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Door detection in 3D coloured point clouds of indoor environments

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ABSTRACT

Door detection is becoming an increasingly important subject in building indoor modelling owing to its value in scan-to-BIM processes. This paper presents an original approach that detects open, semi-open and closed doors in 3D laser scanned data of indoor environments. The proposed technique is unique in that it integrates the information regarding both the geometry (i.e. XYZ coordinates) and colour (i.e. RGB or HSV) provided by a calibrated set of 3D laser scanner and a colour camera. In other words, our technique is developed in a 6D-space framework. The geometry-colour integration and other characteristics of our method make it robust to occlusion and variations in colours resulting from varying lighting conditions at each scanning location (e.g. specular highlights) and from different scanning locations. In addition to this paper, the authors also contribute a public dataset of real scenes along with an annotated ground truth. The dataset has varying levels of challenges and will help to assess the performance of new and existing contributions in the field. The approach proposed in this paper is tested against that dataset, yielding encouraging results.

1. Introduction

Door detection is a critical functionality for automatic building scanning systems. For instance, autonomous mobile robots with 3D scanners must obtain precise information on the location and state of doors (open or closed) for robust and safe navigation (e.g. passing through doors) and manipulation (e.g. opening doors by grasping handles) [1,2]. Another application is the automated generation of as-is/as-built Building Information Models (BIMs) from laser scanned data – a process commonly called *Scan-to-BIM* – that requires the segmentation, recognition and precise positioning of all building components, including doors [3]. Door detection has become a necessary task in both of the contexts described above, and can be made even more difficult when clutter and occlusion conditions exist.

While the subject of door detection has been considered in previous research, this paper proposes a unique approach that:

(1) integrates both geometric and colour information, provided by a calibrated set of 3D laser scanner and a colour camera;
(2) ensures reliable colour information by (a) employing a camera flash to reduce colour variations resulting from non-homogeneous illumination conditions experienced at different scanning locations; (b) detecting and correcting specular highlights that often result from the use of the camera flash; and (c) optimally merging colour information by assessing the suitability of each scanning location as regards acquiring the colour of any part of the scene;
(3) presents a general solution for open, semi-open and closed doors, providing the opening angle;
(4) provides the accurate size and pose of each door in the 3D world-coordinate-system; and
(5) is robust to clutter in the room and the resulting occlusions of the walls.

As will be shown in the review of Related Works in Section 2, existing door detection methods have typically considered only one or two of those aspects.

The document is organised as follows. Section 2 provides a review of the state of the art in door detection in 3D environments. Section 3 sets the general context in which the paper has to be considered, in order to enable the reader to fully understand the inputs of our approach. Our proposed approaches for specular highlight detection and correction, in addition to multiple view merging, are described in Section 4. The door detection algorithm is presented in Sections 5 and 6. The experimental work and results are reported in the long Section 7. Section 8 deals with the choice of parameters and Section 9 presents the conclusion and proposes future improvements to the method.

2. Related work

Door detection in reality capture data (i.e. principally 2D or 3D

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Table 1
Categorisation of prior work on door detection in 2D colour and/or 3D data.

Method	Input data		Applicability		
	2D Colour	3D	Closed	Open	Semi-open
[6–8]	X		X		
[4–5,9]	X		X	X	
[10,11]		X	X		
[1,14,18–19]		X		X	
[13]		X		X	X
[2,15–16]	X	X	X		
[12,20]	X	X		X	
Ours	X	X	X	X	X

imaging data) has already been studied for many years. This existing pool of prior research can be divided into two main approaches based on the type of data acquisition method considered: 2D colour imaging (using digital cameras) [4–9] and 3D imaging (using laser scanners or photogrammetric systems) [2,10–20].

Table 1 summarises the literature review by categorising the methods reviewed according to the input data considered and the applicability of the method (closed, open or semi-open doors). As can be seen, no approach has been proposed to date that has been shown to work with closed, open and semi-open doors. Our method, which is appended to the table, aims to achieve this by integrating both colour and 3D data. A detailed state of the art is presented in the following subsections.

2.1. 2D imaging-based methods

2D colour image-based approaches take advantage of the affordability of digital cameras. Furthermore, focusing on colour (instead of 3D) may be justified by the observation that doors are often within the wall plane, where 3D data may not provide significant added value. Yang and Tian [4] and Marwa M. Shalaby et al. [5] propose an approach based on the extraction of lines and corners in the colour image, and the subsequent detection of coherent sets of two horizontal and two vertical segments making up the door frame. Because they rely on the region boundary features (i.e. colour edges) instead of region features (which are more sensitive to changes in lighting and perspective), they are able to detect doors in challenging contexts, such as glass doors. However, when some of the door edges or corners are occluded (e.g. by curtains) both approaches might fail, and be unable to obtain the correct geometric door model. Yang and Tian's method [4] detects doors through the use of region boundary features, but does not distinguish between open and closed doors. This entails a lot of false positives (23%) in some of the challenging scenarios tested.

Andreopoulos et al. [6] present a method based on the two aforementioned approaches, which requires the door to be almost contained within the view of the camera. In addition to detecting the doorframe using geometrical features (i.e. corners and edges) in the image, this approach detects door handles using a learning algorithm trained with a large handle dataset (1500 samples).

In contrast with the earlier methods, Chen et al. [7] detect doors by using a deep learning algorithm based on a convolutional neural network trained with a large number of examples. The problem with the false positives in approaches [4,5,6] is solved here, but a large number of undetected doors (false negatives) appear. The performance of their method is shown only with closed doors, and no results are shown for open or half-open doors. With a somewhat reversed strategy to that of Yang et al. [4], Kim et al. [8] propose an approach that first detects door handles, and then uses them to claim the existence of doors in the scene. The method detects individual vertical lines and, assuming a specific height for the door handle, obtains a RoI and determines the handle type. The authors prevent their approach from being usable to detect open doors.

Finally, Sekkal et al. [9] first generate a rough 3D model of the scene from the detection of vanishing lines in single colour images. This enables them to infer the location of wall planes within which they detect doors by looking for two consecutive vertical lines spaced by a predefined distance. This makes the method simpler but inefficient for the sizes of other doors. While the authors present some results that show that their ad-hoc method is able to detect both open and closed doors (without distinguishing them), it is certainly restricted to a small number of scenarios in which the images acquired actually contain the necessary vanishing lines (i.e. intersections of the walls with the floors and ceiling). This suggests that the method is not easily usable outside the context of corridor environments imaged with a front-facing camera.

The 2D image-based methods reviewed above are prone to produce large numbers of false positives owing to their typical lack of consideration for the structure of the scene (i.e. where walls are) and the presence of many objects that are rectangular like doors (e.g. windows, paintings, radiators, or furniture).

2.2. 3D imaging-based methods

In order to achieve higher precision and reliability, researchers are increasingly considering 3D reality capture sensors, sometimes together with 2D colour images [1,2,10–16,21]. This strategy is motivated by the value of 3D data in the understanding of the structure of the (indoor) environment, but also by the rapidly decreasing price of these sensors.

Goron et al. [10] obtain point clouds from a 2D Laser Range Finder (LRF) on a tilting platform and extract the planes corresponding to closed doors by applying RANSAC (Random Sample Consensus). The main limitation of this technique is that it is based on the strong assumption that door panels do not lie exactly on the wall planes, which is often not true. Using a 2D range camera, Meyer zu Borgsen et al. [11] segment the 3D point cloud of the scene into planar patches using a region-growing algorithm based on point normal vectors. A door is detected if and only if the dimensions of the detected plane match predefined 'standard' dimensions, and the door plane contains a handle. This approach is optimized to detect single-leaf closed doors and also assumes that door panels do not lie exactly on the wall planes.

Using only a depth sensor (i.e. no colour information), Derry and

Table 2
Comparison with the most related 3D imaging-based methods.

Method	(1) Wall detection	(2) Door's contour	(3) Types	(4) Views integration	(5) Multiple doors	(6) Op. angle	(7) Dealing with colour variation	(8) Occlusion	(9) Restriction: Wall/Door colours	(10) Restriction: Door's size
[12]	X	–	O	–	X	–	X	–	–	X
[20]	X	–	O	–	X	–	–	–	–	X
[2]	–	–	C	–	–	–	–	–	–	X
[15]	X	X	C	X	X	–	–	–	X	X
[16]	–	X	C	–	–	–	–	–	X	X
Ours	X	X	C/O/S	X	X	X	X	X	–	X