Geometric Model for Vision-based Door Detection

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***Abstract*—Emerging assistive technologies, such as assistive domotics and socially assistive robots have considerable potential for enhancing the lives of many elderly and physically challenged people throughout the world. Blind and visually impaired people can use these technologies for many tasks recognizing objects, handling various household duties, navigation in indoor and outdoor environments. Door detection is one of the important issues in indoor navigation. This paper presents a novel vision-based door detection technique. It is based on the geometric properties of the 4-side polygon. The efficacy of the proposed method is tested using large database of images with different levels of complexity. The experimental results show the robustness of the proposed method against changes in colors, sizes, shapes, orientations, and textures of the door. Detection rate of 83% with relatively low false positive rate for simple images is achieved. This proposed algorithm is suitable for real-time, portable applications where it only requires one digital camera and low computational resources.**

I. Introduction

Assistive technology can be defined as any software and/or hardware component or system that helps a physically or cognitively challenged person to increase or improve his/her functional capabilities. This technology can allow a frail senior or a person with disabilities to function more independently, thus gaining self respect and greater acceptance in mainstream society. Blind and visually impaired people can use these technologies for many tasks recognizing objects, handling various household duties, navigation in indoor and outdoor environments.

Navigation through unfamiliar places is one of the challenging tasks for blind and visually impaired people. Smart guidance tools can provide solution for this problem. In order to develop an assistive navigation tool for blind and visually impaired people, a number of sub-problems should be solved first. These sub-problems include, but are not limited to, the ability to detect the static and the moving obstacles, the ability to detect the artificial and/or natural landmarks such as doors, corridors, stairs, etc., the ability to plan an optimal path between the current location and the desired destination, the ability to execute this path and finally the ability to monitor it. In indoor environments, doors are considered as one of the most important and basic natural landmarks. They provide a lot of information about the place and help in localization and path planning missions. For this reason, door recognition and detection has been studied for years to maintain accurate, real-time, and robust detection techniques. A number of research works are based on laser, sonar, ultrasound or range-finding sensors. These methods are subjected to noise, uncertainty in measurements, and errors that are caused by such sensory information [1][2][3].

Vision-based detection methods using digital cameras have drawn high attention because of their high perception capabilities, ease of use, and low cost. Many researchers used vision to tackle the problem of indoor landmark detection, i.e. [4], [5], [6], and [7] [8]. They achieved high performance and good results in comparison with other methods that only use sensory information.

There are many challenges encountered when a visual based approach is adopted for door detection. Doors can be found in different colors, sizes, shapes, and textures. Detection methods must also handle changes in illumination and view points that are common in images. In addition, it has to distinguish doors from other indoor components, like windows and paintings, that can cause false alarms.

The current work is part of a project to build a navigation assistive tool for visually impaired people. The tool will be based on a simple digital camera that may be available in portable devices such as Tablets or mobiles gathering information from the surrounding environment of the user. This research focuses on visual door detection methods. It presents a new technique for reliable and robust door identification based on the general geometric features of 4-side polygons. Implementation and testing of the algorithm are done using MATLAB with its large image processing library. An example for test image is shown in Figure 1. It shows a typical indoor environment inside a building where a door, window, and chairs exist.

The reminder of this paper is organized as follows: in section II, an overview about the recent literature on the addressed problem is shown. section III discusses the proposed method for door detection in detail followed by presenting and discussing experimental results in section IV. Finally, conclusion and future work are summarized in section V.

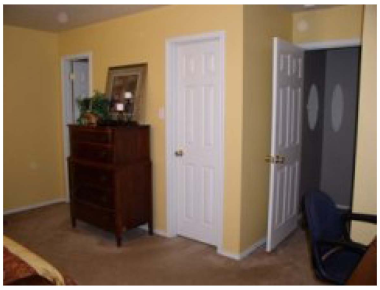
II. Related Work

With the ever-increasing technological advances, researchers have raced to develop smart solutions to help the visually impaired in their routine tasks. And since modern processors are making image processing more and more feasible, many of these solutions have started to rely on computer vision. The majority of recent efforts focus on navigational aids for the blind and at augmenting the blind person's daily experiences [8][9][10].

In recent years, vision-based approaches for door detection have received an increasing amount of attention. In [11], a 3D corridor model was proposed. Door features are considered to be the parallel lines which do not run towards the vanishing point of the corridor. These lines are extracted using a perspective based Hough transformation (PBHT). In [4], a robust algorithm for door detection is proposed. The adopted approach was based on matching detected lines, edges and corners with a general door model. After a preprocessing stage, a Canny edge detector [12] and corner detector were used. Then, a new technique combining edges and corners for door model matching was developed and used. The proposed method was able to distinguish doors from door-like convex objects such as bookshelves and cabinets.

In literature, fuzzy logic was also used in visual door detection methods. The authors in [5] developed a system that is based on a number of designed fuzzy logic concepts. It detected successfully typical doors in different environments in real-time. The system is independent of perspective deformations, color, illumination, and scale changes. However, this method failed in detecting partially occluded doors. It also cannot distinguish doors from rectangular door-like objects such as paintings and windows. Similar work has been done in [13] using almost the same techniques. The algorithm achieved a success of 80% and it also can't discriminate doors from other door-like objects.

(a)



(b)

Figure 1. Examples for test images.

Probability and Bayesian theory are also widely used in the area of object detection. In [14], five features were extracted from both an image acquired by a PC-camera and a sonar sensor. These features are: door width, door frame, depth, door knob, and door states (close/open). Bayesian network algorithm was utilized to calculate the conditional probability of an area. The value of this probability and the entropy identifies weather the area is a door or a wall. The accuracy of this system is not high as it depends on probabilistic concepts and it can only distinguish between doors and wall areas.

The problem of detecting partially occluded doors was tackled in [6]. After detecting vertical lines that form a possible door frame, the size and distances between segments are calculated to decide on candidate doors. Based on five different door features, the candidate door can be selected as a true door. These features were measured using 5 weak classifiers whose performance was improved by using Adaboost training algorithm [15].

The work in [16] represented a door as a rectangular region with proper size and homogeneous color in order to identify it in an image. The suggested method doesn't need the color of the door as a priori knowledge. The researchers used the determinate finite automaton (DFA) to model the detection process. The algorithm goes as follows: motion through the door is detected, edge accumulation is then implemented using Canny algorithm, and finally region growing is applied. This method, however, label all large rectangular objects in the scene as doors. It also fails to identify the door region if no proper motion sequence is perceived. Such technique is not appropriate for accidentally passing users, since motion accumulation needs long monitoring of the scene. Moreover, the techniques that are based on learning classification are not suitable for usage in unknown environment.

III. Proposed Method for Door Detection

In this paper, a novel algorithm is proposed in order to detect doors in different indoor environments. The presented method is based on developing a geometric model for door-like polygons and search for them in the given digital image. Figure 2 is a block diagram illustrating the different stages of the proposed technique.

As a preprocessing step, the RGB image is converted into a gray-scale image and was subject for contrast enhancement. Each of the previously mentioned steps will be discussed in detail in the coming sections.

A. Edge Detection

For image segmentation tasks, edge detection is considered as a basic and essential stage. In order to

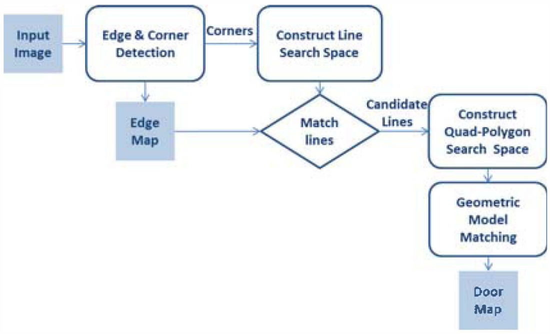


Figure 2. Block Diagram for the Proposed Algorithm

identify certain objects in an image, borders and edges are very important features. When the detected edges are analyzed, they can be very helpful in pattern recognition, corner detection and scene analysis.

Edges occur as a result of changes in intensity. They indicate the boundary between objects and background or between objects and each other. So, basically they can be obtained by calculating the gradients in the image. But this simple technique faces the challenges of noise and weak or faint borders. Operators such as Robert, Sobel, Prewitt or Laplacian filter are not efficient against these challenges [17].

Over the past years, several edge detectors were developed to overcome these problems and to build accurate edge maps. They use techniques of noise reduction as a preprocessing step, i.e. Canny [12], Wavelet transform [18] and SUSAN [19]. Each of these detectors has its advantages and disadvantages. Canny edge detector is the most commonly used detector in image processing area.

In the proposed door detection algorithm, Canny edge detector is used. Afterwards, the edge image is enhanced by increasing the contrast and somehow equalizing the histogram. This step has improved the total door detection rate. Edges can be directly analysed to find straight lines or curves, or, as in our case, used to find corners in the image.

B. Corner Detection

In computer vision, corners are considered very important points of interest. They can strongly infer the content of the captured scene. In door detection techniques, this is a crucial step in many algorithm. A corner is the intersection of 2 edges and its location can be obtained accurately [20]. It provides a two dimensional constraint and can be more reliable than edges and color cues.

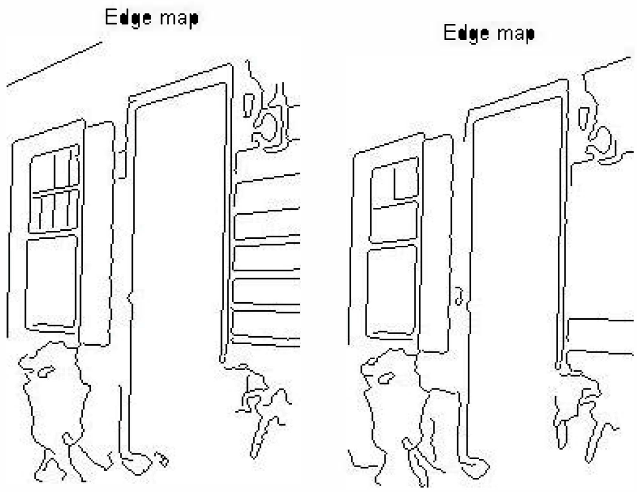
A lot of literature discussed this issue and large number of algorithms were developed. One of the most commonly used corner detectors is Harris Corner detector [21]. It was developed based on Moravec detector but overcoming many of its drawbacks. Newer, more efficient techniques were developed such as FAST corner detector [22]. It depends on machine learning in order to perform fast and high repeatable corner extraction in real-time applications.

The used corner detector in our method is based on global and local curvature properties [23]. With a low computational cost, it is able to detect both fine and coarse features accurately. It depends on Canny edge map to extract the contours and computes the absolute value of curvature of each point on it. Then, it uses an adaptive curvature threshold to remove round corners from the initial list. In comparison with other famous corner detectors, this technique showed very good performance.

C. Corner Reduction

The number of detected corners affects greatly the execution time of the following operations. So, in order to decrease them, an edge preserving smoothing filter [24] was applied to images that have large number of corners (≥ 40). Figures 3 shows the smoothing process done on a door image.

As will be shown in the following section, this algorithm is made to detect doors that are close to the user. Therefore, detectable doors are assumed to have large sizes. According to this, upper or lower door corners can't exist in the middle of the image. To further reduce the number of corner points, the image is divided into 5 equal



(a) Before (b) After

Figure 3. An edge map for an image before and after applying the edge preserving smoothing filter.

horizontal regions and corners that are located in the middle 1/5 of the image were neglected [25].

D. Candidate Lines and Polygon Construction

From previous step, a line was connected between each 2 detected corners and its length was calculated. If the length is $\geq 10\%$ of the height or the width of the image, it got the chance to pass to the next step.

To test if a proposed line between the two corners is a real edge or not, each candidate line was matched with the binary edge map by applying the concept of *fill-ratio* [4]. The fill-ratio is the ratio between the length of the candidate line and the length of the detected edge in the edge map. In our algorithm, a 6x6 window mask was used. A fill-ratio that is greater than 0.8 indicates that this candidate line might be one of the real edges in the original image.

Using the candidate lines that passed the previous step, each three lines were grouped and a fourth line was assumed to close the 4-polygon if it was not found among the candidate lines, and a candidate polygon was formed.

E. The Proposed Polygon Model

As previously mentioned, the aim of the current work is to create a geometric model for doors and compare all detected 4-side polygons in the image with it. This model is a general one that allows different types of doors to be detected. The model is independent on the scale of the door, colors, or occlusions, and it tolerates the parallelism of the door sides for some degree. The proposed polygon model has the following geometric properties:

1) The area of a candidate polygon should be > 10 % of the image, this discards very small and very thin polygons from the test.

2) For a polygon to be a rectangle, the ratio between adjacent sides should be within a given range. So, if s_1 is the length of the horizontal side and s_2 is the length of the vertical one, then:

$$0.25 < s_1/s_2 < 0.8$$

3) At least one corner should be located at the upper 1/3 of the image and 2 corners are in the lower 2/3 of the image. This eliminates windows or paintings from being detected as doors.

4) The sum of angles between the 4 sides of a polygon must be 360 degrees.

5) The angles between all polygon sides are assumed to be 90 degrees, with tolerance of 50% to model the deformation resulted from the acquisition perspective.

6) Opposite sides should have approximately similar lengths, but taking into consideration perspective deformation, the ratio between them can range up to 50%.

7) The larger sides should be the vertical sides.

8) For occluded doors, tests 2 and 7 are not performed, but an edge was assumed between all extreme corners.

Doors are identified out of all detected candidate polygons from the previous step using this geometric model. Algorithm 1 shows the steps of the proposed approach.

Algorithm 1: Proposed Approach

Input : RGB image
Output: Detected door
begin
- **Preprocessing:** Convert colored image into gray level image and enhance contrast.
- **Apply Canny edge detector:** Construct an edge map. Construct corner search space global and local curvature.
- **Match** lines constructed between each two corners and the edge map. Only lines matched above certain threshold is considered for polygon construction.
- **Construct** list of all connected 4-lines.
- **Match** candidate polygons with the predefined geometric door model. Matched polygons are labelled as detected doors.

IV. Experimental Results and Discussion

A. Experiment Setup

The developed algorithm was implemented on MATLAB 7.6.0 and run on Intel Core 2 Duo processor under Windows 7 operating system. In order to test the performance of our algorithm, experiments were executed against challenging datasets of images.

For performance evaluation and comparison with other methods, we used the dataset of [4]. It is composed of 203 images with 210 doors. All test images have the size of 384 x 288 pixels. Images include doors with different colors, textures, viewpoints, occlusions, scales, and lighting conditions. Based on their degree of complexity, the dataset is divided into 3 main subsets of images: simple, medium and complex. For simple images: the captured scenes include only one door with no door-like objects and uniformly colored walls. However, for medium or neutral images, non-uniform backgrounds and more than one door may exist. In complex subset, images include book shelves, chairs, multiple doors, windows and multi-colored walls. Figure 4 shows some successfully detected doors in different environments.

B. Evaluation Metrics

Assessment and evaluation of the performance is a very important aspect after developing a new technique. Among different tools, the *Confusion Matrix* is widely used in machine learning to evaluate the accuracy of classifiers. It analyzes the classification results and defines several terms such as, accuracy, true positive (TP) rate, false positive (FP) rate, true negative (TN) rate and false negative (FN) rate [26]. In this work, detection results were presented according to these terms, especially true positive and false positive rates.
The average processing time (Time) is also considered as an evaluation metric.

C. Experimental Results

Table I illustrates the detection rates for the proposed technique against the simple, medium and complex subsets respectively. N_i and N_d denote to number of images and number of door respectively.

Table I. Door detection results

Dataset	N_i	N_d	TP	FP	Time
Simple	55	55	100%	3.6%	0.225 s
Medium	90	94	82.7%	17.3%	0.6 s
Complex	57	63	68.2%	31.7%	9.8 s

(a) Simple

(b) Medium

(c) Complex

Figure 4. Door Detection Results.

As shown in Table I, all doors in the simple subset were successfully detected with a true positive rate of 100%. This rate is less for the medium subset where only 77 out of 94 doors were detected. For the complex subset, true detection rate achieved about 68%. There are also false positive detection in all subsets. That is, detecting non-door objects as doors. It is also minimum in simple images and increases with the increase of complexity.

In terms of the average processing time, the algorithm needed 0.2 s to detect doors in simple backgrounds, 0.6 s for medium complexity scenes, and 9.6 s for complex images. These results infer that the algorithm is highly dependent on the level of complexity of the captured scene where it showed the best performance against simple images.

Doors were sometimes missed in experiments because of the following reasons:

1) Some images got no enough edges.
2) Deformation of doors is out of specified range.
3) Two detected corners are not overlapped but slightly spaced.
4) Lightening extreme changes (spot light).

V. Conclusion

In this paper, a novel algorithm for detecting door frames in indoor environments was presented and discussed. the proposed algorithm is based on detecting a number of geometric features for each 4-side polygon in the image and compare them with a predefined door model. The algorithm was implemented and tested against different backgrounds in different environments. It showed an average detection rate of 83.6%.

It demonstrated an independence on color, image perspective, lightening, occlusion, and texture of the door. It shows high accuracy in images with complexity degree simple or medium. It was also able to detect doors in some complex scenes. The time consumed in this detection method depends on the number of detected corners in the first step. Accordingly, for simple images it has a fast performance unlike for more complex images.

On the other hand, the algorithm was not designed to differentiate between doors and elevators/door-like objects. In addition, it shows a false detection rate of approximately 25 % of the test image. It also depends strongly on the edge detection stage, therefore if all edges in the scene were not detected efficiently, the door might not be detected. For complex scenes, the algorithm takes large execution time. The door state in our algorithm was not defined. The same door can be detected several times in the same scene, however this is not a problem in our application.

Our future work is to detect signs and tags on or beside the door. This will help to identify whether this door is an office, an elevator, a WC or an emergency exit. This information would help in the navigation mission greatly by finding the destination.

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References

[1] P. Carinena, C. V. Regueiro, A. Otero, A. J. Bugarin, and S. Barro, "Landmark detection in mobile robotics using fuzzy temporal rules," *IEEE TRANSACTIONS ON FUZZY SYSTEMS*, vol. 12, pp. 423–435, 2004.

[2] Y. Priyadarshana and G. Wimalaratne, "Sensing environment through mobile: A personalized wearable obstacle detection system for visually impaired people," *International Journal of Soft Computing and Engineering*, vol. 3, no. 6, pp. 81–88, Jan. 2014.

[3] M. R. B. SELAMAT, "A blind spot detection system based on ultrasonic sensing," UTM, Tech. Rep., 2014.

[4] Y. Tian, X. Yang, and A. Arditi, "Computer vision-based door detection for accessibility of unfamiliar environments to blind persons," in *Proceedings of the 12th International Conference on Computers Helping People with Special Needs*, ser. ICCHP'10. Berlin, Heidelberg: Springer-Verlag, 2010, pp. 263–270. [Online]. Available: http://dl.acm.org/citation.cfm?id=1880751.1880796

[5] R. Munoz-Salina, E. A. Garcia-Silvente, and A. Gonzalez, "Door-detection using computer vision and fuzzy logic," *WSEAS Transaction on Systems*, vol. 10, pp. 3047–3052, 2010.

[6] Z. Chen and S. T. Birchfield, "Visual detection of lintel-occluded doors from a single image," *IEEE*, 2008.

[7] E. Jauregi, E. Lazkano1, J. M. Martinez-Otzeta, and B. Sierra, "Visual approaches for handle recognition," 2006.

[8] M. S. Güzel and W. Zakaria, "A hybrid architecture for vision-based obstacle avoidance," *Advances in Mechanical Engineering*, vol. 2013, no. 11, November 2013.

[9] N. N. Saeed, M. A.-M. Salem, and A. Khamis, "Android-based object recognition for the visually impaired," in *IEEE International Conference on Electronics, Circuits, and Systems*, Abu Dhabi, UAE, December 8-11 2013.

[10] D.-M. Tsai, H. Hsu, and W.-Y. Chiu, "3-d vision-assist guidance for robots or the visually impaired," *Industrial Robot: An International Journal*, vol. 41, pp. 351–364, 2014.

[11] G. Olmschenk and Z. Zhu, "3d hallway modeling using a single image," June 2014.

[12] J. Canny, "A computational approach to edge detection," *IEEE Transaction Pattern Analysis and Machine Intelligence*, vol. 8, no. 6, pp. 679–698, November 1986.

[13] J. Hensler, M. Blaich, and O. Bittel, "Real-time door detection based on ada boost learning algorithm," in *Research and Education in Robotics - EUROBOT 2009*, ser. Communications in Computer and Information Science, A. Gottscheber, D. Obdržálek, and C. Schmidt, Eds. Springer Berlin Heidelberg, 2010, vol. 82, pp. 61–73. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-16370-8_6

[14] J.-S. Lee, N. L. Doh, W. K. Chung, B.-J. You, and Y. I. Youm, "Door detection algorithm of mobile robot in hallway using pc-camera," *PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON AUTOMATION AND ROBOTICS IN CONSTRUCTION*, pp. 456–460, 2004.

[15] Y. Freund and R. E. Schapire, "A short introduction to boosting," *Journal of Japanese Society for Artificial Intelligence*, vol. 14, pp. 771–780, 1999.

[16] H.-Q. Zhang, L.-H. Dou, and J. Chen, "Door detection without apriori color knowledge," *Proceedings of the 17th World Congress, The International Federation of Automatic Control, Seoul, Korea*, 2008.

[17] M. B. A. Haghighat, M. Geravanchizadeh, and E. Namjoo, "A region-based edge detection technique for noisy images," *IEEE*, 2009.

[18] M. A.-M. Salem, *Medical Image Segmentation: Multiresolution-based Algorithms*. VDM Verlag, Dr. Mueller, 2011.

[19] S. M. Smith and J. M. Brady, "Susan—a new approach to low level image processing," *Int. J. Comput. Vision*, vol. 23, no. 1, pp. 45–78, may 1997. [Online]. Available: http://dx.doi.org/10.1023/A:1007963824710

[20] E. Mair, G. D. Hager, D. Burschka, M. Suppa, and G. Hirzinger, "Adaptive and generic corner detection based on the accelerated segment test," 2010.

[21] C. Harris and M. Stephens, "A combined corner and edge detector," in *Proceedings of the 4th Alvey Vision Conference*, 1988, pp. 147–151.

[22] E. Rosten, R. Porter, and T. Drummond, "Faster and better: A machine learning approach to corner detection," *Pattern Analysis and Machine Intelligence, IEEE Transactions*, vol. 32, pp. 105–119, 2010.

[23] X. Chen He and N. H. C. Yung, "Corner detector based on global and local curvature properties," *Optical Engineering*, vol. 47, no. 5, pp. 057 008–057 008–12, 2008. [Online]. Available: http://dx.doi.org/10.1117/1.2931681

[24] N. Nikolaou and N. Papamarkos, "Color reduction for complex document images," *Proceedings of the 17th World Congress, The International Federation of Automatic Control, Seoul, Korea*, 2009.

[25] M. Moreno, S. Shahrabadi, J. JosÃ©, J. du Buf, and J. Rodrigues, "Realtime local navigation for the blind: Detection of lateral doors and sound interface," *Procedia Computer Science*, vol. 14, no. 0, pp. 74 – 82, 2012, proceedings of the 4th International Conference on Software Development for Enhancing Accessibility and Fighting Info-exclusion (DSAI 2012). [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1877050912007715

[26] H. Hamilton. (2012, June) Course notes: Confusion matrix. [Online]. Available: http://www2.cs.uregina.ca/~dbd/cs831/notes/confusion_matrix/confusion_matrix.html