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Automatic building accessibility diagnosis from point clouds

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ABSTRACT

Building accessibility diagnosis is of high interest especially in case of people with reduced mobility. This paper proposes a methodology for automated detection of inaccessible steps in building façade entrances from MLS (mobile laser scanner) data. Our approach uses the MLS trajectory to automatically subdivide urban point clouds into regular stretches. From each stretch, the lower zone of façade is isolated and selected as region of interest. Points belonging to vertical elements are projected onto a 2D image and steps are detected and classified as inaccessible areas according to the comparison of geometrical features such as height jump, proximity to ground and width, with regulation. The methodology has been tested in four real datasets, which constitute > 400 m of different urban scenarios. Results exhibit a robust performance under urban scenes with a high variability of façade geometry due to the presence of different entrance types to shops and dwellings. Results have been quantitatively evaluated and they show global *F1* value around 93%. Moreover, the methodology is very fast since 100 m are processed in < 2 min.

1. Introduction

Due to the increasing availability of 3D point cloud data and acquisition systems, the automated processing of point clouds has emerged as a research topic of a great interest for communities involved in the study of the as-built environment. The reconstruction of digital 3D urban environments is useful for many applications: large scale city modelling for tourism, gaming or visualization purposes [1,2], road and road markings modelling for road inventory and planning [3,4] or control and construction monitoring [5,6]. Within the broad set of applications requiring 3D data, there are of special relevance those applications which used to use 2D data such as path planning and accessibility analysis.

Accessibility to public spaces, including public buildings, is manifested as indispensable by the *United Nations convention on the rights of persons with disabilities* [7]. Accessibility is of special interest for people with reduced mobility (PRM), being included in this group not only wheelchair people, but also people with intellectual or physical disabilities [8]. It is of high importance the fact of ensuring compliance of the same rights for people with and without reduced mobility [9].

In recent years, PRM's rights have gained strength and better awareness in the society. Governments are echoing about this awareness, cities are being reconstructed according to international standards [10] in order to make them more accessible [11] and legislation is being updated to protect the rights of people with reduced mobility. These actions are not limited to urban zones, many routes in nature environments have been adapted for wheelchairs and tourism companies offer activities for disabled people.

As-built environments in which this transformation has not been applied yet, the integration of people with reduced mobility is promoted with different initiatives. Rashid et al. [12] developed an app for mobile phones to collect and match obstacles on sidewalks. In this way, wheelchair users can evade them changing their route. Virtual reality is created to substitute the access to historical and protected environments that cannot be modified. Within the project PATRAC of European Union, Mancera-Taboada et al. [13] explained the process of converting an urban historical centre (San Martin's Church) from point cloud acquired with a TLS to a digital model that can be virtually visited.

Robotic community also supports solutions to accessibility problems. Non-legged robots have the same mobility problems that PRM, so many solutions for these robots are applied to people through the development of novel platforms to help people climbing stairs. One example of this is presented in [14], in which wheels of a wheelchair were replaced by a self-propelled robot platform, composed of four triangles with wheels geometrically positioned according to steps to be climbed. If the person does not have to sit, an erect platform to detect and climb stairs holding a person has been designed by Luo et al. [15].

In the context of as-built environments, accessibility is usually studied from an indoor [16,17] or from an outdoor point of view [18]. However, transition zones between indoors and outdoors such as

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Table 1
Comparative table of the related work summary.

	Point cloud	Indoor/outdoor	Trajectory information	Door detection	Accessibility
Serna et al. [26]	MLS street	Outdoor	Not necessary	No	No
Hernández and Marcotegui [27]	MLS street	Outdoor	No	No	No
Hammoudi et al. [28]	MLS street	Outdoor	Yes (MLS)	No	No
Schmittwilken and Plümer [29]	TLS facade	Outdoor	No	Yes	Yes (stairs)
Serna and Marcotegui [18]	MLS street	Outdoor	No	No	Yes (curbs)
Díaz-Vilariño et al. [17]	TLS room	Indoor	Yes (buffer)	No	Yes (obstacles)
Zhang et al. [31]	Immediate robot surrounding	Indoor/outdoor	Yes (robot)	No	Yes (stairs & obstacles)
Luo et al. [32]	Immediate robot surrounding	Indoor/outdoor	Yes (robot)	No	Yes (stairs & obstacles)
Oßwald et al. [33]	Immediate robot surrounding	Indoor/outdoor	Yes (robot)	No	Yes (stairs & obstacles)
Present work	MLS street	Outdoor	Yes (MLS)	No	Yes (steps)

building entrances along façade lines is of particular relevance. Building entrances give access to both private and public environments such as shops, offices, and residential buildings. Most of the existing literature addressing the reconstruction of urban façade lines focuses on extracting the contour of the façade [19] or its openings, both doors and windows [20–25] while no literature has been found addressing accessibility to buildings.

The aim of this work is to develop a preliminary automated methodology to analyse building accessibility from urban point clouds. The approach is based on detecting steps, accessibility barriers, in the lower zone of facades that correspond with the zone of the building entrances. The methodology departs from point clouds acquired with a Mobile Laser Scanner (MLS). MLS trajectory is used to segment the point cloud in stretches, from which a region of interest is isolated by the crossing ground plane with the façade plane. At last, the steps in entrances are detected from projecting vertical elements in a 2D image and from comparing specific geometric features with regulations. The methodology is tested in four real datasets and results are quantitatively evaluated.

This paper is organized as follows. Section 2 collects related work about accessibility in urban environments, façade processing and MLS trajectory use. Section 3 presents the designed methodology. Section 4 is devoted to show and discuss the results obtained from applying the methodology to datasets and Section 5 addresses the main conclusions extracted from the work.

2. Related work

Façade detection and modelling is one of the main research topics when processing 3D point clouds of urban environments. In the recent years, several papers address this issue. Serna et al. [26] segment façades in point clouds using raster images and morphological operators. They project the point cloud in two dimensions and create an image based on the height of the points. Pixels with highest variation are classified as trees or facades. To differentiate between them, they use height profiles with attributes such as density, and the number of point. This methodology offers a robust façade segmentation under different conditions of data quality and under the presence of other elements in the environment. A similar methodology is introduced by Hernández and Marcotegui [27]. They analyse the height profile of buildings to isolate 3D city blocks. Hammoudi et al. [28] extract façade lines using MLS trajectory and Probabilistic Hough Transform. A façade line in a street is assumed as a dominant vertical plane in the point cloud oriented in the direction of MLS trajectory. In addition, they separate street façades in clusters associated with each building and produce CAD models. Schmittwilken and Plümer [29] reconstruct 3D façade elements (including doors and stairs) with a methodology based on prior knowledge. They take photos of objects in the facades and use probability density functions to find through a decision tree the 3D elements in a facade point cloud. The stair detection is based on the repetition of parameters of each tread and their perpendicular condition to façade. Once objects are detected, their boundaries are estimated. With this methodology they locate facade elements, estimate dimensions and make an accessibility diagnosis with high precision.

Accessibility diagnosis in outdoors is treated by Serna and Marcotegui [18]. They detect curbs in gradient images obtained after rasterising point clouds. A morphological operator is implemented to complete curbs when they are affected by occlusions in the point clouds. Thus, they obtain a raster image of the ground in which curbs are located. Curbs are considered as architectonic barrier to wheelchairs. This methodology is not applicable to the detection of entrance steps because elevated points of facades would hide coplanar steps when the raster is applied to create gradient images. Operations in urban environments such as the already mentioned façade segmentation [26], accessibility analysis [18], and any operation related to soft mobility are recompiled and proved over a benchmark into the project TerraMobilita/iQumus [30]. Another way to perform accessibility analysis is based on using a buffer. Díaz-Vilariño et al. [17] model indoor point clouds to path planning and, with a 3D buffer representing the dimensions of a person, they plan the shortest route saving obstacles. Instead of buffers, robots can be equipped with laser to calculate routes and analyse their accessibility in real time. For example, the non-legged robot platform developed by Zhang et al. [31] use a 2D laser to detect steps. Humanoid robots need more detailed information about stairs to climb them, so calculate in real time their features (as step number, height, orientation, depths, etc.) with statistics [32] or range images, region growing and planar detection [33]. The limitation of the use of buffers and the performance implemented by robots is that accessibility is locally analysed, that is in areas along their trajectory. Therefore, they do not perform global analysis of the 3D scene.

With regard to previous approaches (summarized in Table 1), the authors present a methodology to automatically detect accessibility barriers in building entrances from Mobile Laser Scanning data. There are not other works that directly treats this theme in a large scale of urban environments. The aim is to work directly in street point clouds, analysing the façade along it and searching steps in building entrances without a previous phase of door/entrance detection. MLS trajectory contributes with information about building and ground distribution and it allows to work directly with street point clouds in an efficient and fast time processing, focusing the detection only in the low zone of façades and combining the processing of large urban point clouds with robot approaches.

3. Methodology

The methodology starts by segmenting point cloud in stretches using the trajectory of the MLS. Then, the region of interest (ROI) is located and isolated from each stretch. Finally, steps are detected in entrances along the façade line and their accessibility is evaluated. Fig. 1 shows the workflow of the methodology.