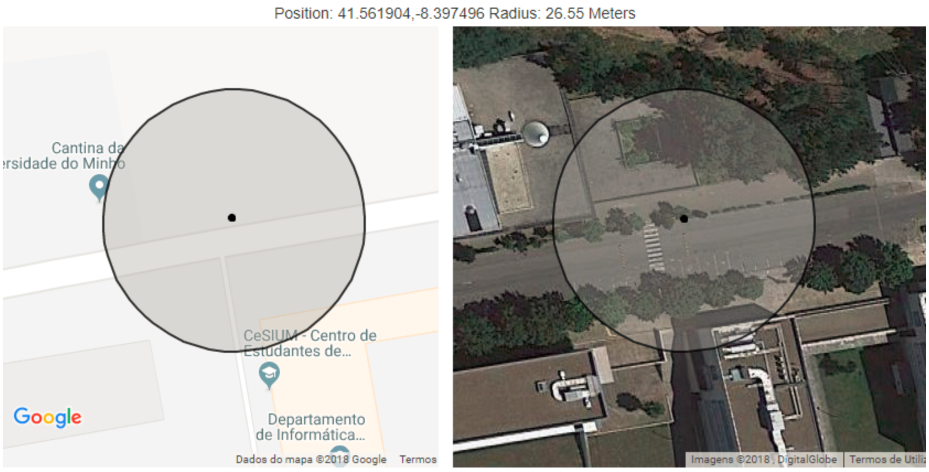

Figure 3: Range calculation of ESP8266 ESP-12E NodeMCU Amica board within a point of interest for Vulnerable Road Users: a pedestrian crossing.

3.2 Smart Clothing

To complement our proof of concept, we aimed to introduce Smart Clothing. In fact, considering how crucial the citizen sensor is to the IoP, there is no doubt smart clothing will play an important role to promote people to such level. Therefore, it will come as no surprise when, in a near future, clothing come equipped with multiple sensors that will help one keep track of his health, cleanliness, running pace or even emotional status for the day. One may see smart clothing as the next level after smartphones, smartwatches and smartbands. Designed primarily for runners and cyclists, the idea was to understand how a sweater, equipped with a BLE transmitter, could allow such users to be detected at the road and, thus, help prevent possible dangerous situations for such VRUs. For that, one resorted to beacons, a new bluetooth-based sensor with low-cost, low-power transmitters, which notify bluetooth devices of one’s presence.

1) The Beacons

To achieve the above goal, Gimbal Series 10 Beacons (Figure 4) were the ones selected. These beacons have important characteristics, being a battery-powered device that transmits a Bluetooth Smart/LE signal that can be detected by other devices/smartphones. This signal makes it possible to identify the beacon and the one wearing it, as well as other telemetry information about the receiving device (e.g., battery level or temperature). The beacon works by periodically waking up, transmitting a signal and then returning to a low-power state, having no user interface or GPS capabilities. It costs 4€, or $5.00, each, it uses standard CR2032 replaceable batteries that last for months, has small dimensions (40x28x5.5mm) and weighs 6.52 grams, holding an omni-directional antenna working on the 2.4GHz channels, which was designed to coexist with Wi-Fi. The range, as advertised by the manufactures, is around 50 meters, although it can often be detected at further distances in clear line-of-sight conditions. In fact, it has a considerable range, which has been confirmed during our tests. However, these beacons present some drawbacks. First, each beacon needs to be manually activated and configured at Gimbal's Manager page. Moreover, to use the beacons one needs to use Gimbal's SDK for beacon detection and feature extraction, requiring internet access to validate each beacon's id. In addition, the SDK is not open source, which was a problem when trying to debug and understand the app's behaviour.

Figure 4: Gimbal Series 10 Beacon.

2) Android Application - ISLab Beacon App

Moving from theory to practice, it was developed an Android App. An open source software was developed in Android Studio and released under an Apache 2.0 License in GitHub (https://github.com/brunofmf/Smart-Clothing). The app targets version 26 of Android API, corresponding to Android Oreo 8.0, but it runs on devices with, at least, version 21 of Android API, corresponding to Android Lollipop 5.0. Essentially, after installing the app, an user is able to detect a beacon if it is within range, is able to detect a geofence (i.e., identifying points of interest, such as pedestrian crossings or bike lanes) and receive notifications provided by a beacon. It is also possible to change sightings intervals and start/stop the scanning. The structure of the app consists of three main packages, viz. The *Model* package contains all classes that represent data objects, including the GimbalDAO, which is responsible to store events on the smartphone's shared preferences, and the GimbalEvent, which represents an event of type PLACE_ENTER, BEACON_SIGHTING or COMMUNICATION_ ENTER, among others; the *Controller* package, containing all app's logic including handling Android's permissions, enable Beacon's monitoring, setting listeners and managers, and starting singleton instances; and the *Activity* package, which is responsible for the User Interface logic, including the settings activity, the list adapters and the main activity. Therefore, this app is able to sigh beacons integrated within clothes, enabling what we called Smart Clothing. In fact, the clothe itself did not require the entire beacon skeleton, but only the bluetooth sensor, so that it could then become another IoT object that would allow the empowerment of the citizen sensor. However, for our proof of concept, the integration of the beacon with the clothes was sufficient to assess the feasibility and utility of the idea. Table 1 shares the activation data for each one of the seven used beacons, including beacon's name, applied configuration and activation bit. The beacon's ID was hidden for security reasons.

Beacons				
ID	Beacon ID	Name	Configuration	Active
1	n/a	The Genesis	Gimbal	Y
2	n/a	Pedestrian A	Gimbal	Y
3	n/a	Runner A	Gimbal	Y
4	n/a	AAA	Gimbal	Y
5	n/a	Runner B	Gimbal	Y
6	n/a	BBB	Gimbal	Y
7	n/a	Cyclist A	Gimbal	Y

Table 1: Gimbal Series 10 Beacon assign management.

3.3 Ethical Considerations

It is important to highlight that our methodology is entirely non-invasive, requiring no user interaction with the developed system. Not in any way did we try to decrypt any data or perform active actions to stimulate or alter normal network behaviour. Our work presents no expectation of harm, instead it aims to commit a benefit to our society by contributing with solutions for the enhancement of road safety.

4 Results and Discussion

The research method used in this work focused on field and laboratory experiments. Naturally, this work created knowledge for a purpose, produced by scientific applied research, having its validity in a matter of efficacy, efficiency and utility. Therefore, for the crowd sensing field experiment, the Smart Scanner was placed in the location depicted in Figure 3. This image shows the 2290m^2 area covered by the board. On March 23, 2018, four measurements were made with a duration of fifteen minutes each. While the Smart Scanner was sensing the environment for people and communicating its findings, an observer would be counting each person and each vehicle that would enter within the Smart Scanner's range. This allowed one to compare both values and have a validation measure. Table 2 shows the outcome of the counting performed by observing the environment vs the sensing of the environment by the Smart Scanner, for each one of the four periods. During these epochs, 640 people and 90 vehicles passed within the Smart Scanner's range, as per the observer's counts, which corresponds to a total of 730 people. On the other hand, the Smart Scanner handled a total of 1062 requests from 722 distinct devices. This is possible to unscramble since the Smart Scanner gathers both the MAC address and the RSSI associated to each request, as well as the timestamp it was received. Even though some fluctuations may be seen, the final value shows very promising results, with the Smart Scanner showing only a two percent difference from the real count. Moreover, it is easy to notice that the number of people tends to increase over time (Figure 5). This is explained with the fact that this point of interest, a pedestrian crossing, is near a restaurant and the experiment took place close to lunch time.

	Observation			**Smart Scanner**	
	People	Vehicles	Total	Distinct	Total
11h46 - 12h01	104	10	114	91	172
12h01 - 12h16	164	20	184	224	322
12h16 - 12h31	180	21	201	170	266
12h31 - 12h46	192	39	231	237	302
Total	640	90	**730**	**722**	1062

Table 2: Outcome of environment's observation vs the environment's sensing.

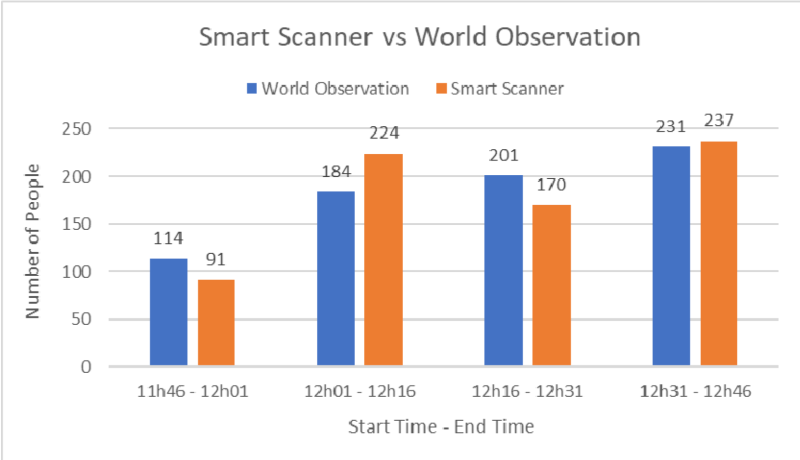

Figure 5: Graphical outcome of environment's observation vs the environment's sensing for each period.

Regarding the handled 1062 Wi-Fi probe requests by the Smart Scanner, Figure 6 presents a bar graph containing the comparison, per period, of the total number of requests versus the number of the distinct ones. For example, in the second period (12h01 - 12h16) the scanner dealt with a total of 322 requests but only 224 where distinct, meaning that 98 requests were discard as repeated. This happens, for example, if a person enters the point of interest but remains in the region for the remaining of the period. In fact, that was a situation reported by the observer, where people where noticed to stay within the point of interest for a few minutes, meaning that several probe requests would be received by the scanner with the same MAC address.

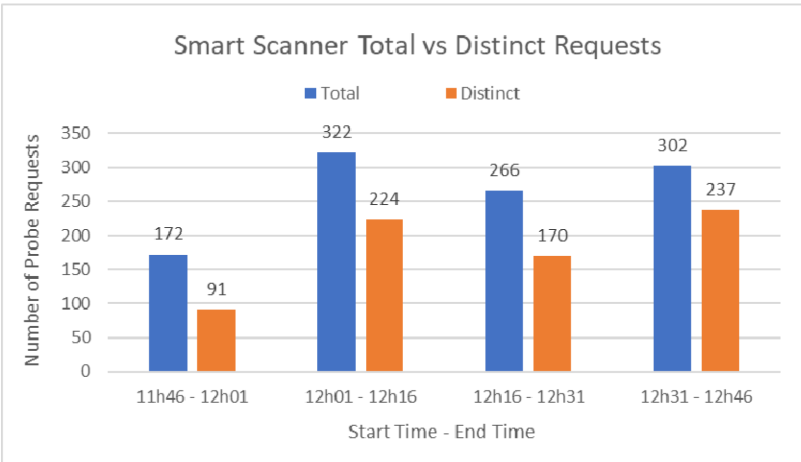

Figure 6: Probe requests handled by the Smart Scanner during the four periods.

It is also interesting to note that, when aggregating the data of the four periods, the number of different people sensed by the Smart Scanner reduces from 722 (Table 2) to 678 (Figure 7). The most obvious explanation is that the same person was sensed in two, or more, periods, meaning that there were 44 people within the designated area in different periods. This is indeed useful because the point of interest is a pedestrian crossing near a restaurant, with the measurement periods happening just before lunchtime. Therefore, it is quite plausible that a person went through the point of interest on a period (e.g., the first one) to have lunch and then passed again in another period (e.g., the last one) after having the meal.

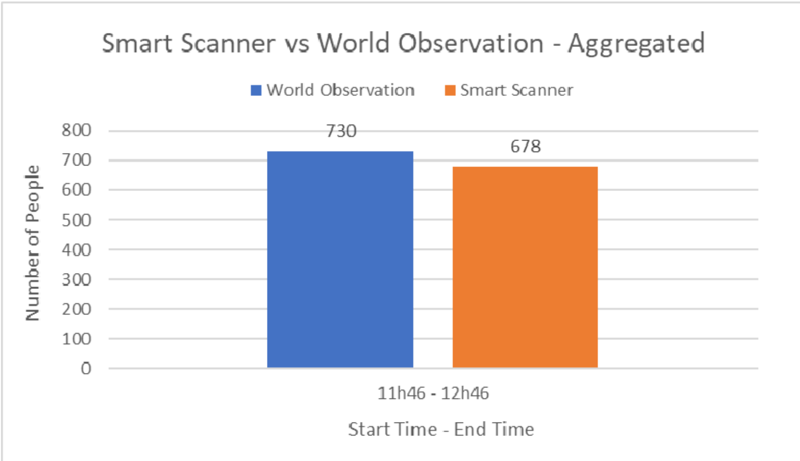

Figure 7: Aggregated data from the four periods.

By focusing on the sensed Wi-Fi probe requests and its attached data, interesting insights can be obtained from the analysis of MAC addresses, where the first three octets of the address correspond to the Organizationally Unique Identifier (OUI), which identifies the vendor of the device. Although IEEE offers the ability to purchase a private OUI that does not contain the company's name, this privacy measure is not being used by any major manufacturer, as demonstrated bellow. The remainder of the address is assigned by the organization, subject to the constraint of uniqueness. In our study, from the 1062 sensed probe requests, 302 where emitted from Android Devices (da:a1:19) which did not discriminate the vendor (Google, Inc.), 127 had a locally administered address, 66 were from Samsung devices (88:83:22 and 04:d6:aa, among others), 20 from Apple and, among many others, 2 from Continental Automotive Czech Republic (9c:28:bf) and 1 from PARROT SA (a0:14:3d), a drone's company (Figure 8). When this data is decrypted, it is interesting to note a significant number of devices transmitting Google's id or having a locally administered address. This is due to recent measures for MAC randomization, in order to increase one's privacy and hinder the tracking of a person's trajectory using the MAC address. Nevertheless, since our proof of concept was on crowd sensing rather than in trajectory estimation, sensing Wi-Fi probe requests proved to be feasible and with practical potential.

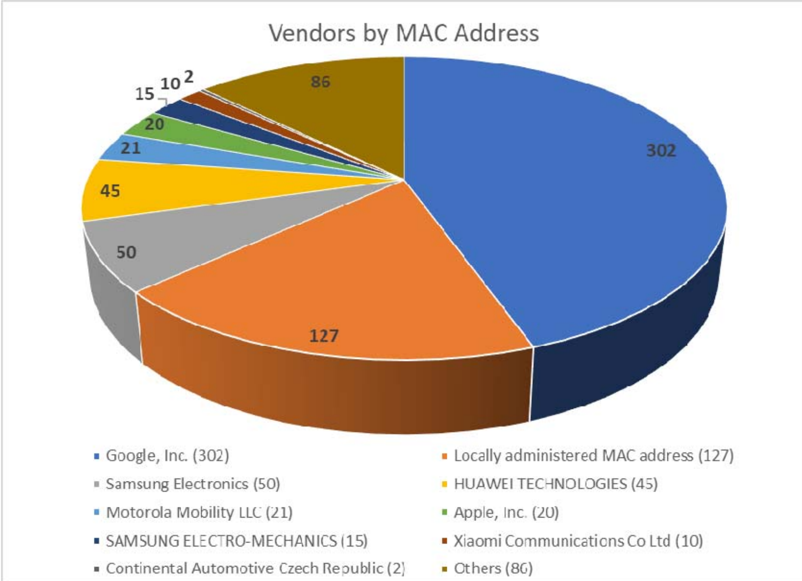

Figure 8: Distribution of the sensed devices by vendor.

As for the Smart Clothing experiment, beacons were introduced in clothes simulating the incorporation of a BLE transmitter, allowing the wearers, the VRUs, to be connected to the IoP, empowering the citizen sensor. An Android app has been developed for this study so that a smartphone running the ISLab Beacon app would have the capacity to detect the wearers as soon as they were within a 50m range. After distributing the beacons and starting the app, sightings of VRUs were detected, as depicted in Figure 9. The user of the app has the possibility of getting more details about each sighting such as the battery level, RSSI, approximate distance to the VRU and the temperature. As shown in Figure 9, several sightings of Runner B were triggered by the app. On the first one, at 15:27, the RSSI was of -55 being the runner at an approximate distance of 0.30m. The next sighting happened a few seconds later and Runner B was now further away, at an approximate distance of 1.26m with an RSSI of -64. The temperature was of 18ºC. Additionally, as soon as the app's user enters a geofence, a notification is raised by the app, as depicted in Figure 9, which shows the app's user entering the ISLab Geofence (an exit notification is also triggered). In this proof of concept, a smartphone's app was developed, with excellent results being obtained. The detection of the VRUs occurred as expected as well as the geofence ones. Once the usability of such a system has been demonstrated, the idea is to proceed from a smartphone's app to an app for vehicles. To this end, one should use Android Auto to deploy this app on cars, allowing drivers to (1) be notified as soon as they enter a specific point of interest (geofence) for VRUs, such as pedestrian crossings or bike lanes, and (2) to be notified as soon as a VRU approaches a vehicle from a dangerous distance.

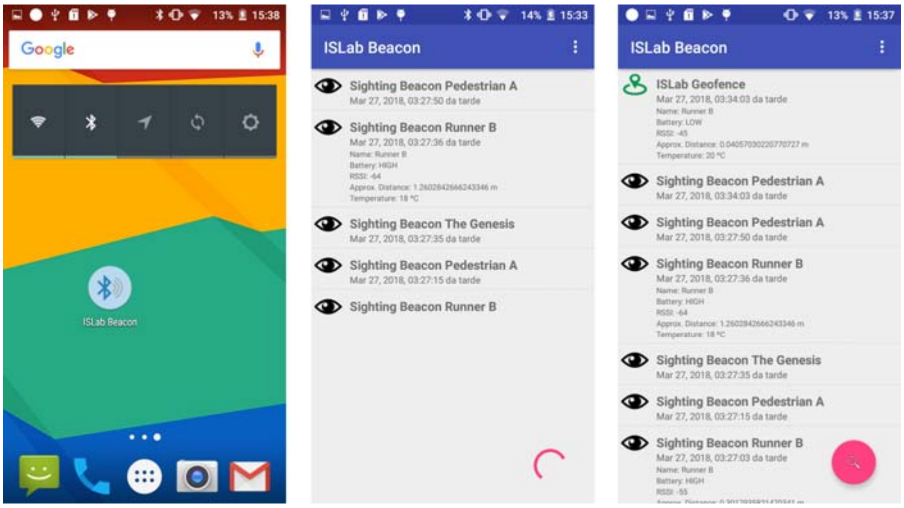

Figure 9: Android's ISLab Beacon app. From the left to the right: (1) app's launcher icon; (2) scanning for nearby Smart Clothing; (3) details of two Runner B sightings.

5 Conclusions and Future Work

Smart Cities are the future, but also the present. The aim of this work was therefore to provide a proof of concept for Crowd Sensing and Smart Clothing, evaluating its feasibility and practical potential for any city that wants to cross borders and become smart. The achieved results exceeded expectations. The Smart Scanner was able to sense 98 percent of the crowd and provide relevant insights on important points of interest for VRUs, such as bike lanes and pedestrian crossings. In addition, respecting budgetary limits imposed on any public and private organization, this was achieved using a 2.4€ board, which as capable of covering more than 2200 square meters. In addition, all produced software was released as open source, advocating for transparency and reliability. Out of road safety's scope, the developed Smart Scanner for crowd sensing can be used in many domains, allowing a city to improve crowd control at big events, improve urban planning or assemble relevant insights on how visited a specific place is, among others. In turn, the Smart Clothing study aimed to strengthen the citizen sensor, the IoP and Smart Cities. Mainly thinking on pedestrians, runners and cyclists, the idea was to understand how a sweater, equipped with a BLE transmitter, makes these VRUs visible on the road. Excellent results were achieved with the smartphone's app in terms of VRUs and geofence sightings, allowing one to understand the presence of VRUs and the approximate distance to each other. Future work on the Smart Scanner will be to leverage the ability to simultaneously act as an AP and as a station, to create a mesh of smart scanners with increased sensing capacity. More goals are to use RSSI measures to estimate the distance to points of interest and to apply the conceived system in different areas. In addition, it is our intention to apply Machine Learning algorithms to the extracted data in order to collect relevant knowledge and information. The ISLab Beacon app will in turn converge into an Android Auto app in order to evaluate its behaviour within a vehicle.

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