

On Combining Crowdsourcing, Sensing and Open Data for an Accessible Smart City

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Abstract—This work presents a novel geospatial mapping service, based on OpenStreetMap, which has been designed and developed in order to provide personalized path to users with special needs. This system gathers data related to barriers and facilities of the urban environment via crowdsourcing and sensing done by users. It also considers open data provided by bus operating companies to identify the actual accessibility feature and the real time of arrival at the stops of the buses. The resulting service supports citizens with reduced mobility (users with disabilities and/or elderly people) suggesting urban paths accessible to them and providing information related to travelling time, which are tailored to their abilities to move and to the bus arrival time. The manuscript demonstrates the effectiveness of the approach by means of a case study focusing on the differences between the solutions provided by our system and the ones computed by main stream geospatial mapping services.

Keywords—smart city; open data; crowdsourcing; sensing, urban accessibility; geospatial mapping systems

I. INTRODUCTION

Nowadays, cities and their populations are facing everyday problems related to transportation and user mobility: congestion, air and noise pollution, public transport efficiency, etc.. Moreover, citizens with reduced mobility (e.g., people with disabilities, elderly people, etc.) have to face also with accessibility issues, encountering barriers both in the urban space and on the public transportation means. The lack of information about accessibility of the transportation means and of the environments is a further barrier impairing their capability to autonomously moving around the city [1].

Some online systems (e.g., Google Maps, Bing Maps) provide geospatial mapping services, suggesting routes from a starting point to a destination chosen by the user, including public means of transports, when available. Such proposed routes are computed for users with average mobility abilities. To provide a more effective service, some additional data on barrier, facilities, bus routing and equipment are needed. In particular:

- Data about urban accessibility, in terms of barriers and facilities, which could be obtained by crowdsourcing and sensing activities conducted by citizens equipped with mobile devices.

- Open data about real time availability of public transportation means, their equipment in terms of accessibility barriers and facilities, their time of arrival and route etc.

With the aim of equipping citizens with a complete and multimodal urban mobility service, we have designed a novel system based on OpenStreetMap. It exploits real time data provided by bus operating companies combined with data produced by sensors and data gathered via crowdsourcing by the users. All these data are exploited to provide users with paths tailored to their specific needs and/or requirements. Our system involves two mobile applications: mPASS and WhenMyBus.

mPASS (mobile Pervasive Accessibility Social Sensing) has been designed and developed specifically to meet the needs of pedestrian users (even with different abilities). In particular, mPASS collects data about urban accessibility and provides citizens with personalized and accessible pedestrian paths and maps. It integrates data produced by sensors and data gathered via crowdsourcing by users, together with official accessibility reviews done by experts. Such data are selected and transformed in order to compute personalized maps and routes and to meet specific users' needs [2].

WhenMyBus has been designed and developed with the aim of supporting citizens who travel by bus in the city, equipping them with a dedicated service. It directly interacts with official open data, providing real time information about public means of transport availability and equipment (in terms of accessibility facilities for citizens with disabilities).

These two applications work on a user's profile, which describes the users' needs and abilities. On the basis of such a profile, the system filters geo-referenced data from OpenStreetMap and specific databases in order to provide personalized paths and maps, by customizing them to meet users' needs. This way, the applications support citizens in moving in the Smart City dimension, by equipping them with personalized, accessible and multimodal paths.

The remainder of this paper is organized as follows. Section II presents some main design issues of our systems and compares them with some other similar projects. Section III describes the system architecture, while Section IV introduces the user's profile. Section V illustrates a case study and, finally,

Section VI concludes the paper and presents some future works.

II. DESIGN ISSUES

In order to provide a complete urban mobility service to citizens, the following design issues are considered:

1. Real time data about public means of transport availability.
2. Density of data (coming from official open data and from sensing and crowdsourcing activities).
3. Trustworthiness of crowdsourced and sensed data.
4. Personalization of the proposed routes (taking into account accessibility of the urban environment and of public means of transports) according to user's preferences and needs.

The first issue has been addressed thanks to the open data published by T-per, the public buses provider in the city of Bologna, that are:

- the whole list of available bus routes (provided as sequences of arcs as well as sequences of stops, intended as nodes), with related pre-defined path and stop lists. These data reports the whole T-per database of bus lines which is organized around the following logical objects: (i) *bus number*, which identifies a specific bus route (or a subset of routes when different routes are used in different times of the day or days of the week); (ii) *bus stop*, which identifies a specific bus stop with its geographic coordinates (latitude and longitude); (iii) *bus route*, which is the set of paths travelled by a given bus number; (iv) *arc of a path*, which is a sequence of points with their geographic coordinates (latitude and longitude).
- The time of arrival of the next two buses of a given route (for a specific bus number) at a given stop obtained by knowing the real position of such buses (by GPS) and by estimating the traveling time to the stop according to what occurred to previous buses on the same route.

Some systems provide similar services (e.g. Google Maps), but none of them provides information about real time bus availability, taking into account delays and similar matters. Some other systems exploit crowdsourcing so as to keep users updated about real time position (and eventual delays) of buses, but they do not provide travel planning and personalized route computing services [3].

Our system integrates the T-per open data with data collected by sensing and crowdsourcing activities. Users' mobile devices (such as smartphones, tablets, and so on) are used to produce geo-referenced data, while users are moving in the urban environment. By exploiting gyroscope, accelerator and GPS, our application (running on the mobile device in use) can identify some urban barriers and facilities (e.g. steps, ramps) and can collect information so as to identify other barriers and facilities (such as semaphores) by a cooperative sensing activity. Moreover, mobile devices are also used to

provide reviews about urban accessibility made by users, collected by crowdsourcing. In particular, our system can collect reviews from volunteers (users who want to send a review about the place where they are or a place where they have been can use our application to fill a short form to accomplish this task) and/or on demand (our system sends a notification to users requesting a simple review about a place where they are or in the nearby) [1]. Data coming from multiple sources are integrated and guarantee a high level of information density which is a fundamental to provide effective services [4, 5]. In fact, for instance, the presence in the proposed route of an undetected barrier could seriously affect a user, preventing him/her from reaching his/her destination.

Crowdsourcing and sensors help in improving data density [4] but put forward the data quality issue depending on the accuracy of sensors and the credibility of users involved in the data gathering [6]. Although any instance of the crowdsourced and sensed data may be unreliable, aggregating a large number of information related to the urban environment (in particular, to the accessibility of Points of Interest, in terms of barriers and facilities) makes the data more trustworthy [7]. The error made by a single sensor or a single user become less significant as the volume of data increases. Moreover, while combining different sources of data, with different credibility/accuracy levels, some questions arise as to which information source might be privileged under what circumstances [8]. To address this third issue, our system assesses trustworthiness of information by combining accuracy of sensors, credibility of users and the credential authority of T-per open data and of official reviews made by experts (e.g. people working for authorities and organizations, such as local administrations, disability right organizations, hotels associations, etc.) [2].

The fourth issue has been addressed by computing a personalized and accessible route (including accessible means of transport), according to a user's preferences and needs. These are described in a profile, both in terms of urban accessibility and e-accessibility requirements, so as to make accessible even the application on the mobile device in use.

Several projects and publications are devoted to support users, providing them information about accessible paths and about the accessibility of urban Points of Interest (POIs), such as [9, 10, 11, 12]. Most of them focus only on special needs of a specific kind of users, or they take into account only a specific source of data (e.g. official reviews, crowdsourced information), making such systems just partially effective.

In our case, by means of the profile, the users can declare specific characteristics, such as average speed when moving in an urban environment. Moreover, device sensors can also track users' movement, compute their average speed and adequately adjust this data in the profile. This information can be very different, in particular for those users who are equipped with a wheelchair (that could be a manual wheelchair or an electric-powered wheelchair) and for the elderly citizens. Users' average speed can become a crucial data in computing a personalized path, in particular when the route includes a pedestrian path to reach a bus stop or a metro station to catch a public transport. Profiling of users put together with the real

time data about buses availability makes our system able to meet effectively the specific need of citizens.

III. SYSTEM ARCHITECTURE

Figure 1 shows the overall architecture of our system, which includes two main services, which work together: mPASS and WhenMyBus.

The user can interact with our system by means of an application running on his/her mobile devices. He/she can set up his/her preferences and needs in the profile (managed by the Profile Module), together with his/her traveling habits in the urban environment. The user profile is organized in Generic Profile, Urban Accessibility Profile and eAccessibility Profile. More details about the Profiling System can be found in Section IV. Both mPASS and WhenMyBus share the user Profile Module.

mPASS computes the pedestrian parts of the path by exploiting the Bidirectional Dijkstra routing algorithm, considering the accessibility barriers as constrains. When a bus route is included in the path, WhenMyBus exploits the T-per open data to compute the bus route parts in the path.

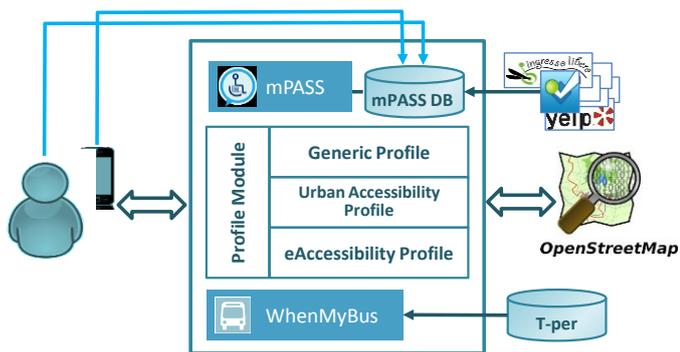


Figure 1 - System Architecture

By means of the mobile Android application, the user can ask for a personalized route, specifying a starting point and a destination. Our system computes a set of proposed paths, involving mPASS and WhenMyBus services (if they include public means of transport). WhenMyBus is directly connected with T-per open data, with the aim of providing real time information about buses availability. mPASS is directly connected to its database, which collects geo-referenced information gathered by means of crowdsourcing and sensing activities (involving the users and their mobile devices). Moreover, the mPASS database includes information coming from geo-referenced social networks (e.g. foursquare, Yelp) and from official reviews done by experts [11], with the aim to provide users with information about indoor accessibility of places which are nearby their destination.

The information about the proposed paths and their accessibility (including the accessibility of the POIs and of the buses) are delivered to the users by means of OpenStreetMap.

IV. PROFILING SYSTEM

To provide personalized services, our system exploits a user XML-based profile, structured in three interconnected

parts: (A) the Generic Profile (GProfile) which includes some general data about the user, such as personal info, language, unit of measurement, device(s) in use, average speed, data about his/her credibility and his/her favorite bus routes; (B) the Urban Accessibility Profile (UAPProfile), which describes user's preferences related to each urban accessibility barrier/facility; and (C) the eAccessibility Profile (eAProfile), which describes user's preferences related to the e-accessibility of the application. Such parts of the profile are not separated, but they are integrated in the same XML elements.

The user can set up the profile data just once, before using the application. Then, he/she can modify it, if necessary.

A. Generic Profile

The Generic Profile describes the general information about the user. It includes personal data and data about the device in use, as well as the language and the unit of measurement. These latter data can be automatically set by the application, deriving them from user's location, or manually set up by the user.

In such part of the profile, the user can also declare his/her average speed when he/she moves in a urban environment. Alternatively, such data can be automatically derived from device sensor, which can track the user's movement and then compute his/her average speed. This information is essential for our system, because the Routing Module computes the best personalized paths taking into account it. This also allows the system proposing different effective paths according to real time availability of buses, when the paths include the use of public means of transports.

Finally, the user could declare here information about his/her traveling habits, providing data about his/her favorite bus routes. The user can provide a location in the city by exploiting his/her current position or an address (i.e. street and number). Then, our system provides all the bus stops that the user can reach (in a configured time) with a list of the bus routes available at those stops; finally, the user can choose bus stops and routes of interest.

B. Urban Accessibility Profile

The Urban Accessibility Profile stores information about users' preferences related to each barrier/facility in the urban environment, which are defined as aPOIs (accessibility Points of Interest). We have classified aPOIs in the following categories:

1. *gap*, which includes gaps, steps, stairs and similar accessibility barriers, together with the corresponding facilities, such as ramps, curb cuts and handrails;
2. *cross*, which 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*, which 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*, which 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);
7. *bus stop*, which contains all the facilities and barriers that can affect a bus stop, such as platform height, pavement of the platform, distance between the platform and the bus floor, distance between the bus stop and the closest crossing, large-print, high-contrast, and non-glare informational signs, braille and tactile information regarding available service, acoustic cues and speakers that announce vehicle identification information [13];
8. *bus*, which consists of descriptions of facilities and barriers that can affect a bus (such as steps, lift or ramps, kneeler features, wheelchair anchorage, large-print, high-contrast, and non-glare informational signs, braille and tactile information, acoustic stop announcements, ticket vending machines with braille and large-print markings, or audible output devices [13]).

In such a part of the profile, users can define preferences about the above listed aPOIs as follows:

- **NEUTRAL**: the user has neither difficulties nor preferences related to the aPOI type. The presence of this type of barrier/facility on a path is irrelevant to the user.
- **LIKE**: the user prefers aPOIs of this type, when they are available. The presence of this type of barrier/facility on a path is positive to the user.
- **DISLIKE**: the user can face this aPOI type, but with some efforts. In this case, an alternative path is preferred (when available), but it is not necessary. The presence of this type of barrier/facility on a path is negative to the user.
- **AVOID**: the user cannot face this aPOI type and an alternative path is necessary. The presence of this type of barrier/facility on a path prevents the user from following this path.

A more detailed description of such preferences can be found in [2]. On the basis of them, our system computes a route that comes across the LIKed aPOIs when feasible, gets round the DISLIKed aPOIs if it is possible, and avoids the AVOIDed aPOIs every time.

It is worth noting that positive preferences can be associated to barriers and negative preferences can be associated to facilities. As an example, a blind user can set as LIKE some specific barriers, such as stairs and steps, because they can represent a reference point. Analogously, wheelchair

users can set tactile paving as DISLIKE, because such surfaces can be uncomfortable for them.

C. eAccessibility Profile

The e-Accessibility Profile is devoted to store preferences and needs in terms of maps rendering. The main selection is the one related to textual/graphical representation of the map. On the basis of it, users can choose specific styles to represent aPOIs. For instance, the graphical representation can be personalized in terms of colors and size of the aPOIs icons in the map, addition of textual labels, visualization (show or hide) of aPOI categories or of aPOI types. In particular, different style rules can be associated to the whole application, to a specific preference (LIKE, DISLIKE, etc.) or to a single type of aPOI. More details about maps personalization and adaptation can be found in [2].

V. CASE STUDY

In order to prove the effectiveness of our approach, we tested our system with many different user profiles (such as users with reduced mobility, elderly people, blind users and users with low vision). In this section, we present a scenario which illustrates a user with special needs and preferences, who requests a personalized path, by using a smartphone. In particular, let us consider a male user equipped with a manual wheelchair who asks for a specific path (including accessible bus routes) in the city of Bologna (Italy).

```

<gap>
  <steps type="barrier" pref="avoid"/>
  <gaps type="barrier" pref="avoid"/>
  <stairs type="barrier" pref="avoid"/>
  <ramps type="facility" pref="like"/>
  <curbcuts type="facility" pref="like"/>
  <handrails type="facility"
pref="neutral"/>
  ...
</gap>
...
<bus_stop>
  ...
  <braille_info type="facility"
pref="neutral"/>
  <acoustic_info type="facility"
pref="neutral"/>
  ...
</bus_stop>
<bus>
  ...
  <lift type="facility" pref="like"/>
  <kneeler type="facility" pref="like"/>
  <wheelchair_anch type="facility"
pref="like"/>
  ...
</bus>

```

Figure 2. Wheelchair user's profile fragment

The user has set up his UAProfile declaring that he LIKES ramps and curb cuts (as gap facilities), parking slots reserved to people with disabilities (as parking facility), kneeler features and wheelchair anchorage (as bus facilities), zebra crossing and

traffic lights (as crossing facilities). He initialized uneven road surface and tactile paving (in the surface category) as DISLIKE and gap and obstructions barriers as AVOID. Handrails, audible, braille and tactile information are NEUTRAL for him. Figure 2 depicts a fragment of such a user's profile.

Figure 3 shows a portion of the map of Bologna with the starting point (blue circle) and the destination (green circle) chosen by the user. The path shown in Figure 3 is the one suggested by the most commonly used geospatial mapping platforms (e.g. Google Maps, Bing Maps, etc.), taking 17 minutes as a whole and being in structure in three parts:

(a) a pedestrian part to reach the bus stop (represented with a blue bus icon in Figure 3); this part is supposed to take 8 minutes to the user;

(b) a part of a bus route (from the blue bus stop to the green bus stop); this part is supposed to take 8 minutes (with four in-between stops);

(c) another pedestrian part from the arrival bus stop (represented with a green bus icon in Figure 3) to the final destination; this part is supposed to take 1 minute.

This path presents some issues our user has to face:

1. there is a stair in the first pedestrian part of the path (highlighted in Figure 3 with a red icon) and there is no information about its presence; this means that our user cannot afford the suggested pathway, but he has to find another alternative and accessible route;
2. there is no information about accessibility of the public mean of transport and of the bus stops; in particular, not all the vehicles are provided with facilities to support our specific user, such as ramps, kneeler features and lifts;
3. estimated time to reach the departure bus stop from the starting point (8 minutes, for 600 meters) is computed taking into account abilities and speed of an average user, instead of considering the actual abilities average speed of our specific user;

4. information about bus arrival time is derived from a time table, instead of referring to the real bus position and availability.

Our system computes a different and personalized path, by taking into account real data about bus availability and the user's profile, in terms of barriers to avoid, LIKED facilities to include as much as possible, user's personal average speed (set up as 0,98 m/s [14]). This path is structured in three parts (shown in Figure 4), where only the first part is different from the path shown in Figure 3. In particular:

1. our path suggests a different first pedestrian part of the path, taking into account the presence of that stair and finds an alternative accessible path, including a ramp (highlighted in Figure 4 with a green icon);
2. information about the accessibility of the public means of transport is provided; in particular, the path is computed taking into account a bus equipped with a kneeler and wheelchair anchorage features;
3. estimated time to reach the departure bus stop from the starting point is computed taking into account our specific user's abilities and average speed, as declared in his profile (16 minute, for 900 meters);
4. information about bus arrival time is provided taking into account T-per open data about the real bus position and eventual delays.

The time to complete the path is estimated to be 30 minutes and it is computed according to the user's average speed and real bus availability (by considering T-per real time data about eventual delays, traffic, and so on), as follows: 16 minutes for part (a), 12 minutes for part (b), and 2 minutes for part (c).

The whole path proposed by our system is the result of the mPASS routing module (based on the Bidirectional Dijkstra routing algorithm), which considers user's preferences about APOIs as constrains for the pedestrian parts, and of WhenByBus and T-per routing algorithm for the bus routes.



Figure 3. Path proposed by traditional geospatial mapping platforms

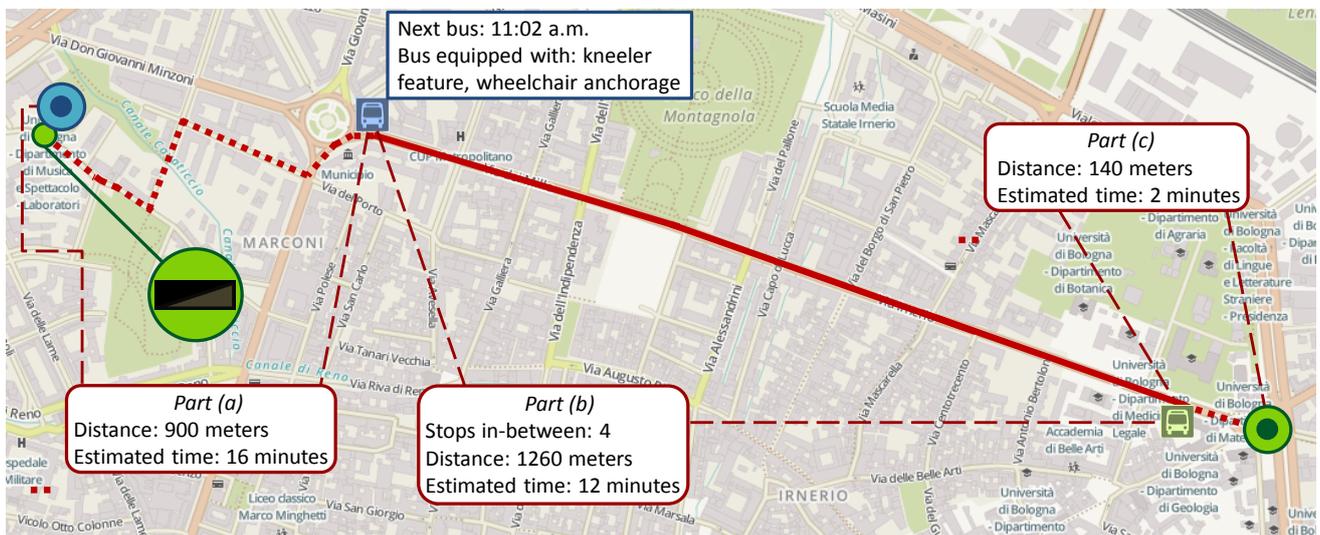


Figure 4. Path proposed by our system, tailored on user's needs and preferences and on public means of transport real time data

VI. CONCLUSION

Traditional widely used geospatial mapping services provide users with suggestions tailored to average abilities. As discussed in the design issue section and shown by the case study, these suggestions can be almost useless for users with special needs, especially users with reduced mobility.

In order to offer a service tailored to the actual abilities of each single user, we have designed and developed a novel geospatial mapping services which provides customized suggestions based on a user profile and a complex set of data sources including: (i) data from sensing and crowdsourcing provided by users in order to map barriers and facilities they faced in the real urban environment; (ii) open data provided by bus service providers which are used both to know the actual facilities and barriers of a specific vehicle and to obtain real time data related to the bus position and the time it will take to reach the bus stop.

Dealing with all these different sources of data and with the different quality (reliability, trustworthiness) of such sources is one of the main challenge of our approach. We are now doing further studies with the aim of profiling users from their behavior, by exploiting machine learning techniques. Adaptation mechanisms will be applied to the profile, so as to dynamically and automatically modify it according to user's actual abilities.

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