Building a Crowdsourcing based Disabled Pedestrian Level of Service routing application using Computer Vision and Machine Learning

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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 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 decision.

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 people with disabilities to move around a city suggesting the most adapted routes according to the person's disabilities. To summarize, 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 crowdsourcing based disabled pedestrian level of service for pedestrian networks, which are applied the technologies of computer vision and machine learning. Finally, we conclude with a summary of the current work, and we present suggestions for future research.

II. Related work

A. *Models of disabled pedestrian level of service*

Safety and accessibility of pedestrian infrastructure regulation developments have historically been supported by governmental institutions. For example in the United States was carried out the Americans with Disabilities Act (ADA) in 1990. The ADA was designed in order to guide the implementation of regulations and specifications for pedestrians.

The first formalization of sidewalks performance assessments was carried out by [**?**]. His approach is the only quantifying established methodology to measure the capacity of sidewalks [3]. The practical usage of his methodology has its limitations, in fact only around 3 percent of the sidewalks could be effectively assessed by Fruin's method.

Given that sidewalks are one of the most important and secure places for pedestrian to walk on the urban areas, several studies have focused their researches on characterizing and assessing sidewalks accessibility, even based on perceived security from the pedestrian point of view [4]. According to Landis et al. [3], it is more difficult to assess walking conditions than assessing vehicular roadways. Furthermore research focused on PLoS for disabled people (DPLoS) is rather new. Asadi et al. [5] have for example calculated 10 main feature indicators based on several studies and guidelines regarding the presence of facilities for disabled people, like wheelchair users or blind people. Once the 10 DPLoS indicators were developed they proceeded to establish 10 PLoS indicators with the same methodology. The combination of the DPLoS and PLoS is a General Pedestrian Level of Service (GPLoS), which assesses the inclusive walking conditions for both pedestrians and disabled users.

B. Computer Vision and machines learning based techniques for assessing relevant street features

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

The slope of a street and the detection of obstacles are focus of research in the subject of accessibilities. The using of geolocation with odometric data, mainly GPS trajectory, is a common solution. Hara et al. [8] show how computer vision may be used to determine accessibility from physical features of the real world based on Google Street View images coupled with machine learning techniques. Within the latter domain, convolutional neural networks (CNN) are especially designed to extract features from images [9]. Based on these techniques, field of autonomous driving also brings a solid background for street images segmentation [10]. Existing street scene datasets along with semantic segmentation and region-based methods [11] have proven the need of fine grained labeled images to suit a particular task. Using weights of low level features extracted by some CNN on these datasets may be a good starting point to build a more specific architecture dedicated to the DPLoS features extraction.

Moreover, steroscopic vision provides at low cost the useful depth information as a disparity map. This is done by computing a 3D point cloud from stereo images pairs, which can help to better isolate relevant objects. Coughlan and Shen [12] make use of an embeded stereo camera to detect negative obstacles on the wheelchair user's path.

But there are still two main bottlenecks to build a supervised computer vision classifier based on machine learning. These are 1) data acquisition and 2) the presence of high quality associated labels. If nowadays huge amount of data is available, they may not be well enough labeled nor suited to a given specific task, hence well managed crowdsourcing tasks may provide an invaluable help in both.

C. 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 considered 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. [13] 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, [14] and [15] shown how participatory 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 the literature and apply selective recruitment and training of participants to provide the high-quality crowdsourcing data in addition to computer vision based techniques.

D. Combination of crowdsourcing and computer vision to evaluate the DPLoS model

Computer vision is an useful technology for the autonomous driving and objects detection, but features extraction relies frequently on domain experts. Integrating crowdsourcing is not an easy task. A recent survey by Kovashka et al. [16] addressed some of the most important questions regarding computer vision and crowdsourcing, which provided useful general guidelines. But only a few studies took advantages of both techniques for DPLoS assessment and the application design. Hara and Froehlich [17] 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.

More recently, Hara et al. [8], [18] designed a specific tool which makes use of Amazon Mechanical Turk (AMT) to achieve rapidly with lower costs on images detection tasks. Recall of AMT workers combined with computer vision algorithms was higher and faster than AMT workers alone. Therefore, combination of both technologies could provide a better accuracy on objects detection. The challenges of this kind of approach are reflected in how to motivate the participants for data acquisition and how to ensure the quality of collected data. The latter requires substantial time a or money investments and high knowledge demanding operations.

III. Methodology and preliminary results

Based on the relevant literature, our research methodology is divided into three main phases: 1) the creation of the DPLoS model; 2) the establishment of a pedestrian network at a city-scale level; and 3) the design of a computer vision and machine learning architecture dedicated to features detections, coupled with crowdsourcing applications to collect data, digitize and label features and evaluate the detection results.

A. DPLoS model

The DPLoS established model retains the 5 following features based on the literature: 1) slope; 2) sidewalks width and presence of obstacles; 3) crosswalks and security signals (e.g. pedestrian light, refuge island); 4) presence of curb ramps to cross the road; and 5) coating quality (e.g. pavement, smooth concrete).

A normalized score S_i for each feature i is then weighted to compute a global DPLoS score for any street edge as eq. 1 shows.

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

Weights w_i calculations are based on local conditions and street users perception. A key factor during the calculation of the recommended route for users is to provide the shortest path. The integration of a DPLoS into a short-path calculation service can easily be achieved via a Dijkstra algorithm [**?**]. Indeed, the DPLoS is calculated through a weighting process in a graph and the DPLoS range of values is always a positive real number. These two properties are essential for this kind of algorithms. The behavior of an individual with reduced mobility wishing to travel from point A to point B in a city, is dependent on the street graphs on the one hand and on the other hand their adaptations to the mobility possibilities in a given city.

From a formal point of view, this is a path calculation problem in a graph. In this context, the DPLoS deals with the adaptation of the environment to the potential mobility of the person and the graph represents the territorial support. The nodes of the graphs are the street intersections and the arcs are the streets. Still on the formal level, the setting up process of a graph evaluated by a DPLoS is a simple question that can be processed by a query in a database containing the geometric description of the graph. This can be done through the usage of a geographic information system where the DPLoS evaluation is an attribute of an arc between two vertices.

B. Pedestrian graph as an input

DPLoS computation for street edges requires a pedestrian graph as an input. In order to build this graph, we relied on existing open data such as National Map Agency (NMA) Cadastral Survey, OSM streets and footways. In order to obtain the high quality vector data to draw the pedestrian graph, we used the high resolution satellite data to extract a road network with segmentation-based classification methods.

The figure 1 illustrated the results to show a pedestrian network by applying the data from OpenStreetMap. This graph was created by using is a dedicated tool named OSMnx [19]. The light lines display the available sidewalks information on this network.

C. Combination of algorithms and crowdsourcing

In this section, we use four steps to explain how the computer vision algorithms and crowdsourcing technologies could be combined together. These steps contain: 1) footways network update; 2) data acquisition; 3) images features digitizing and labeling; and 4) end-user route choice and update abilities. We propose to develop a specialized application for each step.

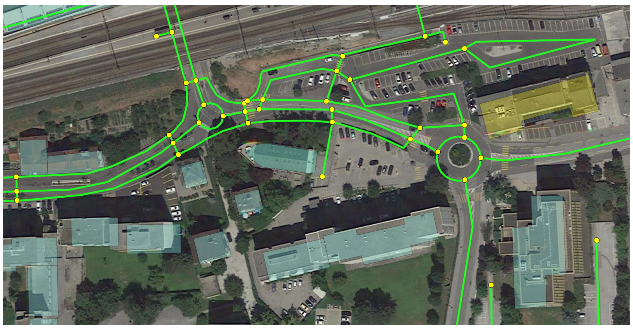

Figure 1. Part of the pedestrian network extracted from OpenStreetMap (OSM) data (light) in a downtown area.

1) Footways network update: The initial pedestrian network may not be totally fulfilled (fig. 1) due to its voluntary basis and interest of local citizen for geographic data. A first application is designed and proposed to give crowd-workers a friendly way to complete and make it fit the actual reality more precisely based on a recent orthophoto background with a 30 cm minimal resolution and a sub-meter accuracy.

2) Data acquisition and geolocation: In this step, a second application would be proposed to serve as a feeding source for raw images. We apply a set of crowdsourcing motivation methods [13] to ask the application users to take a picture with their mobile device. These pictures will be used as raw data input for the digitizing stage. If the picture's position and orientation (azimuth) values are recognized from a GPS and compass, then it could be stored in our database. Otherwise, a geolocation tool will be proposed to the user to geolocate and orient its pictures before uploading it.

3) Feature digitizing and characterizing: The main goal of the third step is to detect one or more of the 5 identified DPLoS features on raw images and marking them with a score 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.

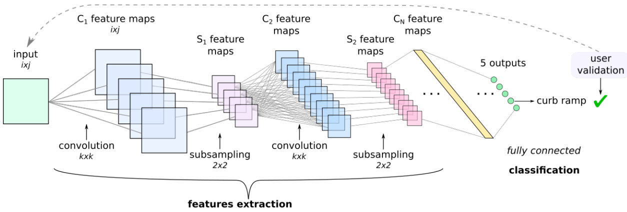

Figure 2. A CNN detecting a curb ramp. User checking may disable the label associated with this image if the result is a false positive.

Let us think about the following examples, if a mobile user sees a curb ramp on a picture, he/she 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 "impossible for a single wheelchair" based on the perceived width on the given picture. If depth information is also available, a distance-measuring tool may also be provided to directly measure the sidewalk width from the image.

This stage will also give the user a tool to check the

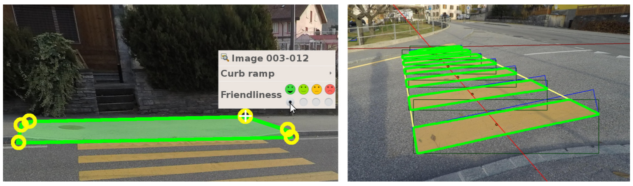

Figure 3. Image examples of a manually digitized curb ramp with a friendliness score selection toolbox (left) and a true positive automatically detected crosswalk (right).

features that were detected by algorithms. This important step provides two advantages. It will first classify automatically detected features according to a standard confusion matrix. And then, machine learning detection algorithms could be refined with these new positive and negative labeled images. Training and testing results will be tracked to avoid overfitting in addition to some optimizations.

4) End-user route choice assessment and update: The final application will directly target the impaired pedestrian street users. It will propose the route with the best DPLoS value between two points based on the weighted sum of the DPLoS of each n edges composing the route as define by eq. 2.

$$\text{DPLoS}_{\,route} = \frac{1}{n}\sum \text{DPLoS}_{\,edge\ \ n} \tag{2}$$

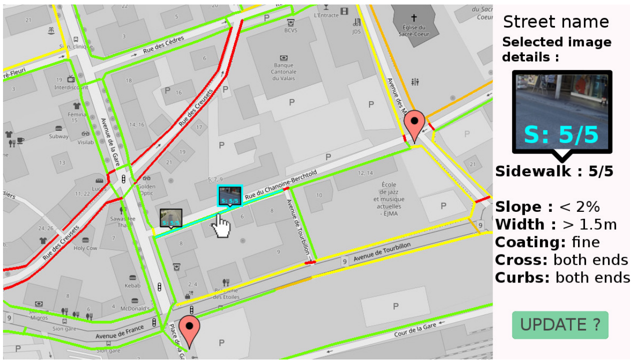

Figure 4. Prototype of the final application with edges of the pedestrian graph colored according to their DPLoS value (red=low value, green=high value). The selected edge shows that two different images participated to its score. Features' details for this edge and the selected image are shown on the right.

Informations about the edge as well as an update button (fig. 4) will offer the user the possibility to give its feedback on a selected segment, for example if he sees an inadequate between the real world and a digitized feature. This will continuously improve the pedestrian network and update it as urban environment is changing.

IV. Conclusion and Future Work

In this paper, we describe how to build a crowdsourcing based disabled pedestrian level of service routing application using computer vision and machine learning. We analyze the existing technical algorithms for images processing, and explain their deficiencies. More importantly, we present the combination of these algorithms with crowdsourcing technologies to improve the recall and the specificity of features detection. Our methodology contains a four-step process, which gives a detailed view to the practitioners about this combination. The preliminary results highlight that the accuracy of the features detection has been improved by apply the technology of crowdsourcing. The next step for this study would be to implement our solution with the geolocation data from big cities in our country. The expected results will help people with mobility disabilities to plan their trips with an easy and secure way.

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