CrowDPLoS: a Feasibility Study to Assess the Level of Service for Disabled People on Pedestrian Urban Network Using Computer Vision and Crowdsourcing

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***Abstract*—Availability of global and scalable tools to assess disabled pedestrian level of service (DPLoS) is a real need but still a challenge in today's world. It is usually summarized by lacking of tools that can ease the measurement of a level of service adapted to disabled people, and the limitation concerns the availability of information regarding the existing level of service in real time as well. This paper aims to use advanced computer vision technologies and benefits from the prevalence of handheld devices in order to respond to those needs. Our approach allows the development of a navigation tool with crowdsourcing technologies that can help a disabled person to move around a city, and suggest the most adapted routes according to the person's disabilities. This solution provides the opportunity to get the up-to-date data with valuable field observations.**

I. INTRODUCTION

Creating the disabled pedestrian map-based routing is a challenge for both researchers and practitioners. Disabled pedestrian level of service (DPLoS) have been studied and discussed by more and more people. One of the most important reason is maps-based routing solution provides information about the available facilities of transitory obstacles to enable people with mobility disabilities to travel more easily. In fact, the demand for disabled pedestrian level of services is enormous. According to World Health Organization [1], over a billion people live with some form of disability. This correspond to about 15% of the world's population, and between 110 and 190 million adults have very significant difficulties in functions that include the wheelchair users. The interdisciplinary researches are working together to make contributions in this domain.

Despite the existence of standards and regulations to increase the ability of both disabled people and persons with limited mobility to independently use pedestrian networks, there is still a lack in replicable, objective, cost-effective systems to assess pedestrian infrastructure [2]. Therefore, two main limitations have been identified. On the one hand, there is a lack of tools that can ease the measurement of a level of service (LoS) adapted to disabled people. These tools can help assess the level of accessibility of a pedestrian network. On the other hand, the missing of the availability of information regarding the existing level of service in real time causes problems. When moving through a network, a disabled person needs this kind of information to take a right decisions.

In this study, we present a technical approach, named CrowDPLoS, which uses advanced computer vision technologies and benefits from the prevalence of handheld devices in order to meet the challenges discussed above. This approach allows the development of a navigation tool with crowdsourcing technologies that can help a disabled person to move around a city suggesting the most adapted routes according to the person's disabilities. As illustrated in Figure 1, the best route in our approach is based on the highest level of service of route and adapted to the user's handicap. Specifically, we give people with mobility impairments, mainly wheelchair users, a mean to travel safely and with ease through a modern urban area by applying the algorithms of computer vision. These algorithms use crowdsourced images taken by the users of a mobile application in order to determine a level of service adapted to disabled pedestrians.

This paper is organized as follows: section 2 presents a summary of the related works of computer vision based techniques and crowdsourcing in disabled pedestrian level of service, in section 3, we explain our approaches to develop models that measure a disabled pedestrian level of service for pedestrian networks by applying computer vision and crowdsourcing. Finally, we conclude with a summary of the current work, and we present suggestions for future research.

II. RELATED WORK

A. *Crowdsourcing in disabled pedestrian level of service*

Research on disabled pedestrian level of service (DPLoS) is relatively new. The analytical methods to estimate the DPLoS is not only consider as a narrow range of pedestrians, but also need to apply more diverse pedestrian populations with different characteristics, to ensure inclusive walking conditions. Therefore, a good quality of crowdsourced data from citizens is the key element to create the DPLoS. Liu et al. [3] identified three useful techniques for improving crowdsourced data quality when building accessibility maps, including qualification tests, reputation system, and aggregation techniques. Their findings highlighted that the accuracy rate has a significant increase after applying the intervention of quality control methods. Moreover, [4] and [5] shown how participatory

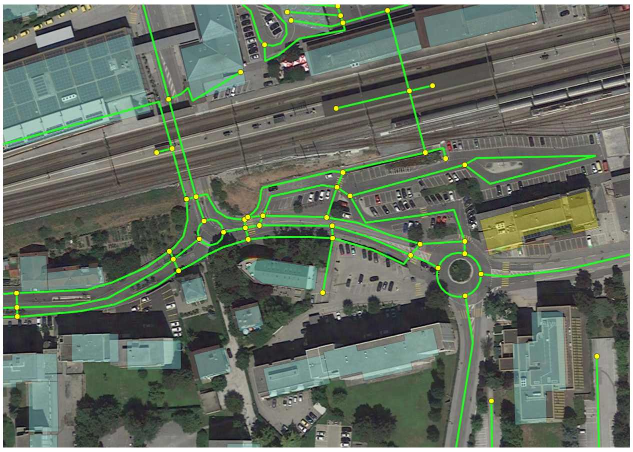

Figure 1. Part of the pedestrian network extracted from OpenStreetMap (OSM) data (green) in a downtown area. On can clearly see that sidewalks information is not present everywhere. Background map: google satellite imagery.

Geographic Information System (GIS) using Free and Open Source Software (FOSS) may help provide high quality open-GIS data and make them available to the public using web technologies. In this study, we follow the guidelines from literatures and apply selective recruitment and training of participants to provide the high-quality crowdsourcing data.

B. *Computer Vision based techniques*

Historically, computer vision tends to extract the most important features from images like color histograms, edges [6] or specific patterns [7]. Hough transform is a well know line detector that may be used to extract street borders [8] as well as vanishing point extraction [9]. The latter relies on image geometric properties [10].

Making use of GPS trajectory and images taken perpendicular to the street axis, Lu and Karimi [11] showed a simple approach to compute the slope of a street.

Hara et al. [12] show how computer vision may be used to determine accessibility from physical features of the real world based on Google Street View images. This approach makes use of the modern approach of machine learning techniques, especially convolutional neural networks (CNN) which are typically designed to extract features from images [13]. Field of autonomous driving brings a solid background for street images segmentation [14]. Coupled with steroscopic vision this provides the useful depth information [15], [16] to better isolate street portions.

C. *Coupling the two techniques*

As sidewalks are probably the most important and secure places for pedestrian to walk on in urban areas, several studies have focused their researches on characterizing and assessing sidewalks accessibility, even based on percieved security from the pedestrian point of view [17].

But it's rather new that a PLoS has been specifically investigated for disabled people (DPLoS). [18] have for example calculated 10 main feature indicators based on several studies and guidelines regarding the presence of facilities for disabled, like wheelchair users or blind people. [19], [20] focused on mapping the level of accessibility of street networks and [21], [22] on creating an accessibility mapping mobile application using a user-centered design approach.

[15] and [23] used a calculated depth map to detect negative obstacle edges on wheelchair users path by directly embedding a stereo camera onto the wheelchair.

Other embedded based techniques make use of a smartphone camera to detect crosswalk [24] or straight paths using stereoscopic based vision [25].

Mapping project like OpenSideWalk [26] investigated routing techniques for sidewalk graph analysis in order to propose the better paths for disabled people. This project is now proposing a schema to better and more finely represents sidewalks as separate footways from the drivable roads in OpenStreetMap (OSM).

Even the tourism industry may take some advantages of disabled accessibility researches [27].

While [28] addressed some of the most important questions regarding computer vision and crowdsourcing and provide useful general guidelines, it is only recently that DPLoS assessment or application design took advantages of these techniques. [29], [22] have shown the opportunity of integrating final users in the design of an application devoted to disabled pedestrian and to assess scaled street segments aptitude.

Some of the most advanced studies [30] have shown how to combine crowdsourcing and computer vision on Google Street View images to collect informations on disabled pedestrians accessibility. Some tools [12] make use of Amazon Mechanical Turk (AMT) to achieve rapidly and at low cost some detection tasks on images. Recall of AMT workers combined with computer vision algorithms is higher and faster than AMT workers alone [31]. Thus, computer vision still endorse an important role in detecting features, especially when combined with machine learning.

The bottleneck in such approach is data acquisition and labeling. The latter is one of the highest time demanding operation and may lead to noisy results. Therefore great care must be taken to maintain data quality while keeping crowdworkers motivation and quality of their work [32].

III. Proposed approach

Based on the relevant literature, the research proposal is articulated in several phases. First, two preliminary steps must be taken:

A) the creation of the DPLoS model and
B) the establishment of a pedestrian network at a city-scale level

These two steps have to be closely related in their development as part of user inputs may influence detection algorithms. On the other hand, detection results will have to be evaluated by crowd-workers and final users.

Meanwhile, computer vision and machine learning algorithms dedicated to features detections will be settled together with dedicated crowdsourcing applications to collect data, digitize and label features and evaluate the detection results (C).

A. DPLoS model

The DPLoS established model retains the 5 following features based on literature guidelines:

- slope
- sidewalks width and presence of obstacles
- coating quality (pavement, smooth concreet)
- crosswalks and security signals (pedestrian light, refuge island)
- presence of curb ramps to cross roads

Each feature normalized score S is then weighted to compute a global DPLoS score for any street edge as:

$$\frac{1}{5}\sum_{i=1}^{5} S_i \cdot w_i \tag{1}$$

Weigths have to be determined based on local conditions and street users perception.

B. Pedestrian graph

Existing data to establish the pedestrian graph may include National Map Agency (NMA) Cadastral Survey or vector data if available, OSM streets and footways or third party road networks.

It is also conceivable to use high resolution satellite data to extract a road network using segmentation-based classification methods in regions where high quality vector data does not exist.

For this study, OSM street pathways data were extracted over a european small town using a dedicated Python package [33].

C. Crowdsourcing, Computer Vision and Machine Learning

It was first decided to use 4 different tools depending on the goal to achieve. These goals are as follows:

1) Footways network update
2) Data acquisition: raw images + geolocation
3) Images features digitizing and labeling
4) End-user route choice and update abilities

Footways network update: The initial pedestrian network may not be totally fulfilled 1. It will be proposed as a Tool-as-a-Game (TaaG) to give crowd-workers a way to complete or make it fit the actual reality more precisely based on a recent orthophoto background.

Data acquisition and geolocation: The second stage, would basically serve as a feeding source for raw images.

Everyone can take a picture with a handheld mobile device and upload it to a database. Along with existing street pictures sources like GSV or mapillary [34] they will be used as raw data input for the digitizing stage. If position and orientation (azimuth) values are know from a GPS and compass, they are stored along the picture. Otherwise, a geolocation tool will proposed to the user to geolocate and orient its photograph before uploading it.

Feature digitizing and characterizing: The third stage main goal is to detect one or more of the 5 identified DPLoS features on raw images and marking them with scores based on the DPLoS model. If the former may be done by a well trained CNN (fig. 2), the latter would be evaluated by crowd-workers.

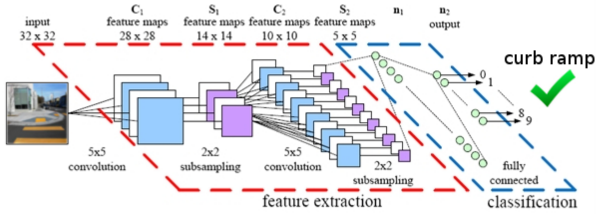

Figure 2. Conv Net detection of a curb ramp unknown image.

E.g., if someone sees a curb ramp on a picture, he will be able to digitize it more accurately and marking it as a more or less friendly curb ramp (fig. 3). An other example would let the user annotate a sidewalk surface width as "no possible way for a single wheelchair" based on the perceived width on the given picture. If depth information is available a measuring tool may also be provided.

Figure 3. An example on digitizing a curb ramp on a picture.

This stage will also give the user a tool to check the features that were detected by algorithms. This important step provides two advantages:

1) it will classify detected features according to the confusion matrix given in table I.

Table I
CONFUSION MATRIX

		Detection	
		Positive	Negative
Ground truth	Positive	True positive	False negative
	Negative	False positive	True negative

2) machine learning detection algorithms could be trained again with these new positive and negative labeled images. Training results will be tracked to avoid overfitting in addition to some optimizations.

End-user route choice and update: The last application will directly target the impaired pedestrian street users. It will propose the best route between two points based on the better DPLoS edges as define by eq. 2.

$$\mathrm{DPLoS}_{route} = \frac{1}{n}\sum \mathrm{DPLoS}_{n \cdot segment} \tag{2}$$

An additional tab will offer the user the possibility to give its feedback on a selected segment, for example when he sees an inadequate between the real world and a feature on the segment. This will improve the pedestrian network and update it as urban environment is changing.

IV. Conclusion and future work

This project is in its early stages. The first version of the DPLoS model is ready. The setting up of a database to store images metadata like geolocation, as well as algorithms and crowd-workers labeling results is taking place. This same database will serve the four different applications through APIs that need to be developed. It will finally need further investigating and tests regarding coupling of CV and ML algorithms. Database populating and labeling will be the most resource demanding tasks.

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