

Accessible Wayfinding for the Visually Impaired through Sustainable Smartphone Based Sensing

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Abstract—Cities have been developed to support cars rather than people. This has led to a decrease in people's ability to move, live and interact with their urban surroundings, thus affecting the quality-of-life. Obviously, this applies to all of us, especially to people suffering from impairments. Surprisingly, the lack of information is one of the main obstacles to the construction of services that could bridge the gap between people living in urban areas and their environment. Take Google Maps as an example; one can request a route between any two destinations and will surely be provided with the shortest path, whether traveling by car, public transportation, or on foot. However, there are no pathways or information available to help visually impaired people. In response to the above issue, in this paper, we discuss how the widespread presence of sensor-equipped smartphones can be harnessed to create innovative services capable of improving factors such as interaction with the environment, social inclusion, and quality of life.

Keywords—accessibility; mobile; smartphone; visually impaired

I. INTRODUCTION

We live in cities increasingly congested by the vehicles we regularly use, even for short commutes. This change in our urban environments has clearly impacted on our quality of life and increased the disparity between those able to move freely and those suffering from mobility limitations due to physical impairments. Consider individuals moving between any two locations; if one does not know how to reach a particular destination, Google Maps or even another map tool can definitely provide a solution. However, these services do not provide accessible pathways for those who are visually impaired. We could even argue that each individual would like to have proposed itineraries considering their preferences, whether in terms of road safety, noise level, beautiful scenery along the way, the possibility of meeting up with friends, etc.

The primary challenge in developing a digital service capable of generating adequate and accessible urban transport is actually the lack of information. Indeed, in order to generate only pathways including, for instance, traffic lights with audio signals, the data on all traffic lights must first be acquired and stored in a database; this would be a massive and expensive project. Nevertheless, with the widespread use of smartphones, we now have the ability to use the pervasive presence of sensors capable of communicating via crowd-sensing as a tool to collect all the necessary geo-referenced urban data.

This vision is not unrealistic as we demonstrate through a system we designed and implemented to provide accessible wayfinding for the visually impaired. Our system includes (i) distributed and sustainable sensing performed by already existing smartphone sensors and (ii) web services able to elaborate the sensed data to generate pedestrian routes that take into consideration useful information for visually impaired users. In particular, our system allows users to prefer pedestrian routes with accessible traffic lights (i.e., with audible signals) and with certain levels of noise and brightness, as both factors have a particular impact on the senses used by visually impaired users while walking towards a destination.

The rest of this paper is organized as follows. In Section II we overview related work. Section III is devoted to discussing in general components required to implement a sensing based system enabling accessible wayfinding services. Section IV and Section V presents two Proof of Concept (PoC) sensing applications we have developed and tested that allows us to detect accessible traffic light and identify roads with desirable noise/brightness conditions, respectively. Finally, conclusions are drawn in Section VI.

II. RELATED WORK

This section provides an overview of solutions designed for urban mobility and accessible to individuals with impairments. Many smartphone applications, have been developed by researchers and developers to monitor human behaviors [1]-[5]. These applications can detect if the user is driving a vehicle, walking, ascending stairs, or falling, among other things. The technology at their core might be used to detect accessibility characteristics (e.g., a curb without a ramp) [6], [7]. For example, we can utilize data collected from the accelerometer readings of a smartphone to determine if a person is crossing a road as well as whether pedestrian traffic lights are present [8]. Collaborative sensing may clearly be used to enhance the accuracy and range of sensed data [9], [10].

Focusing on wheelchair users, it is worth noting that there are applications that are able to locate wheelchair-accessible restrooms, parking lot spaces, and services in general [11]. Some applications also rely on crowdsourcing: users must actively upload information and images to document the inaccessibility of a particular site [12]. Furthermore, formal reviews performed by accessibility expert volunteers are used

in similar approaches. This is especially important for indoor assessments where autonomous sensing may fail [13].

General mobility impairment has been addressed by providing accessible solutions exploiting IoT, mobile/wearable devices and augmented experience. Examples have been developed for both limited environments (e.g., a campus) [14], [15] and more general ones (e.g., a city) [16].

Hybrid techniques that depend on specialists and exhibitors have been proposed to assist pedestrians suffering from impairments, such as presenting a map of the city with information regarding accessibility barriers and facilities [17].

Finally, mPASS is a system that may recommend pathways to users depending on their preferences and requirements [18], [19]. It may thus consider not just accessibility barriers for individuals with impairments but also other concerns like safety, strollers-friendly, and many more [20], [21].

III. FROM SMARTPHONE BASED SENSING TO ACCESSIBLE WAYFINDING

We propose a system that gathers environmental data from smartphone sensors and employs them to provide customized paths to visually impaired users. The fact that these sensors are already pervasively present and do not require any new infrastructure investment, makes the solution sustainable. Furthermore, collected data can also be used for many other purposes, including but not limited to planning smart city development.

To this end, let us consider a person that has to walk between any two locations. The Google Maps service (as well as other similar ones) suggests routes generally based on either the shortest or the fastest path. Instead, a visually impaired user would probably prefer an accessible path where crossroads are regulated by traffic lights with audible signals. Furthermore, they would probably prefer routes with less noise to not overwhelm their hearing-based orienting capabilities and with more illumination in case they have (at least) partial sight and to avoid being hit by vehicles. A visually impaired user could deem these properties so important to be willing to sacrifice the length optimization.

Our solution is indeed able to take into consideration data collected from smartphones, through two PoC sensing applications, to create layers of information enriching wayfinding services such as Google Maps. Data is gathered with basically no human intervention and results of good quality thanks to the sensors. Collected data regards the presence of an audible signal when in proximity of a pedestrian traffic light (see Section IV) and of street noise/brightness levels (see Section V). We then use these data to implement accessible wayfinding for the visually impaired. Furthermore, the users are presented with the possibility to select a weighted combination of the available criteria and the system presents a ranked list of available paths towards destination and their characteristics. Finally, we have also developed a Google Maps based service that enriches maps with historical values about sensed data to provide the municipality or anyone interested with a heatmap representing instances and trends.

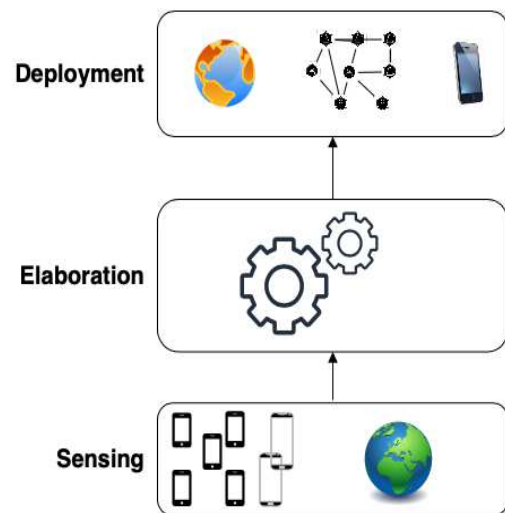


Fig. 1. From distributed sensing to accessible services: architecture layers

A. General Architecture

It is not easy to create an application that collects and shares sensor data. Fundamentally, the architecture of the system and the logic of the application must be built to meet the application's desired aim while preserving users' privacy [22]. Certainly, this involves breaking down the entire problem into sub-parts that are treated by specific layers (or modules) in the architecture [23].

These layers are illustrated in Fig. 1. First, the *sensing layer*, which must be present on the mobile device, is in charge of collecting unprocessed data from sensors. The *elaboration layer*, on the other hand, analyses data and creates outcomes. This layer can utilize various strategies to achieve this goal, ranging from simple empirical algorithms to artificial intelligence systems. This layer might exist on the smartphone or be outsourced to an external server [7]. When considering interactive applications, the *deployment layer* is responsible for displaying results to the end-users; it may also be responsible for convincing the user to do particular activities.

Individual sensing applications display results directly on the screen of the device which was responsible for collecting the sensor data. In a *group sensing* application, as in our case, the sensor data and results are shared across users in certain groups, and it is even possible to share them via social networks. If considering *community sensing* applications, information is delivered to the widest possible audience using whatever methods are available.

B. Design issues

The main concern with sensor applications regards overloading the device and depleting its limited power resources. This can strongly impact the utilization of sensing applications as not having enough energy for their phone calls or any other favorite application during the day would annoy users. Indeed, the collection and categorization of vast amounts of sensor data necessitate the use of more powerful mobile devices, especially if done in real-time.

Excessive computational resource consumption is caused by data processing, which relies heavily on sampling since the amount of data to be examined and inferences to be formed varies. In contrast, a variety of variables causes energy consumption. A more significant volume of data plainly equates to a greater use of processing resources. Generally, sensing causes a high consumption of energy, but the most prominent issue is presented by applications that demand continuous sensing since sensors must be in an active state. Furthermore, if another service consumes resources or if a user does another action concurrently, it may interfere with sensing. Continuous sensing necessitates full multitasking and background processing capability, as well as a phone profile that allows sensor management. Furthermore, the transmission needed for delivering the data to a server or a social network is another significant source of consumption.

Sensing relies heavily on the smartphone environment and user habits. Data may be gathered (and transmitted to a server) only when mobile devices are in a specific context, and sensor quality is not influenced by the environment or users. As a result, mobile devices should belong to specified user classes or act in ways that match the expectations and models made by developers. Unexpected changes in the background environment or user activities may jeopardize the quality of acquired data and invalidate the accuracy of collected samples. It is hence necessary to elaborate collected data to generate reliable information to be fed to deployed services.

IV. POC#1: IDENTIFYING ACCESSIBLE TRAFFIC LIGHTS

Researchers have proposed solutions to assist mobility-impaired pedestrians using custom-built route generators [24]-[28]. However, they are dependent either on the availability of route accessibility data or on the active engagement of users, who should generate and update geospatial data. Nevertheless, the critical issue of acquiring accessibility information for every road remains unresolved.

As shown in Fig. 2, it would be helpful to include information about the availability of traffic lights with audio signals at crossings in the route search given by Google Maps. This additional feature needs the creation of a database with information about each traffic light at each crossing. However, this database does not exist and cannot be built simply by employing someone to check every intersection and fill the database; it would be too time consuming and expensive.

Instead, we may take advantage of the ubiquitous presence of smartphones in modern cities and employ gamification techniques. Users will be enticed to participate by capturing as many auditory signals as possible from various traffic lights via a rewarding system. All captured audio files will be sent to a cloud service-hosted server, where they will be analyzed and may be used to create the database mentioned above.

A. Autonomous Monitoring of Audible Traffic Lights

The main challenge is the requirement for a community of active users voluntarily providing the needed data. Clearly, gamification could be used; yet, it would be much more effective to have an autonomous mechanism able to extract information and generate the expected service. To enable this

option, we need a system that can recognize when any person gets close to a traffic light and only then enable the microphone of her/his smartphone in order to detect possible audible signals coming from the traffic light.

To achieve this feature, the smartphone's accelerometer may be used. Indeed, it might be used to distinguish among different walking patterns and determine when the user is about to cross an intersection and then actually crossing it [29]. That would be the moment when the traffic light is playing the audible signal, if present, and hence when the microphone should be activated to search for its presence.

The accelerometer data has the following characteristics: acceleration along three axis x, y, and z. The basic idea is to be able to identify a simple series of events, such as (see Fig. 3):

1. walking at a regular speed;
2. stopping at a red light;
3. heading across the road on a green light;
4. resume walking at regular speed.



Fig. 2. Route generator including accessible traffic lights information

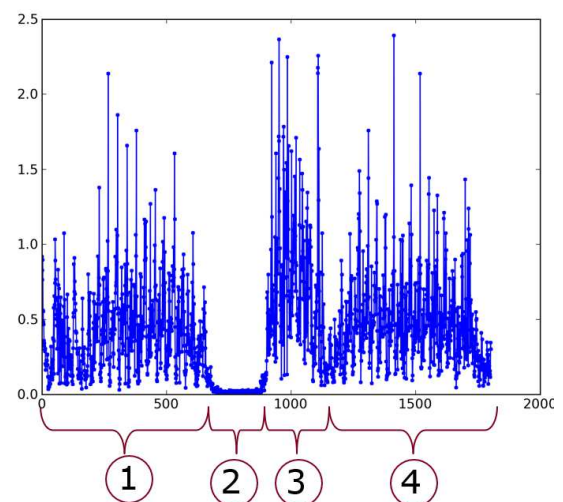


Fig. 3. Movement magnitude detected corresponding to different behaviors: (1) walking at regular speed, (2) stopping at a red light, (3) heading across the road on a green light, (4) resume walking at a regular speed

TABLE I. POSITIVE RATE VS. FALSE POSITIVE RATE

Positive rate	88
False positive rate	38

A high-pass filter is applied to the original data gathered in order to acquire only higher values that are more reflective of movement. Furthermore, rather than dealing with three separate vectors (x , y , and z), we elected to combine the three axes into a single vector and assess the magnitude.

The rationale in using the magnitude of the movement is that we do not want to distinguish between the numerous positions of a smartphone in relation to the user's body (in her/his hand, pocket, etc.). The system's performance is shown in Table I. We have been able to attain a favorable positive rate (i.e., the percentage of times the system actually recognized a pedestrian crossing and activated the microphone). Having missed 12% of the potential traffic lights is not a big issue as other users will pass through the same location and record the surrounding noise. On the other hand, having a 38% of false positives may seem a high value. Indeed, in all these cases, the microphone was activated while not necessary and the recording was then sent to the server, thus consuming energy and bandwidth; yet, as no traffic light is present, even no accessibility-related audible signal is going to be present and the recording will be discarded without affecting our database.

V. POC#2: DETECTING NOISE AND BRIGHTNESS LEVELS

This PoC is focused on pervasively gathering street noise/brightness data. Indeed, visually impaired users may feel more comfortable in using streets where their hearing capability (a crucial sense when sight is impaired) is not overwhelmed and/or the environment is well illuminated in case of partial visual capability to reduce the risk of accidents.

The data entry point is an Android application. It collects data about ambient noise (microphone) and light (brightness sensor). Gathered data would be erroneous if the smartphone is concealed in a pocket or a handbag. This is the main reason that made us create a smartphone application that requires the user to look at the device while holding it in her/his hands.

We have hence integrated data sensing capability into an Augmented Reality (AR) application for (any) pedestrian navigation and Point of Interest (PoIs) display. An initial warning informs the user about the anonymous data sensing that will be conducted. When environmental data is collected, a GPS location is linked to it. Once gathered, the data is sent to the server, which is in charge of storing and analyzing it.

Our application can lead users to their destination by employing the pedestrian navigation mode, showing them textual or graphical instructions. Furthermore, having employed Wikitude SDK, we can provide navigation instructions in AR, creating a more engaging experience than the one we would have obtained with a simple map. Indeed, users can place on the top of the map PoIs related to specific topics (e.g., events, attractions, restaurants, etc.), as shown in Fig. 4. Then, they can acquire information about a PoI or interact with it (e.g., open a website, dial a phone number, etc.).

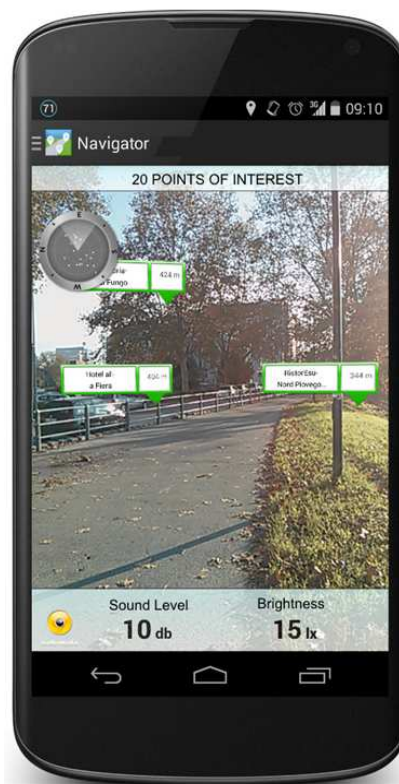


Fig. 4. Pedestrian navigation screenshot

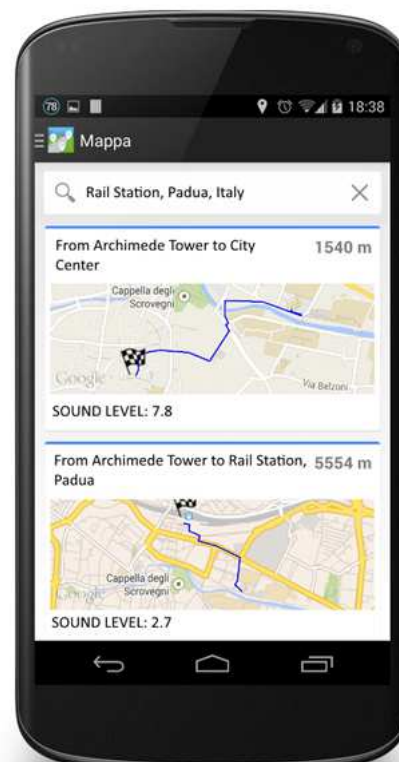


Fig. 5. Wayfinding screenshot: two routes differing by sound levels



Fig. 6. Web heatmap service visualizing collected data.

When the software is launched, the user is presented with a general Google Map view. The user must input a destination into the address bar, which is subsequently transmitted to the server. The server will then provide a list of different routes (Fig. 5), including the standard shortest route and alternative routes that consider customers' preferences in terms of noise and brightness/shadow (special menu). The AR navigation view may be accessed by touching one displayed route.

Clearly, the AR navigation application is intended for any user. Its purpose is to collect noise/brightness data. Then these data can be also utilized to create accessible wayfinding. The accessible path will be provided to the visually impaired users through appropriate means [30]: audio navigation, vibrating wristwatch coding, etc.

A. Data Presentation on the Web

Aiming also at fostering new sustainable services and at increasing the awareness of citizens and municipalities about the different values of noise and brightness on diverse days, hours and locations, our system provides online the collected data, exporting them from the server. To show an example of this functionality, we present part of the data collected during a trial in Padua (Italy). In particular, Fig. 6 shows the values employing a heatmap style provided by Google APIs. Users can click any point on it so that they can visualize detailed information and data evolution, presented in the form of histograms, over time regarding the selected location. Clearly, the amount, and hence the quality, of the data depends on the number of users of our application.

Even though we set some specific sampling frequencies for our trials (60s for noise and 100m for brightness), users can configure them through a dedicated menu. Then, once data is gathered, they are elaborated locally and sent to the server at the proper moment. Users can also configure the application to defer the transmission of data if connected to cellular connectivity, thus preferring cheaper wireless one.

VI. CONCLUSION

We discussed how the vast popularity of sensor-endowed smartphones can be exploited to create unprecedented services able to improve the interaction with the environment, the social

inclusion, and the quality of life. In particular, we have presented our platform and two applications developed to enable accessible wayfinding for the visually impaired.

As future work we plan to further extend our platform by providing more sensing capabilities and offered services, even considering other categories of impairments. We also plan to perform an energy consumption assessment and a user evaluation of the proposed solution.

REFERENCES

- [1] M. Ciman, O. Gaggi, "From a physical system to a pervasive solution to increase people physical activity: is it possible?", in Proc. of IEEE International Conference on Multimedia and Expo Workshops (ICMEW 2013), San José, California, USA, July 2013.
- [2] F. Aioli, M. Ciman, M. Donini, O. Gaggi, "ClimbTheWorld: Real-time staircase counting to increase physical activity", in Proceedings of the 11th International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (Mobiquitous 14), London, Great Britain, December 2014.
- [3] F. Aioli, M. Ciman, M. Donini, O. Gaggi, "A Serious Game to Persuade People to Use Stairs", in Proceedings of the 9th International Conference on Persuasive Technology (Persuasive 2014), Padova, Italy, May 2014.
- [4] S. Ferretti, M. Furini, C. E. Palazzi, M. Rocchetti, P. Salomoni, "WWW recycling for a better world", Communications of the ACM 53(4):139-143, 2010.
- [5] M. Furini, F. Mandreoli, R. Martoglia, M. Montanero, "A Predictive Method to Improve the Effectiveness of Twitter Communication in a Cultural Heritage Scenario", ACM Journal on Computing and Cultural Heritage 15(2): 21:1-21:18, 2022.
- [6] Sangil Choi, Richelle LeMay, and Jong-Hoon Youn, "On-board processing of acceleration data for real-time activity classification", in Proc. of the IEEE International Conference on Consumer Communications and Networking Conference (CCNC 2013), Las Vegas, NV, USA, January 2013.
- [7] Alvina Anjum and Muhammad U. Ilyas, "Activity recognition using smartphone sensors", in Proc. of the IEEE International Conference on Consumer Communications and Networking Conference (CCNC 2013), Las Vegas, NV, USA, January 2013.
- [8] Armir Bujari, Bogdan Licar, and Claudio E. Palazzi, "Movement pattern recognition through smartphone's accelerometer", in Proc. of the IEEE International Conference on Consumer Communications and Networking Conference (CCNC 2012), Las Vegas, NV, USA, January 2012.
- [9] Mikkel B. Kjærgaard, Martin Wirz, Daniel Roggen, and Gerhard Tröster, "Detecting pedestrian flocks by fusion of multi-modal sensors in mobile phones. In Proceedings of the 2012 ACM Conference on Ubiquitous Computing (UbiComp '12), Pittsburgh, PA, USA, September 2012
- [10] F. Zambonelli, "Pervasive Urban Crowdsourcing: Visions and challenges", in Proceedings of the International Conference on Pervasive Computing and Communications Workshops (PERCOM '11), Seattle, WA, USA, March 2011.
- [11] Wheel Map. Available from: <http://wheelmap.org/en/> [Retrieved: October 2022].
- [12] Cardonha, C., Gallo, D., Aveglia, P., Herrmann, R., Koch, F. and Borger, S., "A crowdsourcing platform for the construction of accessibility maps", in Proceedings of the 10th International Cross-Disciplinary Conference on Web Accessibility (W4A '13), Rio De Janeiro, Brazil, May 2013.
- [13] Ingresso Libero. Available from: <http://www.ingressolibero.info/> [Retrieved: October 2022].
- [14] C. Prandi, G. Delnevo, P. Salomoni, S. Mirri, "On Supporting University Communities in Indoor Wayfinding: An Inclusive Design Approach", Sensors 21(9): 3134, 2021.
- [15] A. Arengi, S. Belometti, F. Brignoli, D. Fogli, F. Gentilin, N. Plebani, "UniBS4All: A Mobile Application for Accessible Wayfinding and

- Navigation in an Urban University Campus”, in Proc. of GOODTECHS 2018 - 4th EAI International Conference on Smart Objects and Technologies for Social Good, Bologna, Italy November 2018.
- [16] C. Prandi, G. Delnevo, C. Ceccarini, “On augmenting the experience of people with mobility impairments while exploring the city: A case study with wearable devices”, in Proc. of the IEEE International Conference on Consumer Communications and Networking Conference (CCNC 2018), Las Vegas, NV, USA, January 2018.
- [17] AccessibleMaps. Available from: <http://www.accessiblemaps.org/> [Retrieved: October 2022].
- [18] C. Prandi, P. Salomoni, S. Mirri, “mPASS: Integrating People Sensing and Crowdsourcing to Map Urban Accessibility”, in Proc. of the IEEE International Conference on Consumer Communications and Networking Conference (CCNC 2014), Las Vegas, NV, USA, January 2014.
- [19] S. Mirri, C. Prandi, P. Salomoni, “A Context Aware System for Personalized and Accessible Pedestrian Paths”, in Proceedings of the 2nd International Workshop on Location-based Services and Applications in Ubiquitous Computing (LSAUC 2014) – International Conference on High Performance Computing & Simulation, Bologna, Italy, July 2014.
- [20] S. Mirri, C. Prandi, P. Salomoni, F. Callegati, A. Campi, “On combining crowdsourcing, sensing and open data for an accessible smart city”, in Proceedings of the 3rd International Conference on Technologies and Applications for Smart Cities, Oxford, UK, September 2014.
- [21] S. Mirri, C. Prandi, P. Salomoni, “Trustworthiness assessment in mapping urban accessibility via sensing and crowdsourcing”, in Proceedings of the First International Conference on IoT in Urban Space, Rome, Italy, October 2014.
- [22] Marco Furini, Silvia Mirri, Manuela Montanero, Catia Prandi, “Privacy Perception when Using Smartphone Applications”, *Mob. Networks Appl.* 25(3):1055-1061, 2020.
- [23] N. D. Lane, E. Miluzzo, H. Lu, D. Peebles, T. Choudhury, A. T. Campbell, “A Survey of Mobile Phone Sensing”, *IEEE Communications Magazine*, 48(9), 2010.
- [24] T. Völkel, G. Weber, “RouteChecker: Personalized Multicriteria Routing for Mobility Impaired Pedestrians”, in Proc. of the 10th ACMASSETS'08, Halifax, Canada, October 2008.
- [25] H. Holone, G. Misund, “People Helping Computers Helping People: Navigation for People with Mobility Problems by Sharing Accessibility Annotations”, in Proceedings of ICCHP'08, Linz, Austria, July 2008.
- [26] P. Kasemsuppakorn, H. A. Karimi, “Personalised Routing for Wheelchair Navigation”, *Journal of Location Based Services*. 3(1):24-54, 2009.
- [27] Beale, L., Field, K., Briggs, D., Picton, P., Matthews, H., Mapping for Wheelchair Users: Route Navigation in Urban Spaces. *The Cartographic Journal*, Maney Publishing. 43(1):66-81, 2006.
- [28] Sobek, A., Miller, H., “U-Access: A Web-based System for Routing Pedestrians of Differing Abilities”, *Journal of Geographical Systems*, Springer. 8(3):269-287, 2006.
- [29] G. Marfía, C. E. Palazzi and M. Rocchetti, “Combining web squared and serious games for crossroad accessibility”, in Proceedings of IEEE International Conference on Serious Games and Applications for Health (SeGAH), Braga, Portugal, November 2011.
- [30] Bujari, O. Gaggi, C. E. Palazzi, “A mobile sensing and visualization platform for environmental data”, *Pervasive and Mobile Computing* 66, 101204, 2020.