Door Detection Algorithm Development Based on Robotic Vision and Experimental Evaluation on Prominent Embedded Systems

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Abstract. Accurate and reliable door detection comprise a critical cornerstone for nowadays robots aiming to offer advanced features and services. At the same time, the range of robotic platforms for indoor scenarios is continuously expanding, emphasizing on the use of low cost, versatile components able to boost widespread use of such solutions. However, respective door detection algorithms have to address specific challenges such as, not relying on specialized expensive sensors, being able to offer robust and accurate operation based on commodity cameras as well as efficient execution on low resource embedded systems. Driven by aforementioned observations in this paper the design and development of a practical and reliable door detection methodology is presented based solely on typical off the shelf web-camera, while posing minimum requirements on the height or angle it is mounted. Furthermore, a critical contribution of this paper is the experimental evaluation of the developed algorithm on popular embedded systems that are based on Micro Controller Units (MCUs) commonly found on contemporary robotic platforms.

Keywords: Robotic vision · Door detection algorithm · ADLs · Embedded systems · Experimental evaluation

1 Introduction

During the last few years Robots and Robotic Platforms of various forms and types have been increasingly utilized in indoor and everyday life applications. This observation is further emphasized by the high interest respective research and development efforts have attracted by both academia and industry [1, 2]. A key reason for this continuous expansion of robots' use in common home environment relates to the drastic advancements in various research and engineering domains, effectively enabling, even low-end, robots to perform complex tasks. Furthermore, advancement in embedded systems also come to play promoting the development of low cost yet, highly functional, versatile and expandable programmable platforms.

At the end of the day, any complex operation a Robot aims to offer is based on specific fundamental, for a human being, operations which must be performed efficiently, accurately and with minimum false positives/negatives. Such a characteristic

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example is the capability of door detection. The importance of the door as a specific object is highlighted by the fact that it is involved in a wide range of everyday life activities of a person in an indoor environment even if, in some cases we don't notice of it because respective detection is taken for granted [3, 4]. Specifically, as a stationary object it comprises a critical landmark in any indoor environment. The position of various other objects or even the distance from a wall can be expressed in relation to a door since a door a steady, non-movable object with constant characteristics. Even more, as a mobile object (a door can open, close or reside in a range of degrees of openness), the door can be related to a wide range of activities, such as a person entering or exiting a room. At the same time an open door has different characteristics that should be taken into consideration. For example, when a robot is moving, an open door can be perceived as an obstacle or when a door is open it can pass through whereas if it is closed it cannot etc. Therefore, door detection is a crucial elementary operation for a range of complex robotic operations pertaining to Activities of Daily Life (ADLs) detection, safety and navigation [5, 6].

However, developing accurate and practical vision based door detection solutions proves to be a highly challenging task, especially when assuming zero or minimal a priori knowledge of the specific door and assumptions regarding the height and/or angle of the camera. A major reason for this challenge relates to the wide range of different and diverse types of doors encountered in various environments. Specifically, doors can have different poses, lighting situations, reflections and different specific features. Furthermore, great challenges steam from the fact that, in practical scenarios, it is common that a camera is unable to capture the whole door in a single image as well as the fact that even small differentiations regarding the distance from the door or/and the angle of the camera or the door (e.g. when a door is open) can lead to substantially different results [7].

Focusing on real deployment and operation, another aspect that is often omitted in relative efforts concerns the experimental evaluation of the execution of the detection algorithm on prominent processing units found on robots nowadays. Since one of the cornerstone objectives of such platform is power conservation, respective processing components offer relatively limited resources also aiming to contribute to minimization of energy expenditure. Therefore, it is critical to compare and objectively evaluate the efficiency and performance of any such proposed solutions to low power processing elements mainly encounter at the embedded systems domain [8].

Driven by the challenges and needs identified above the contribution of this paper is twofold. On one hand the design and development of a door detection algorithm focusing on efficiency, feasibility, low cost/complexity and resource expenditure is presented. On the other hand, a hands-on experimental evaluation is undertaken integrating and executing the proposed algorithm on prominent diverse processing environments typically encountered in contemporary robotic platforms.

The rest of the paper is organized as follows: Sect. 2 offers important background information and relative literature review. Section 3 main objective is the presentation of the design and development effort regarding the proposed algorithm, while Sect. 4 presents and analyses the efficiency of the algorithm. Section 5 focuses on the experimental performance analysis with respect to real embedded systems used in Robots and finally Sect. 6 concludes discussing the most important aspects of this work.

2 Background Information

Door detection methods have attracted considerable research interest highlighted by the wide range of different approaches proposed. The most prominent methods focus on feature extraction of the doors through an image. Such a vision-based system approach for detection and traversal of doors, is presented in Eberst et al. [9]. Door structures are extracted from images using a parallel line based filtering method, and an active tracking of detected door line segments is used to drive the robot through the door. Thus a limitation identified is that the algorithm's robustness is achieved by requiring consistency of pose estimates over time and motion of the robot.

Another method is proposed by Kragic et al. [10], where the main characteristic is that the doors are not really identified since they are imprinted on a known map. The main focus is on identifying rectangular handles for manipulation purposes. The handles are identified using cue integration by consensus. Consequently, the overall approach omits several practical and challenging realistic parameters.

Another approach widely considered, addresses the detection of doors challenge, through computer vision. Such a method was presented in 2005 from Seo et al. [11] which focused on extraction of features such as edges based on a different proposal for the vision-based door displacement behavior. In this case, the Principal Component Analysis pattern finding method is applied on images taken by the camera to identify the door.

The same year, the Muñoz-Salinas et al. [12] proposed a visual door detection system that is based on the Canny edge detector and Hough transform to extract line segments from images. Then, features of those segments are used by a genetically tuned fuzzy system that analyzes the existence of a door.

A door identification and crossing approach is also presented the 2002 in Monasterio et al. [13], where a neural network based classification method was used for both, the recognition and crossing steps. More recently, the year 2007 in Lazkano et al. [14], a Bayesian Network based classifier was used to perform the door crossing task. Doors are assumed to be open, the opening is identified, and doors crossed using sonar sensor information.

The aforementioned methods have exhibited satisfactory results, on the supposition that there aren't other objects like a door such as cabinets or libraries with the same rectangular shape. Following a respective analysis, three main challenges can be identified. The first problem is the shape because the rectangular shape of door is quite similar to other objects such as cabinets or bookcases. A second problem is the limited number of features which can be extract from a door. Finally, the third problem are the different ornamentals which can be found on different doors. All these challenges are adequately addressed by the proposed methodology focusing optimum tradeoff between accuracy and resource conservation.

Additionally, apart from the challenges posed by the characteristics of a specific door, another issue concerns the identification of the same door considering differences of visual angle views received frames (video). Such differences are created when the robot is in motion, or the door is in motion (due to opening or closing) or there are different lighting conditions etc. It is easily understood that in such cases it is considerably more difficult to identify a door compared to a static image.

3 Proposed Door Detection Algorithm Design

The proposed methodology of object detection is based on Haar-like features method [15]. The specific technic although well-known, it is typically used to identify objects characterized by high number of key features thus enabling the effective training of the algorithm. Such identification objects include faces, cars, bicycles, etc. Furthermore, aiming towards enhanced applicability the proposed approach focused on limited number of positive images (approximately 400) in contrast to at least 1500 typically required by relative approaches. In the same context, doors considered, have different characteristics on the decorative architecture. Consequently, algorithm training is stressed, because every door have different inherent characteristics (Fig. 1). In the context of the proposed technique various image processing algorithms (Fast, LBP, GBA) has been tested belonging to the Adaboost algorithm family.

Fig. 1. The differences in characteristics on the decorative architecture in each door

After several experiments, the operations of the proposed training algorithm set were segmented by using two techniques. A critical step of the followed approach concerns the handling of the photos' format, where negative photos are transformed into grayscale, whereas positives are transformed from "jpg" to "bmp" and retained in RGB forma. Following this transformation, the final classifier is extracted which proves to be highly efficient and accurate while yielding a low number of false positives recognitions.

The overall proposed procedure is depicted in (Figs. 2 and 3) and here a brief elaboration of each step is indicated.

The first stage comprised by the following steps. The first step concerns the conversion of all positive photos in "bmp" files (uncompressed) and RGB color format. In the second step all positive photos are converted to the same size while in the third step all of the negative photos are converted into in Greyscale and "jpeg" file format to save space.

In fourth step, Haar training is applied based on University of Auckland in New Zealand tools [16]. Specifically, manual annotation is conducted of positives photos while the "bg" creator tools is used for negatives photos. On every photo, annotation is made in two places (Fig. 4), one concerning the whole door contour and one focusing on the knob, and thus creating a respective file with the coordinates of annotated doors.

In fifth, and final, step for this first stage, a vector of positive images is extracted by the aforementioned file. Following the completion of the first stage of our method, as a 2nd stage we transfer the images (positives and negatives), including also the created

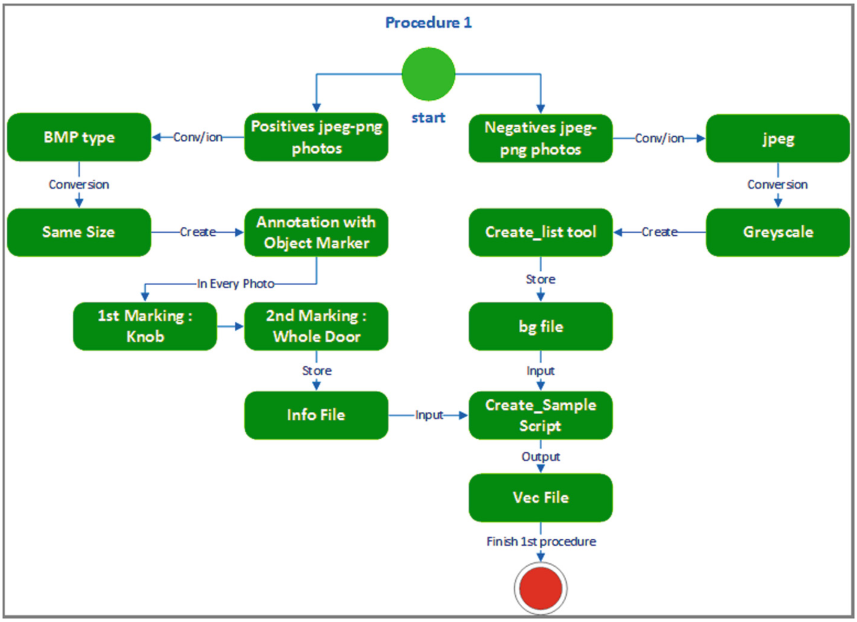

Fig. 2. 1st part of our procedure

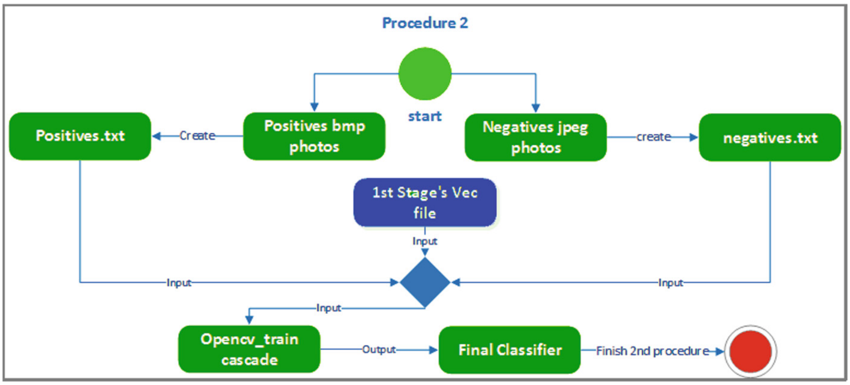

Fig. 3. 2nd part of our procedure

vector file in another Haar training set based on [17]. Finally, the positive and negative text files are created, and a training commences comprised by just 15 stages, compared to the classical automated training method requiring 22 to 25 stages. It is noted that the automated training approach even with the increased number of stages did not yielded the anticipated efficiency.

As a critical advantage of the proposed methodology, it is emphasized that while typically this process requires a three day to one-week time period, based on the

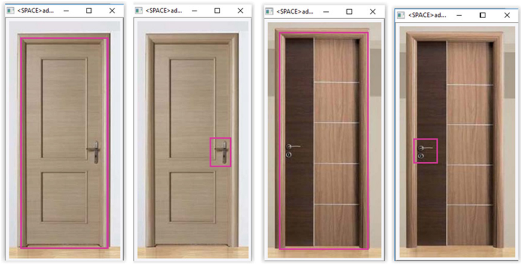

Fig. 4. Positive photos annotation

proposed approach the training lasted only approximately 45 min. It is noted that these measurements are based on experiments made on an 8 GByte RAM, 2 Core, i7 Laptop computer.

4 Evaluation of Door Detection Accuracy

For algorithm's testing and from hardware side, we used a laptop computer with i7 1st generation's processor, 8 GByte RAM DDR3 and a Logitech HD 1080P webcam. The operating system considered was the well-known Ubuntu 14.04 LTS Linux distribution, with OpenCV and Python 3.2. The implementation of the methodology was based on Yann KOËTH [18] program, from GitHub (Fig. 5).

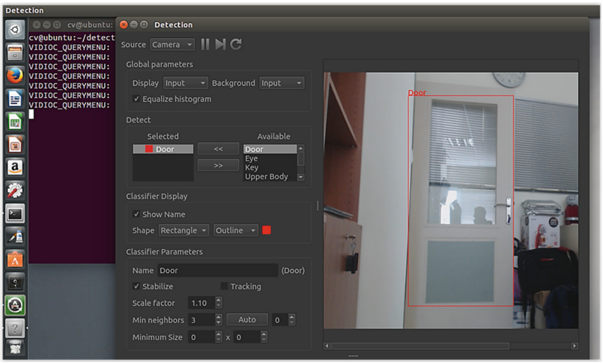

Fig. 5. Yann KOËTH detection user interface

The experiments performed considered a wide range of different interior doors. Both natural day light and artificial lighting scenarios were included as well as cases during afternoon with limited lighting and finally cases where obstacles were placed in front of the doors.

Also, a group of tests focused on different camera's tilting, ranging from 45° to 90°. Specifically, the tests which we made are described below:

(a) The first test considered ten (10) different doors with the camera mounted in front and perpendicular to them and with natural daylight. In Fig. 8, we see the results from some doors with the camera in frontal side (90°), where there was 100% successfully recognition.
(b) The second test considered fifteen (15) different doors with the camera mounted in 45° to them and with natural daylight. In Fig. 9, we see the results where there was 80% successfully recognition. At this point, it is noted that with orientation greater than 5°, the recognition was unreliable.
(c) As a third test we performed the recognition with obstacles, in a sample of six (6) doors in which the obstruction overlapping the door incrementally reached up to 50% of the door area. The recognition proved quite reliable in all cases since positive identifications were reported in all cases.

Below in Fig. 6 we present the results from our tests.

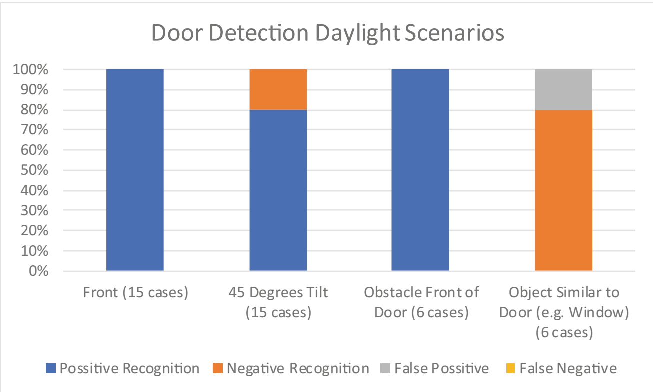

Fig. 6. Door detection test results in daylight scenarios

Explanation of types of recognition in above figure:

(a) With terminology *Positive,* we mean the recognition of the door by the algorithm.
(b) With terminology *Negative*, we mean that is not recognizing the door by the algorithm where there is a door.
(c) With terminology *False Positive* recognition, we mean the false recognition of a door by the algorithm where there is no door.
(d) With terminology *False Negative* recognition, we mean when a positive sample is misspelled as a negative (In our tests there was no such recognition).

In Fig. 7 indicative examples are depicted for the daylight experiments conducted.

The proposed approach provided quite reliable with respect to different lighting conditions since, considering the same test set, the same results were extracted considering either artificial lighting or even during afternoon with low natural light (Fig. 8).

Fig. 7. Recognition's tests indicative examples

Fig. 8. Recognition considering lit room and afternoon with natural light

Concluding it is emphasized that a negligible percentage was measured regarding false negative (i.e. a door identification was missed) while a 20% false positives was recording where positive recognition events were triggered for a shape which was not a door.

5 Experimental Evaluation of Algorithm Efficiency on Embedded Systems

Aiming to propose an efficient and practical approach with respect to nowadays Robotic systems, the detection algorithm is also tested in two embedded systems. The first system was a Raspberry pi 3 m while the second system was the PicoZed development platform from Xilinx based on the ARM Zynq processor. Both of them, although offering considerable less resources compared to an i7 based computer, they comprise prominent solutions for Robotic systems due to their low power, size, and cost characteristics combined with high degree of versatility and configurability. Of course, the same camera hardware is used in all recognition experiments.

The first and most important observation concerns the fact that there was no degradation of the recorded identification accuracy, due to the low computational resources. In fact, the results extracted concerning the identification performance are the same as the ones extracted using a resource rich computational environment.

The second observation concerns the algorithm's execution delay, where a relatively limited reduction of frame rate is observed. This is anticipated, due to the limited processing capability of the embedded hardware, yielding an output rate of the processed frames below 22 fps for Raspberry and 19 fps for PicoZed compared to ~30 frames per second recorded using the i7 laptop indicated earlier (Fig. 9).

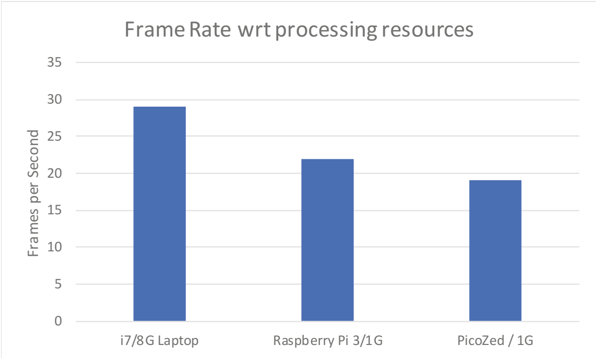

Fig. 9. Algorithm execution performance wrt prominent embedded platforms

6 Conclusions

A wide range of basic yet critical operations of modern robotic systems are based on accurate and efficient object recognition algorithms. Focusing on indoor Robot navigation and movement Door Detection comprises a critical objective due to role of a door as a moving as well as stationary area landmark. However, it is imperative that any relative methodology and algorithm takes into consideration the realistic processing capabilities of Robotic systems in order to offer a viable and realistic solution. In this paper authors address the challenge of Door Detection from multiple perspectives. On one hand a complete methodology is presented extending well established approaches offering critical advantages concerning resource conservation. In parallel proposed methodology is evaluated and validated as highly accurate and reliable in a wide range of test-objects as well as operational conditions. On the other hand, respective solution has been ported and evaluated in the context of prominent embedded systems encountered in Robotic platforms. Respective evaluation validated that the presented methodology remains highly reliable even in low resource hardware infrastructures and only a slight degradation is observed in frame rate which has zero effect on identification accuracy and robustness.

As future work, authors plan to extend the capabilities of the developed methodology so as to be highly efficient while the robot is moving and being able to identify the percentage a door is open.

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Open Data Access. All images used as training and test sets throughout this paper are owned by the Embedded System Design and Application Lab (http://esda-lab.cied.teiwest.gr). The training/test sets are offered to the research community for open access (https://github.com/ESDA-LAB/Door-detection) under the requirement to reference properly the current paper whenever they are published, presented or announced.

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