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Wegoto: a Smartphone Application to Assess the Accessibility of Roads and Public Spaces for People with Disabilities – A Proof of Concept Study

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Abstract: This paper proposes an approach based on the use of a Smartphone application to evaluate and improve the accessibility of roads and public spaces for people with reduced mobility. It records measurements from several complementary sensors (linear acceleration, angular velocity, orientation, GPS) and allows the designation of alert points. Subsequently, these measurements are interpreted and transformed into an index that takes into account the user's profile. A case study was conducted with three wheelchair users to assess the feasibility of our approach. Although preliminary, our results suggest that the calculation of custom index works for these profiles. Our results also demonstrate the importance of taking into account differences in inter-profiles for the development of customized trips. Thus, the system could be used as a support to an innovative wheelchair navigation system and, more generally, for people with reduced mobility to improve their independence and quality of life.

Key words: Accessibility, Smartphone, inertial motion unit, wheelchair, spinal cord injury, handicap.

1. Introduction

Being able to move independently and secure at work, at school, to go shopping or to visit friends or family is essential for our well-being and social life. Loss of mobility and independence for a person increase his isolation, anxiety and can lead to depression. [1] For people with disabilities, accessibility of roads and public spaces is of utmost importance. In many countries, including France and the United States, the accessibility of a place for people with disabilities must be taken into account in the construction or renovation of a building or a road. However, work on accessibility is a long process that requires the involvement of a large number of stakeholders such as policy makers, urban planners, but also (and especially) users. In order to select the most suitable route for a person based on the capabilities and constraints, we need to objectively and quantitatively evaluate the accessibility of a place. Such evaluation methods are the subject of several studies [2, 3]. However, these studies are not always based on consistent and comparable procedures, that make comparisons difficult too make. Church and Marson were the first to suggest that the measurement of accessibility should take into account both "absolute" accessibility (technical) and "relative" accessibility (user perceptions, travel time) to get a reliable measure [2]. The "technique" measurement is carried out via comparison to the standards of different laws, while the "absolute" measure is based on evaluation of user perception techniques, for example, to weigh the criticality of difficulty [3]. However, this method led to a unique ('averaged') index of accessibility which does not consider the particular profile of the person, who is waiting for a customized response that takes into account his own capacities.

Furthermore, over the last two decades, advances in the miniaturization of sensors and wireless technologies have enabled the development of monitoring actimetric systems through inertial units [4]. The development of these inertial motion units (IMU) is so important that they are now embedded in many everyday objects such as Smartphones. Smartphones are now used by people for self-measurement (movement of the "Quantified self"), but also as part of research into the assessment and rehabilitation of balance [5] and walking capacities [6] or more specific clinical tests such as the Timed Up & Go [7]. The aim of our work is to develop a record system for accessibility of roads to obtain all the necessary information in order to offer a customized index including the inherent capabilities of the user. This paper presents the survey system "Wegoto" based on the use of this everyday tool, now available for the greatest number that is the Smartphone, and which goal is to record sensors measurement that lead to create an accessibility index for each user profile

The organization of the paper is as follows. Section II describes the different situations of disability which are integrated in the tool for our study. Section III presents the architecture and operation of the "Wegoto" system. Section IV illustrates, through a case study conducted on three disabled persons who use a manual or an electric wheelchair, the feasibility of the method in real conditions. Finally, the results are discussed in Section V.

2. User categories and specificity

Each of us has his own abilities to cross or clear obstacles. For someone with limited mobility capacities, such as wheelchair users, this may be their ability to take a step height. Some people are able to cross a level difference of 2 cm whereas other may pass over 6 cm, or conversely, only 1 cm. We present in this section (i) generic profiles of wheelchair users, and (ii) the profile of an "urbanism expert" whose mission is specifically to improve diagnosis and accessibility of roads.

2.1 The wheelchair user's profile

Each wheelchair user has a specific "profile" which depends on numerous factors: (i) his pathology, (ii) the characteristics of his wheelchair (electric or manual, mechanical efficiency ...), (iii) the use of his chair (style propulsion, level of expertise) [8]. Taking into account all these parameters, we want to create a reliable, valid, useful and usable by the largest number of wheelchair users index. This is why we distinguish electric wheelchairs from manual ones. These last are divided into two categories: (1) "comfort" (e.g., NETTI 4 U FA medical Eureka, Action 3 NG COMFORT Invacare) and (2) "active" chairs (e.g., EXELLE of Progeo EASY MAX Sunrise Medical). The energy cost and energy expenditure for propulsion are calculated from direct measurement of oxygen consumption [9]. As an indication, the energy expenditure of a manual wheelchair, on a smooth and even surface without any hindrance, is about 210 J/m [9], which is close to walking with a value between 150 and 220 J/m. However, when environmental constraints such as slope, soil irregularity or barriers increase, the cost of energy increases significantly and exceeds that of walking. To reduce stress to a minimum and prevent musculoskeletal disorders, or injuries related to the use of the manual wheelchair, our goal is to offer the most accessible path to users based on their own specific profile and to create an accessibility index of their own. Chesnay and Axelson have developed a first method to measure the effort made by a person while walking on various surfaces over a short distance [10]. They propose a first technical for calculating an index on a long distance using the developed force measurement as a reference. Thereafter, Kockelman et al. have identified, in their review, factors that influence the perception of comfort while traveling on a sidewalk for wheelchair users, and particularly the influence of the degree of slope and cross slope [11]. These factors are the following: the length of sidewalks (in function of the slope), the proportion of road above the threshold of 2% of the cross slope, the vehicle traffic volume adjacent to the road, the state of the slope and width the coating of the sidewalk, weather, and finally all the specific amenities to accessibility (e.g. curb cuts, pedestrian crossing). Ferreira and Sanches have used a technical evaluation of the infrastructure design of sidewalks and crosswalks, weighted according to the relative importance of each attribute of the road in terms of wheelchair users to also create an accessibility index [3]. The point of view of the user is a perceived difficulty which allowed the authors to validate their index. Concerning "Wegoto", indicators considered to quantify objectively and automatically access are the following: the degree of slope and cross slope, coating, holes or slots at the ground, the height of the pavement, the presence of stairs, lighting, obstacles on the road, and two original weighting factors are the rolling resistance and the technical / handling.

2.2 The urbanism expert profile

A "urban planning expert" refers to a person whose work is related to the accessibility of the road. This person may be responsible for public works or elected politics. To date, these experts have no portable tool to evaluate objectively and quantitatively the accessibility of the road for the different kinds of people with disabilities. Taking into account the needs, expectations and wishes of these people is part of a more comprehensive approach and is of prime importance. The "Wegoto" application allows performing data records for accessibility for most profiles via weighting factors.

In order to calculate the accessibility index, a measurement tool capable of addressing the specifics of each type of profile has then been developed. These data will then be used to provide a guidance service for each profile and suggest the most appropriate journey for each user profile.

3. The Wegoto records system

The record system "Wegoto" is developed as a Smartphone application. This is justified by the fact that this device is small, lightweight, communicating and has become a tool of everyday life available to the largest number (due to its affordability). The application allows users to record, in real time, his GPS location, his orientation, acceleration / deceleration, his instantaneous speed and if so, the inclinations of his chair in the frontal and sagittal planes. In addition, the system allows the identification and specification of different points of alerts, such as obstacle (wherein category), tactile strip, and comments in different formats (photo, audio and text). The GPS may be the one of the Smartphone or another connected GPS (SX Blue II) which is more accurate and can interface via a wireless Bluetooth connection. In future developments, we plan to use the principle of map-matching to improve the accuracy of our records of GPS position. [12] These records are then used to automatically calculate an accessibility index for a targeted portion of the road. The interpretation of this index allows us to edit specific maps from the OpenStreetMap mapping free service. In the remainder of this section we describe successively (3.1) the equipment used for the recording system, (3.2) the algorithm for data fusion and (3.3) the data processing.

3.1 Equipment

The IMU used is the Galaxy Nexus (Samsung, Seoul, South Corea). It is equipped with the following three triaxial sensors:

- a gyroscope (MPU InvenSense-3050) measuring the angular velocity;
- an accelerometer (BMA220 Bosch) measuring linear acceleration;
- a magnetometer measuring the ambient magnetic field.

In addition, the Smartphone features a GPS function (using a GPS SiRF SiRFstarIV GSD4t and GSM module) to the geographical location, a camera and a microphone that can be easily used for surveys of barriers and the creation of alerts points.

3.2 Data fusion algorithm

The stability of measurements is enabled by the use of an algorithm for merging data from the various sensors (accelerometer, gyroscope, magnetometer) based on a Kalman filter. Exploiting the redundancy of information corrects the biases specific to different types of sensors, such as measurement noise, drift integration, latency answers ... The angles obtained are then used to determine the user's movements.

3.2 Data processing

All collected data (Fig. 1, step 1) are initially stored in the internal memory of the Smartphone and then, extracted and interpreted by both the user and an automatic processing software on a secure server dedicated to health data. Thus, the automatic treatment offers its own interpretation of the road that can be verified and validated by the instigator of the record.

A hierarchical classification of motion was then constructed (Fig. 1, step 2) taking into account these different profiles. It allows us to classify user activities using signals inertial sensors. The first hierarchical level is used to determine if there is a movement or not. The second level contains three movement categories - (1) fall, (2) propulsion and (3) change in direction - which can lead to response activities (alarm, turn). Finally, when the activity is characterized, one of the last three categories (green, orange, red) representing the level of difficulty may be selected (Fig. 1, step 3). An algorithm was developed for each decision node. It also includes a real-time data processing step for fall detection and alarm triggering in order to ensure the user's safety. The accessibility index is processed post the record. Two specific parameters that guide the accessibility level (Fig. 1, step 2) for people using wheelchairs are (i) the rolling resistance and (ii) the technical / handling.

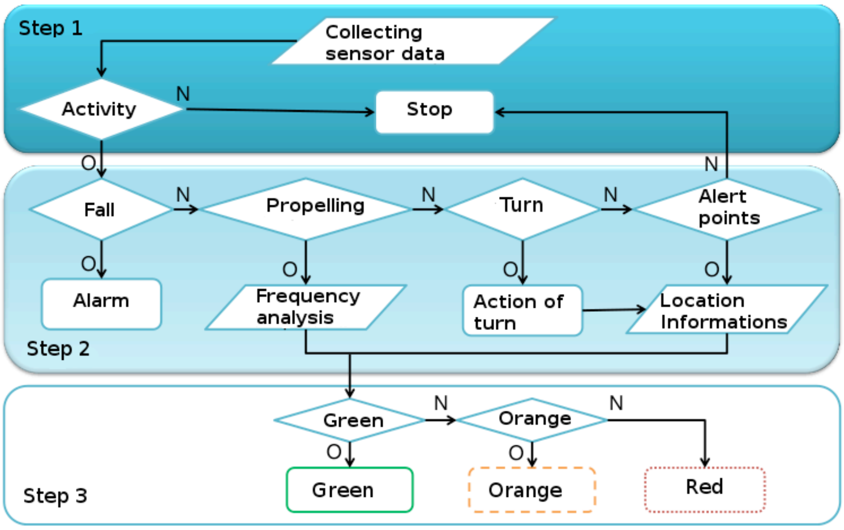


Fig.1. Flowchart of the classification process. Step 1: Data Collection; Step 2: Data Analysis; Step 3: Extraction of the index.

These parameters can only be obtained by the statement of a person with motor disabilities. This allows us to refine the index and make it closer to reality compared with a statement made by an expert in urban planning.

The rolling resistance of the wheelchair, which is opposite to the movement when a body (such as a ball, a tire or a wheel) runs on a surface, is quantified by analysis of the acceleration / deceleration signals from the wheelchair. To do this, we use a three step process. First, we start by selecting the time range to be observed depending on the activity. For this, we chose to differentiate the activities by performing a frequency analysis of peak accelerometer signals (Fig. 1, step 2). A large increase in the frequency of these peaks is considered representative of a portion of easy course, unlike a difficult part of the course where the cycles indicating the pushing action of the person are longer.. After this distribution, the standard deviation and the mean energy are determined according to [12]. The energy for the y-axis (axis in the anteroposterior direction of thrust), denoted E_y, is given by the following equation:

$$E_y = \sum |f_y(j)|^2 / N \quad (1)$$

where f_y is the Fourier transform of the signal in question and the number N of samples. It allows us to detect three types of periods: (i) containing no movement, (ii) movement with a normal rate and (iii) movement with a steady pace (requiring more effort). It has been shown that the use of the mean, the standard deviation and the acceleration energy makes possible to distinguish dynamic activities [13]. The standard deviation of the acceleration signal was used to quantify the variability due to the activity concerned. However, the most important issue is the observation that the frequency is reflected in the frequency domain based on the value of energy [13].

Regarding the technical / handling, consideration of changes in positioning to overcome an obstacle, combined with tilt measurements allows us to determine the level of difficulty. Finally, these observations are combined and checked against values of good practice, to define the problem and therefore the final index of the portion of the course. For example, a sidewalk with a cross slope less than 2% is recommended [14], which will be factored into our decision algorithm index. If this value exceeds 6%, whatever the outcome of the other comments, the portion of the course is deemed "inaccessible" for all the preset profiles. This eventually leads to the construction of a decision tree based on various observations and information signals characterizing a specific situation.

3. Case study

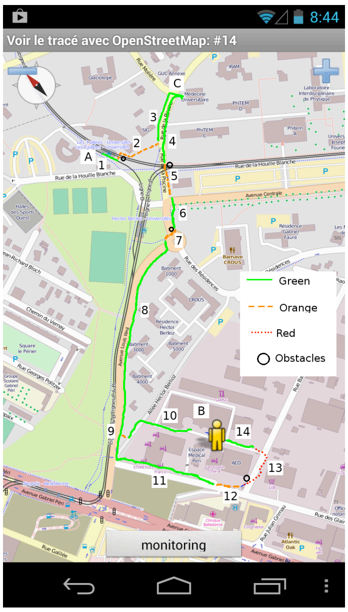
In this section, we present a case study to evaluate the use of a Smartphone application to measure and improve the accessibility of streets and public spaces. Three individuals with spinal cord injury who use a manual or an electric wheelchair voluntarily participated in this study.

Our first volunteer is a paraplegic young male adult (age: 30, height: 160 cm weight: 60 kg, injury level scoliosis of birth). He uses his manual wheelchair every day for 20 years. His style of propulsion is the "semi-circular" [15]. Our second volunteer is a quadriplegic young male adult (age: 34, height: 183 cm, weight: 70 kg, injury level: C5 / C6 partial). He uses for his daily commute a manual wheelchair. Style propulsion is also the "semi-circular" [21] but he has difficulties in grasping the handrail. Our third volunteer is a quadriplegic young male adult (age: 28, height: 177 cm, weight: 80 kg, injury level: C5-C6). He uses an electric wheelchair since two years instead of a manual to facilitate his efforts during his outside trips. These three individuals gave their written consent to the experimental procedure, which received a favorable opinion from the Ethics Committee for Non-Interventional Research (CERNI 2014-04-21-44) after the nature of the study was clearly exposed.

The Smartphone used for the survey was positioned horizontally on the seat of the chair or on the armrest, facing the screen up and pointing forward. The ride was set to go from point A (tram stop opposite the Home Handicap Service of the University of Grenoble) to point B (center medical equipment sales) through a point C (center Michel Zorman health from the University of Grenoble). The test was conducted in the afternoon in rainy weather. The road so borrowed (Fig. 2) presents in its first part (1) a regular tarred ground and a slight downhill slope. This part has been interpreted "green" after analysis (Table 1). The rupture index with the next section (2) is the alert point reported by users corresponding to crossing tramlines. This passage is followed by a zone with significant cant slope (5 to 7%), but also many elevations of the road caused by tree roots. Cycles thrust on that part are longer and less frequent for the quadriplegic manual users (Fig. 3). Thus, this volunteer deploys more force on this portion of the course. This is also confirmed by the analysis in the frequency domain by using the energy calculation. The paraplegic users, due to his good physical condition, has not encountered the same difficulty level. For the electric wheelchair user, a significant slope indicates a greater risk of falling. This therefore maintains the index in orange for both quadriplegic users, to the junction with a pavement surface that seems more suitable for rolling. In part (7), the crossing was reported as difficult by the quadriplegic voluntary with the manual wheelchair due to a non-compliant curb cut. However, this curb cut has not been a problem for the two others since one is able to raise and lower the sidewalks of a certain height, and this height remains passable for an electric wheelchair. From part (9), the two manual volunteers did not followed the same path. The paraplegic chose to pursue his course, while the quadriplegic person took a turn to the left. So the rest of the course of the manual and electric wheelchair quadriplegic voluntaries went without a hitch, unlike the paraplegic user. After experimentation, it turned out that the paraplegic person did not know the path. The following path was more deteriorated, particularly in terms of floor covering. It became less smooth and more resistant to the advancement of the wheelchair, which was found also on the accelerometer signals. One difficulty has been encountered in part (12) due to a barrier consisting of a non-compliant curb cut. In part (13), the user has reported an electric pole located in the middle of the sidewalk and preventing the passage of a wheelchair. This forced him to cross the street without suitable transition. The paving of the sidewalk on which is then found the user became even more erratic. The worst trouble was that the user had to go down a sidewalk with a height of 12 cm. This can be seen via the (non-cyclical) accelerometer signals, finding of a "technical" area. Other difficulties have been encountered which that had the effect to class the portion in “red”. Part (14) has finally allowed him to reach his destination. These are the different measures of orientation, slope and acceleration / deceleration that enabled segmentation portions. The analysis of signals each portion was then used to determine the specific to each of the three users accessibility index. The two paths taken by the three users enable to obtain a statement from the finish area wider. The results were presented to all subsequent users. They agree with the interpretation.

Table 1: Description of index selection

Areas	Informations on the level of the index		
	Paraplegic manual wheelchair user	***Quadriplegic manual wheelchair user***	***Quadriplegic electric wheelchair user***
1	Regular tarred ground, slightly downhill (5%)		
2	Cant (7%), listed one obstacle (tramline)		
	Energy difference: 0,10	Energy difference: 0,41	None
3	Sol tarred recent sidewalk, no drop-offs or significant slope		
4			
5	Cant (about 7%), irregular floor tiles, a listed obstacle (tramline)		
6	Sol tarred recent sidewalk, no drop-offs or significant slope		
7	No difficulty in crossing	Height curb cut embarrassing when approaching the crossing	No difficulty in crossing
8	Paved road, downhill (6%) and cant (7 to 9%)		
9	Continuity of road 8	Cant (7%)	
10	-	Paved road, downhill (5%)	
11	Continuity of road 9	-	
12	Curb cut improper, uneven coating		
13	Height slabs (12 cm), dangerous crossing (traffic, no curb cut)		
14	Tarred regular ground		



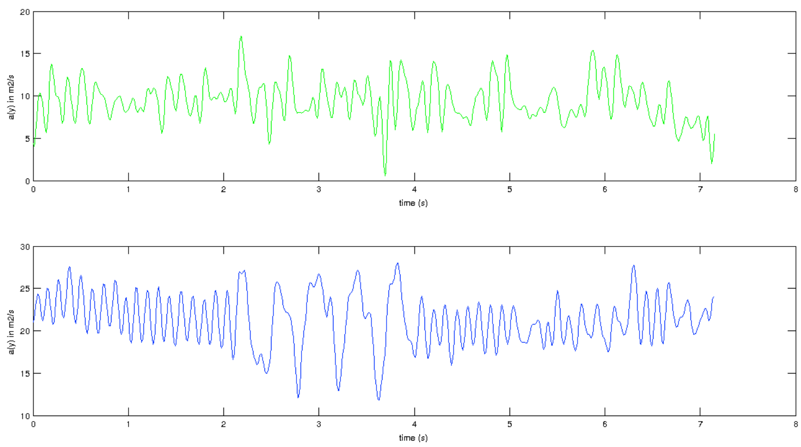


Fig.2. Screenshot of the path from A to B via C with cutting parts of the journey from 1 to 14 for the three volunteers and Fig.3 accelerometer signals according to the anteroposterior axis low pass filtered, in m²/ s versus time obtained for paraplegic wheelchair user (top) and quadriplegic wheelchair usjer (bottom). These signals were collected on the stretch of road (3) a distance 86 meters.

4. Discussion

The case study allowed us to get three different interpretations of the accessibility of a course, similar in its major part, for three wheelchair users with different profiles. However, the alert points have not been incorporated into the automated calculation of our index yet. Furthermore, Holone et al. have assessed the possibility of feedback indices stretch of road through a collaborative tool [16]. They observed that the indices on road segments are not subject to spontaneous collaboration, unlike the reporting of barriers. Our case study shows the same results. Moreover, urban experts require a map which is constantly up to date. That is why we believe that our survey data must be enriched by a crowdsourcing collaboration via a transmission by end users. Therefore, future research will be concerned with classifying all obstacles in order to consider them when planning routes. As Ren and Karimi [12], we also used the sensor data to identify and classify the movements of the wheelchair. Compared to this research, we have added the inclusion of inclinations (frontal and sagittal), obstacles and amenities accessible data which enables us to create our accessibility index. To confirm these preliminary results and to improve our classification, a study involving a larger number of wheelchair users is currently being conducted.

Conclusion

In this paper, we describe the possibility of indexing the accessibility of road segments using the dedicated Smartphone application "Wegoto". The results of this proof concept study confirm the usefulness of our approach to determine quantitatively the accessibility indices by combining both our organizational decision processes and data processing algorithm. The analysis of this journey has also highlighted the importance of inter-profile differences that must definitely be considered for the development of an index to the nearest specific user characteristics. Finally, we would like to mention that the data record system "Wegoto" course is not a dedicated and specialized equipment, but is fully integrated into a Smartphone, which corresponds to the needs, expectations and wishes of wheelchair users that we assessed in a previous user-centered design approach for the development of the Wegoto system.

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