mPASS: Integrating People Sensing and Crowdsourcing to Map Urban Accessibility

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***Abstract*—This paper presents mPASS (mobile Pervasive Accessibility Social Sensing), a system designed to collect data about urban and architectural accessibility and to provide users with personalized paths, computed on the basis of their preferences and needs. The system combines data obtained by sensing, crowdsourcing and mashing-up with main geo-referenced social systems, with the aim of offering services based on a detailed and valid data set.**

Keywords-crowdsourcing, sensing, accessibility, mashup, personalized path

I. INTRODUCTION

Urban spaces and specifically the pedestrian environments are frequently inadequate to the needs of elderly people and people with disabilities. The demand of specific pedestrian paths is not necessarily limited to those citizens. Examples are the requirement of safe pedestrian paths for kids coming back from school or the preference to avoid unsafe areas at night.

While communities are working to improve urban accessibility for all citizens, independently from age and needs, the urban built environment still represents one of the most actual examples of how people with impairments can be disabled by barriers [1]. Moreover, the lack of information about the urban environment and its accessibility represents itself a barrier to users with disabilities who are discouraged from venturing outside known territories.

Many attempts have been done to use current technologies with the aim of offering appropriate information services to users with unconventional needs. A list of the most interesting ones is reported in Section II. None of them has a significant impact on people life, due to the difficulties in collecting enough information (in terms of quantity and quality) to provide effective routing/mapping services. In order to offer a service with such characteristics, information about urban accessibility (in general, about pedestrian facilities) should be:

- *valid* enough to avoid errors about a specific barrier or facility. If the data set contains incorrect detected or classified barriers, the user could take wrong decisions in computing routes (and the same would be for routing algorithms computed by the system);
- *dense* enough to effectively decide about a path. The user (and/or the algorithm) should know about all the possible barriers and facilities. In fact, the presence of an undetected barrier could seriously affect the effectiveness of the service.

To obtain such a kind of geo-referenced data base, many different sources could be used:

1. Sensing: data produced by users moving in the urban environment. Users equipped with a smartphone are obviously equipped with gyroscope, accelerator and GPS, so they can run an app to sense data about urban accessibility. While data sensed by a single user can be considered not very accurate, multiple sensing of the same barrier/facility makes the data valid.
2. Crowdsourcing: data produced by users interested in reviewing urban accessibility can be gathered by using a mobile app. Applications like this one can collect both textual information and multimedia (pictures, video) data. Even in this case, multiple data enforce the validity of gathered information.
3. Official reviews: many authorities and organizations (e.g., local administrations, disability right organizations, hotels associations, etc.) do official reviews about indoor and outdoor accessibility. They ask experts to evaluate and to write structured or unstructured reviews of the actual accessibility. Usually these evaluations are too few to be significant in deciding a route, but they are surely valid.

The above mentioned data gathering systems are different in terms of validity and density and none of them seems to be a definitive solution to the problem. Moreover, mash-up should be used as a forth source of information: lots of data about urban accessibility are currently available, but they are dispersed in different systems. In particular, existing systems show one or more of the following lacks: (i) few data; (ii) data referred to specific or small places/territories; (iii) data about a limited set of barriers/facilities; (iv) data about accessibility are provided together with lots of other data (e.g., Foursquare [2]).

This paper presents mPASS, a system designed and developed to provide people with specific needs with personalized geo-referenced information and routing services related to urban environments. The system uses data produced by sensors as well as data provided via crowdsourcing by users. It combines its own data with the ones available from other sources to maximize density of information and to offer users an effective service. It also permits to organizations responsible of official reviews to add information and to fix data gathered by others in order to improve their validity. The set of aPOIs (accessibility Points Of Interest) collected by the system can be used to ask customized routing services or to have a personalized map of main accessibility barriers and facilities in a specific area. Personalization is performed on the basis of a user's profile to better meet his/her preferences and needs. The system development and the evaluation phases are still ongoing.

The remainder of this paper is organized as follows. Section II presents main related work and compares it with the mPASS system. Section III presents the Data Model, while Section IV introduces the User Profile. Section V illustrates the prototype development and, finally, Section VI concludes the paper and presents some future works.

II. RELATED WORK

In analyzing related work we considered four main groups of researches and applications: (i) crowdsourcing platforms for urban accessibility; (ii) sensing system to detect accessibility/pedestrian barriers and facilities; (iii) routing system for users with special needs; (iv) integrated systems that include one or more of the above mentioned activities.

In the last few years, several crowdsourcing apps are been developed that allow citizens to collaborate in improving the quality of life in their urban environment [3, 4]. A part of these apps are devoted to collect data about urban accessibility, on the basis of surveys about indoor and outdoor places. The goal of [5] and [6] is to review the accessibility of specific type of POIs (Points of Interest) considering the special needs of wheelchair users. In [5] it is possible to review and to find wheelchair accessible toilets and parking spaces while in [6] users can rate the accessibility of a service (e.g., related to tourism, sport, education, etc.). In [6] POIs are displayed with icons of different colors (green, yellow and red) based on the accessibility level (accessible, partially accessible and not accessible). Moreover the app shows the particular type of service. In both apps [5 and 6] there are no clues about the specific barrier/facility that impacts on the POI accessibility level. The application presented in [7] is available both via browser and as mobile app, developed directly inside the Foursquare [2] app. It allows users to answer to a long survey with very detailed questions about the accessibility of a POI. On one hand the review asked to users is very accurate. On the other hand it could confuse novice users and it could become boring or difficult to complete. A mobile app that permits to add photos and comments related to barriers and obstacles on sidewalks is presented in [8]. All the above mentioned systems rate accessibility by means of user's opinions, without involving experts in review process. An example of official reviews (done by professionals) is available in [9], which reports a collection of reviews related to indoor accessibility of POIs located in Bologna (Italy), done both by users and by accessibility experts working for a disability right organizations. Note that these data are not geo-referenced, not structured and they delivered only via web.

Many sensing apps have been developed to monitor human activities and a part of them could be effectively used to detect accessibility/pedestrian barriers (such as stairs) and facilities (such as zebra crossing). These researches present sensing architectures and algorithms studied to be used in different contexts, so they need to be adapted in order to be exploited in detecting barriers and facilities (see for example [10] and [11]). In [12], the authors (by using data obtained by a smartphone accelerometer) aim to recognize the position where a pedestrian stops and crosses a street ruled by a traffic light. Some barriers and facilities could be recognize more easily by using cooperative sensing, working on detecting movement of groups of people [13].

Routing algorithms for people with special needs are based on geo-referenced data about barriers and facilities that are usually collected by crowdsourcing. In [14], the authors describe a system that use GIS and GPS to support the creation and the use of network based barrier-free street maps, using specific hardware. RouteCheckr [15] is a client/server system for collaborative multimodal annotation of geo-referenced data. It provides personalized routing to mobility impaired pedestrians thought the configuration of a user profile. U-Access [16] is a Web-based application developed in the specific context of the University of Utah campus for identifying the shortest accessible route on the basis of three physical ability levels (peripatetic, aided mobility or wheelchair user). This classification requires users to choose one of these three levels, avoiding any further personalization. Finally, some works are devoted to find route for elderly people [17, 18]. In particular, in [18] the authors present a barrier notification service running on cellular phones equipped with GPS sensor.

Two examples of complex systems, that integrate different data sources and provide multiple geo-referenced services are describe in [19] and [20]. The authors of [19] propose to mix data gathered by sensing with data from crowdsourcing in order to compute accessible routes. In [20], a system called EasyWhell is described. It is mainly devoted to support wheelchair users and it encourages people to write reviews providing reputation and rewards via Facebook.

III. DATA MODEL

To defined aPOIs (accessibility Points Of Interest) we have analyzed more than 200 accessibility requirements, divided in two main classes, respectively devoted to indoor (architectural design) and to outdoor (urban design) accessibility. In this phase of our work, we are mainly considering urban design requirements that are sub-classified in six categories:

1. *gap*: this category includes gaps, steps, stairs and similar accessibility barriers, together with corresponding facilities, such as ramps, curb cuts and handrails;
2. *cross*: this category consists of all the facilities and the barriers related to crossing, e.g., the presence or absence of zebra crossing, traffic lights, audible traffic lights;

3. *obstruction*: this category contains all the obstructions and the protruding elements that can block or limit the way. It includes traffic lights, traffic signs, trees and garbage bins;

4. *parking*: this category is used to specify position and type of parking spaces, with attention to slots reserved to people with disabilities;

5. *surface*: this category consists of descriptions of pathways and ramp surfaces that can represent an accessibility barrier, such as a uneven road surface;

6. *pathway*: this category includes all the types of sidewalks and their characteristics (e.g., width).

Each requirement corresponds to a type of aPOI that represents the presence/absence of an accessibility barrier/facility. A small but significant part of such aPOIs can be detected by sensing with smartphones (which are equipped with accelerometer and gyroscope). Examples are steps and stairs that can be detected by a single walking pedestrian, ramps and curb cuts that can be detected by wheelchair users or traffic lights and zebra crossings that can be detected by groups of users. Other aPOIs cannot be detected by sensing so that users are needed to identify and to add them to mPASS DB.

Each aPOI and its related data can be added to our system by means of one or more *reports*. Reports are classified in three different source classes, accordingly to how they are collected. The three source classes have a growing validity:

- S-report (report obtained by sensors). The mPASS app running on Android (http://www.android.com) systems can automatically produce data by sensing. These reports are supposed to have a low validity, since sensors can generate false positives and false negatives.

- U-report (report obtained by users). By using the mPASS app, users can add aPOI to the DB system. This can be done in two ways: (i) *spontaneously*: a user encountering a specific barrier or an accessibility facility can send a report to the mPASS; (ii) *on demand*: the mPASS app can ask users to improve validity of an existing aPOI (usually an aPOI reported by sensors). Since this, the system will exploit the user report instead of sensor ones and the user gets an award badge on his/her public profile.

- A-report (report produced by administrators). Administrators are people working for organizations involved in monitoring urban accessibility (such as local administrations and municipalities or disability right organizations). Being professionally able to correctly classify and measure every kind of aPOIs, their reports are considered totally valid. Reports from administrators can be added in two ways: (i) *spontaneously*: administrators add reports accordingly to their program of activities, sending to the mPASS system reports on barriers or accessibility facilities; (ii) *on demand*: the mPASS app can ask to administrators to improve validity of an existing aPOI (usually a user-added one). Since this, the system will use the administrator report instead of user ones.

Hence, mPASS can have more reports of the same aPOI, classified with one or more different source classes. Both the map provided to users and the data set considered by the routing algorithm are based on the more valid reports available. For example, if an aPOI is added both by sensors and by users, U-reports are used instead of S-reports, since they are considered more valid. Analogously, if an aPOI is added both by users and by administrators, A-reports are used instead of U-reports, because they are considered more valid. To populate the mPASS DB we also added some aPOIs and reports obtained by converting, filtering and mashing up existing data (see the following Section V).

Fig. 1 shows the gathering architecture of mPASS. Reports related to aPOIs are collected by Sensors, Users and Administrators. Data gathered by other systems are added by filtering or mashing-up. The thin dashed arrows describe the on demand mechanism set up in order to improve the validity of reports. The final user interacts with the system to obtain personalized data and routing services.

IV. USER'S PROFILE

To support personalized services, we developed a user profile on the basis of the above described categories of aPOIs. Users are identified with access credential and classified as simple user or administrator, according to the model used to gather data. Users running the mPASS app can activate/deactivate the sensing module.

The profile describes the user's preferences related to each accessibility barrier/facility classified by mPASS (i.e., each aPOI). In order to represent such preferences, the profile associates a value to each type of aPOIs. Possible values for each user preference are:

- NEUTRAL: this value indicates that the user has neither difficulties nor preferences related to the aPOI type and it's totally irrelevant to him/her to meet such a kind of aPOI on his/her way. For example, in the profile of a young walking pedestrian, the value for the "*stairs*" aPOI type could be NEUTRAL.

- LIKE: this value means that the user prefers this type of aPOI, when available. This value is usually related to accessibility facilities and not to barriers. For example, in the profile of a user who wants to follow a safe path, the value for the "*zebra crossing*" and "*traffic light*" aPOI types could be LIKE.

- DISLIKE: this value is used when a user can face an aPOI type, but with some efforts. In this case an alternative path is preferred, but it is not necessary. An example of possible use of the DISLIKE value is in relation with the "*stairs*" aPOI type in the profile of an elderly user.

- AVOID: this value means that the aPOI type represents an insurmountable barrier to the user. As an example, in the profile of a wheelchair user the value associated to the "*stairs*" aPOI type should be AVOID.

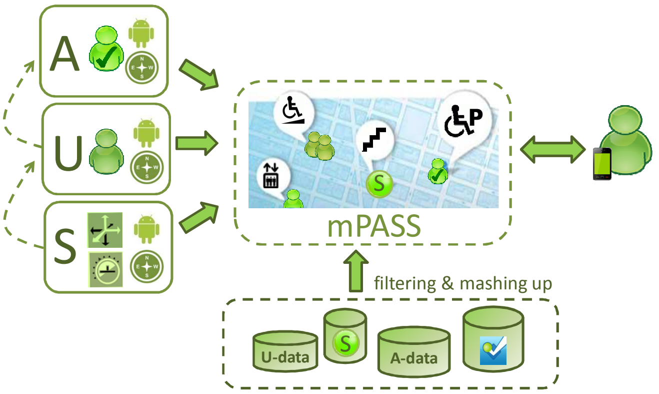

Figure 1. Data Gathering in mPASS

This set of values is used by the mPASS routing algorithm to compute a path that meets the LIKEd aPOIs when possible, gets round the DISLIKEd ones if feasible and totally avoids the ones labeled as AVOID. Currently the profile is pre-compiled on the basis of self-declarations done by users. A screenshot of the profile set up is depicted in Fig. 2. It shows the settings related to the aPOI type *gap* done by a wheelchair user. We are now studying how to improve it by observing the user's behaviors. For instance, if the user likes to cross on zebras, the system could learn it and could assign the LIKE value to the "*zebra crossing*" aPOI type.

V. SYSTEM PROTOTYPE

The system architecture is shown in Fig. 3. mPASS users can access to services both by using mobile devices and through the web. Mobile services are provided by an Android app that includes the sensing module. It communicates with the Sensor Analysis Module, which performs the data fusion and analysis, in order to add S-reports in the mPASS DB.

Main mapping and routing services are provided by the Services Manager that includes the following components: (i) a module to manage users' profile (Profile Module) that stores information about users preferences and provide users profile to mPASS each time a map or a route is provided; (ii) a module to manage notifications (Notification Module), that is responsible of sending requests to the mPASS app on the user mobile device and to add the obtained U-report to the mPASS DB; Fig. 4 shows a notification as it appears on the user's smartphone; (iii) a Routing Module, that is in charge of computing the best route for a user, according to his/her profile.

Data provided by other systems and services are added to mPASS by using the Data Filtering Module. This activity needs to be managed, in order to fit data collected by others inside the mPASS DB. Finally, to provide a better integration with Foursquare, reports can be added and retrieved from the mPASS DB by using a Foursquare application. Due to Foursquare wide diffusion, this application extends the range of platforms that can be used to interact with the mPASS system.

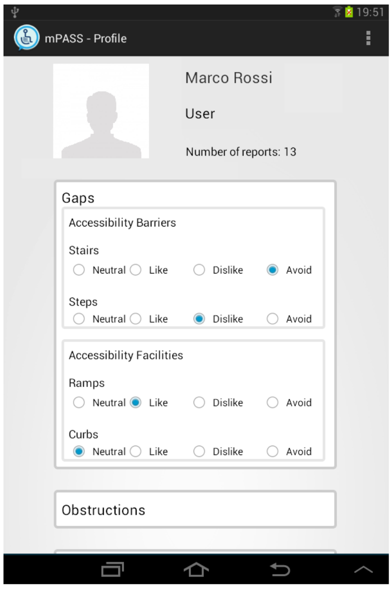

Figure 2. A screenshot of the user's profile set up

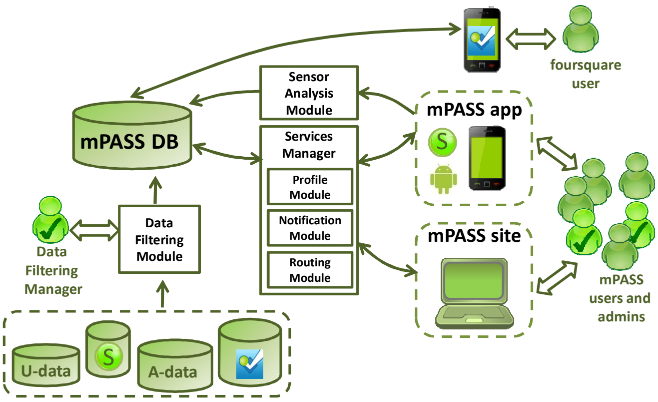

Figure 3. mPASS architecture

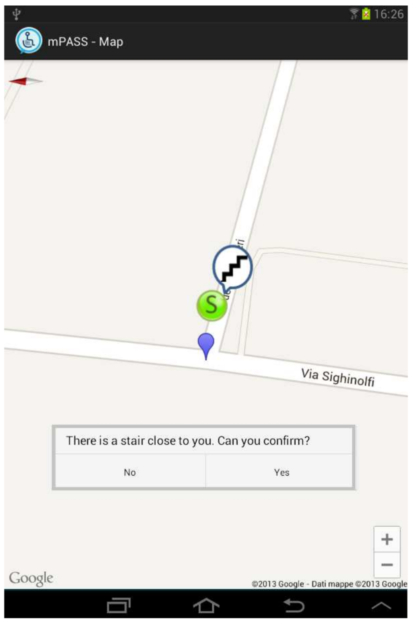

Figure 4. Notification to barrier close to the user

We have developed a prototype of the mPASS system that provides the main functions described above. In particular, we have created the mobile apps needed to access the system: the mPASS app and the Foursquare application for mPASS. The mPASS app runs on Android version 3.0 Honey and greater. It allows users to: (i) configure their profile; (ii) spontaneously insert a report; (iii) receive notifications to validate the presence/absence of accessibility barriers/facilities; (iv) view the past report logs; (v) display the report localized in Google Maps (https://developers.google.com/maps/); (vi) search the best route. Tasks (v) and (vi) are performed on the basis of the user profile. A simple sensing system to detect steps has been developed, together with the corresponding part of the Sensing Analysis Module. The Foursquare application for mPASS allows the user to join the app and to answer to a survey during the check-in phase. We took care to provide users with a simple and short survey.

Reports are stored in the mPASS DB by using the Google Fusion (https://developers.google.com/fusiontables/). We have developed the Data Filtering Module and we have filtered and integrated data provided by several existing systems. We re-used both geo-referenced data (filtered to fit the mPASS DB) and not geo-referenced data. The latter one has been automatically geo-referenced by means of their address and name. Moreover, data provided by other services are re-classified as S, A or U-reports, depending from the source type. For example data gathered by the Foursquare [2] community are considered U-reports, while data provided by Ingresso Libero [9] and the other official reviews providers, are classified as A-reports.

VI. Conclusion and Future Work

In this paper we introduced mPASS, a system that has been designed with the aim of providing personalized maps and routes to users with special or specific needs. The system is still under development and in this paper we presented a prototype that performs a set of basic functions, including a simple sensing module to sense steps, a basic routing algorithm, the user profiling, an app to support users and administrators in adding reports about accessibility barriers and facilities and, finally, a notification system to ask users and administrators to improve validity of data. A significant part of the work has been devoted to filter and mash up data provided by other services, including an app obtained by mashing-up the mPASS features with Foursquare. The prototype is under test and we are doing a first set of trials with users. Currently, we are working on adding sensing features and specifically we are interested in detecting ramps, stairs, traffic lights and audible traffic lights. We are working on the routing algorithm, in order to obtain paths that fits the user needs, as they are expressed in his/her profile. Finally, we are working to understand the effect of the mPASS app on the power charge, to avoid a too fast battery drain.

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