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Wegoto: a Smartphone-based approach to assess and improve accessibility for wheelchair users

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***Abstract*— This paper proposes a description of a Smartphone-based approach to assess and improve accessibility for wheelchair users. The developed system employs a dedicated Smartphone application that records various complementary sensor measurements (acceleration, deceleration, inclination, orientation, speed, GPS position) and permits obstacle denunciation. Then, accessibility information are reported on maps in a Geographic Information System which can calculate the most accessible route for wheelchair users taking into account their profiles and capabilities. A case study involving a wheelchair-dependent paraplegic was performed to preliminary assess the feasibility of our Smartphone-based approach to provide an accessibility index for wheelchair users. Although preliminary, our results do suggest that the Wegoto system could be used as an innovative assistive navigation system for wheelchair users and ultimately could help to improve their autonomy and quality of life.**

***Index Terms*— Accessibility, Wheelchair, Smartphone, Inertial motion unit, Personal navigation**

I. Introduction

Mobility does represent a crucial activity of human daily life. Being able to independently go to work, school, shopping, visiting friends or family is essential for our well-being and social life. Limited mobility for a person is known to increase isolation, anxiety and depression [1]. For people with reduced mobility, accessibility of pavements is essential. In many countries, including France and the United States, the accessibility of a place for people with reduced mobility must be taken into account during new construction or during the renovation of any building. However, there is still a huge amount of work to conduct to make streets or sidewalks fully accessible. To point out the most accessible route to an individual depending on his mobility, one must objectively and quantitatively assess the accessibility of a place, street or sidewalk. This has already been the subject of several studies [2], [3]. Assessment methods vary from one country to another and are not always based on concrete procedures. Besides, the past two decades advances in miniaturization of sensors and wireless technologies have enabled the development of systems to monitor person's activity [4] and, more specifically, to identify and classify his movements through the use of inertial sensors [5]. The development of these inertial motion units (IMU) is such that today they can be found embedded in many everyday devices such as Smartphones [6].

This paper presents the so-called "Wegoto" system, a Smartphone-based approach to create an accessibility index for wheelchair users. It is organized as follows. Section II describes the different categories of disabled people concerned (by the categories of wheelchairs used). Section III describes the architecture and functioning principle of the Wegoto System. Section IV presents a case study designed to assess the feasibility of our Smartphone-based method to provide an accessibility index for wheelchair users. Section V discusses the obtained results.

II. The Wheelchair Categories and Specificities

This work first focuses on three specific profiles of wheelchair users. Each user has a specific profile depending on his pathology, wheelchair settings, style of propelling, expertise… [7], etc. However, through some choices, we expect to create an index that will be useful and usable by the largest possible number of wheelchair users. We distinguish therefore the electric wheelchair from the manual wheelchair. In the manual wheelchair, there are two subcategories that are comfort and active (in which we place the specific case of electrically assisted manual wheelchair). For those two subcategories, the mechanical efficiency of the wheelchair, which is the energy provided by the wheelchair user given the displacement, is of the order of 10% [8]. The energy expenditure of a manual wheelchair in propulsion speed comfort, on ground smooth and regular, without any obstacle is about 210 J/m [8], which seems so close to walking with a value between 150 and 220 J/m. However, when the environmental constraints such as slope, uneven floors or obstacles increase, the energy cost becomes higher and then requires an effort that exceeds walking. In order to reduce effort to a minimum and prevent wheelchair

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related injuries, we aim at offering the most accessible courses to wheelchair users based on their profile. We have therefore developed a system path statement to retrieve specific data on the constraints of a route while wheeling. This system is specifically designed to provide an accessibility index which is a fixed scale. These data will then provide users with the most appropriate route to their destination considering their profile and this index can also be used by planners to objectively and quantitatively assess, then to accordingly and appropriately improve accessibility.

III. WEGOTO SYSTEM

The Wegoto system path statement is based on a home-made Smartphone application. Smartphone choice is explained by the fact that this device is small, lightweight, but also communicating and commonly available. The system can record the GPS position of its user, the frontal and sagittal inclinations of the wheelchair, its direction, acceleration and deceleration, as well as its instantaneous speed. Furthermore, the system allows the identification and specification of point of interest (POI) in different formats (photo, audio and text). All these data can be recorded in real-time on the Smartphone and can be exported to different file types (GPX, OSM, Excel). In future developments, we plan to use the principle of map-matching to improve the matching records GPS map with OpenStreetMap [9]. These statements are then used to automatically calculate an accessibility index for a targeted portion of route. The interpretation of this index will allow us to edit specific OpenStreetMap maps to offer, via a dedicated Smartphone application, a navigation assistance for people with reduced mobility, as well as support for the health and well-being (fall detection [10], calling assistance). Maps are then included into a Geographic Information System (GIS) that allows route determination taking into account the profile in order to give the most accessible route. All these softwares take advantage of open standards and open geodata (OpenStreetMap). In this section, we describe (A) the hardware tools we used for the recording system, (B) the data fusion algorithm and (C) the framework.

A. Hardware tools

The inertial motion units we used is the Galaxy Nexus (Samsung, Seoul, South Corea). It is equipped with three different inertial sensors:

- a 3-axis gyroscope (InvenSense MPU-3050), which measures the angular velocity;
- a 3-axis accelerometer (Bosch BMA220) which measures the linear acceleration;
- a 3-axis magnetometer which measures the ambient magnetic field and can be used to deduce the orientation considering the projection of the Earth one.

In addition, the Smartphone has a GPS function (using GPS SiRF SiRFstarIV GSD4t and GSM network) for the geographical positioning, a camera and a microphone which could be easily used for obstacle reports.

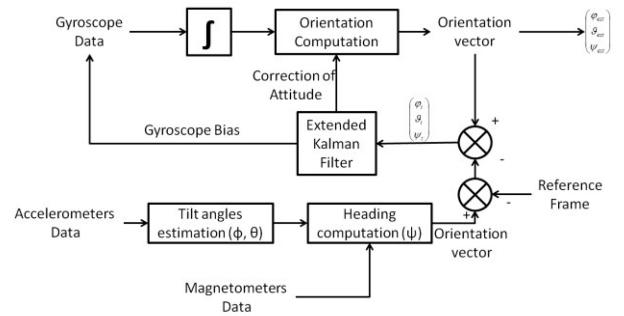

Fig. 1. Computation of the orientation of the phone considering the values of the different sensors [11].

B. Data fusion algorithm

We used an algorithm to merge records from sensors and counterbalance their respective defects. Gyroscopes have a drift due to the integration of the noise. Magnetometers are noisy due to the weakness of the measured signal and have also a longer response time. All these weaknesses can be compensated by using an algorithm of data fusion such as Kalman filtering. Considering the sensors altogether will reduce the noise effect and limit the drift of sensor values. Fig. 1 shows the use of the Kalman filter for the computation of the Smartphone angles.

C. Data processing

All collected data are saved on the Smartphone internal memory. These data are then be extracted and interpreted by both the expert user who made the survey and by an automatic data processing software in a secure server for health data. Thus, the automatic processing offers its interpretation of the route that would be modified and validated by the expert user.

We initially thought to characterize and classify each user movement with the data we obtained through surveys. We have thus constructed a hierarchy of movements (Fig. 2). The purpose of this hierarchy is to classify activities of wheelchair users using signals from the inertial sensors and GPS embedded in the Smartphone in order to identify the best accessibility index of a selected route part. The first hierarchical level is used to determine if there is a movement, then the second level contains three movement categories (fall, propelling and turning) and can lead to activities decisions (alarm or turning). Finally, when propelling is detected, the last three categories represent the index that can be chosen. An algorithm was developed for each decision node. There is thus a data processing in real time using a pattern matching to detect a fall and trigger an alarm. The data are then handled *a posteriori* of the statement of route. This automatic post-treatment course, which follows the framework (Fig. 2), is based on two parameters that indicate a level of accessibility (easy, medium, and difficult) which are (i) the rolling resistance and (ii) the technical/handling.

The wheelchair rolling resistance, representing the force opposite to the motion when a body (such as a ball, tire, or wheel) rolls on a surface, was quantified on the analyses of acceleration/deceleration signals. For settings acceleration/ deceleration, we use a process in several parts. As a first step, we select the time ranges to observe. For this, we chose to differentiate activities by performing a frequency analysis of accelerometer signal peaks.

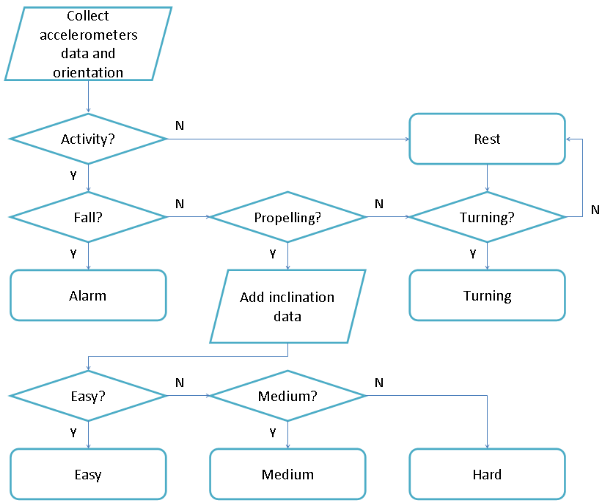

Fig. 2. Flowchart diagram showing the classification process.

We interpret a strong increase of the frequency of these peaks as representative of a simple portion with regard to a more difficult one in which the cycles (given by the action of pushing of the person) are longer. Following this distribution, we calculate the mean, standard deviation and energy according to [9]. The energy for the x-axis Ex is given by the following equation:

$$E_x = \frac{\sum_{j=1}^{N} |f_x(j)|^2}{N}$$

where f_x is the FFT of the considered time frame of the signal and N is the number of samples. It will allow us to detect 3 types of movement: (i) no movement, (ii) normal pace and (iii) steady pace. Furthermore, we shall put then these observations in connection with slopes rose in the same ranges of time to define the difficulty. Uses of mean, standard deviation and energy of acceleration [12] have been shown to result in the distinction between dynamic activities. In the present study, we decided to add the peaks frequency analysis in order to improve this distinction. The mean acceleration value is considered as the DC component of the signal over the window. Standard deviation of the acceleration signal was used to quantify its variability due to the different activities performed. However, what is most needed is the observation of the periodicity which is reflected in the frequency domain through the energy value.

In France, there is a specific law called “law for the equality of rights and the chances, the participation and the citizenship of the disabled persons” [15]. It describes best practices to be adopted for the public space layout. We chose to use these references as basis qualifying the difficulty of a way. For instance, a sidewalk with a crossfall of less than 2° is recommended, which will be taken into account in our decision algorithm.

Regarding the technical/handling, we believe that this is the observation of positioning changes, combined with inclinations measures that will allow us to interpret a difficulty. Furthermore, the break in movement will be visible on the accelerometer signal (and the instantaneous speed). It is also necessary to keep in mind that all of these measures depend on the type of wheelchair used and thus its category (electric, comfort and active). It yields to the construction of a decision tree according to the various observations of signals characterizing an identified situation.

IV. Case Study

In this section, we present a case study designed to evaluate the feasibility of our Smartphone-based approach to assess and improve accessibility for wheelchair users.

A paraplegic male (age: 47; height: 180 cm; weight: 82 kg; lesional level: D6/D7) was volunteered for the present study. He gave his written informed consent to the experimental procedure as required by the Declaration of Helsinki and the local Ethics Committee after the nature of the study had been fully explained.

He is wheelchair dependent, and is using his hand-rim wheelchair propulsion by use of two hands daily travel since 27 years. His style of propelling is *the Semicircular* [13].

The Smartphone has been positioned horizontally on the basis of the wheelchair, face screen upward and the y-axis (Fig. 3) pointing forwards.

The selected route (see Fig. 4) presents in its first selected part (A) an irregular ground, with a significant side slope. This requires the user to propulse more significatively compared to insignificant slope. The second portion (B) of the route has a more regular tarred ground but presents a significant slope (more than 2 degrees) and thus implies to the user to hold the acceleration of his wheelchair. This route was made in the town of Crolles, France.

The various measurements of orientations and slopes made possible the portion segmentation (A, B) due to their significant differences. Then, we extracted, from accelerometers values (Fig. 5), mean, standard deviation and energy for these two separate parts. In the time domain, we noticed that the cycles of pushes were regular and wide on the first part, then irregular and absent on the second part.

We also confirmed it in the frequency domain using the energy. These calculations gave the accessibility index of the route portions.

Fig. 3. Smartphone location and acceleration axes.

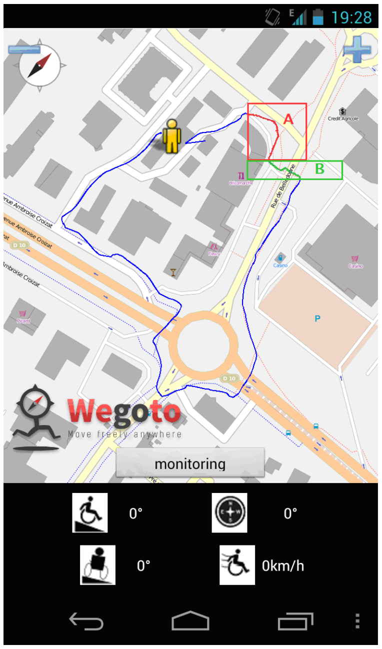

Fig. 4. Screenshot of the geographical pattern (A,B) of the route in the Smartphone application.

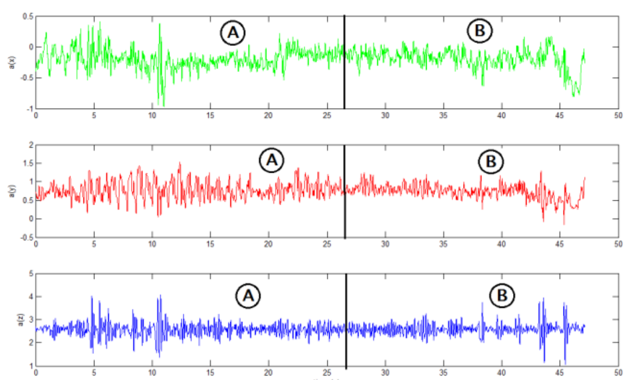

Fig. 5. Corresponding acquired signal for the route. From top to bottom, low-pass filtered accelerometer signal along the x- (resp. y-, z-) axis. Sections A and B of the way are depicted on each signal.

V. Discussion and Conclusion

In this paper, we describe the ability to index route segments with expert user feedback using both obstacle denunciation and sensor measurements. Preliminary results from this case study confirm the validity of our approach to determine indexes of accessibility by combining both our framework and algorithm, and the expert user. However, the results of obstacle denunciation have not been integrated yet. Holone and *al.* [14] studied aspects of personal navigation with collaborative user feedback. They observed that ratings of route segments were not primarily a result of explicit collaboration, whereas absolute obstacle is. We agree with this analysis and our application integrates collaborative denunciation. Future work will consist in classifying these obstacles and consider them into route planning. According to Ren and Karimi [9], we also used sensors data to identify and classify wheelchair movements. We further added inclination data and obstacle denunciation; because we think that rating route segments could be possible using both sensors data from the use of the wheelchair and a subjective confirmation of the expert user. To confirm the preliminary results provided by this case study and to improve the classification, we will extend the study to additional wheelchair users with various profiles and wheelchair settings. Finally, we would like to mention that, interestingly, the Wegoto route record system is not an equipment dedicated and specialized for personal navigation, but is entirely embedded on a Smartphone. Interpreted data are inserted into GIS application that allows users to plan personalized accessible route navigation on Smartphone or computer and then follow this route with the assistance or guidance of the Smartphone application that could bring sensory feedback. To conclude, we believe that the Wegoto system could be used as an innovative assistive navigation system for wheelchair users and ultimately could help to improve their autonomy and quality of life.

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