Door-detection using computer vision and fuzzy logic *

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Abstract: One of the existing methods to perform the navigation in indoor environments consists in using a topological map in combination with appropriate behaviours. Door is a very common element in this kind of environments and its detection can be very useful either to know the environment structure, to aid an exploration task and to perform an efficient navigation. In this work we use the information provided by the camera of a robot to assign a belief degree on the existence of a door in it. The segments of the images captured are analyzed in order to detect those segments that could belong to the frame of a door. Several fuzzy concepts are defined to lead the search process and find different cases in which doors can be seen. Features of the segments like size, direction or the distance between them are measured and analyzed using fuzzy logic in order to establish a membership degree of the segments on the defined fuzzy concepts. The proposed method has proved to successfully detect typical doors of indoor environments under strong perspective deformations using grey-level images. Furthermore, according to our experimentation it is suitable for real-time applications in mobile robots.

Key-Words: Mobile robot, Robot vision, Robot navigation, Perceptual fuzzy models, Computer vision.

1 Introduction

In the autonomous robot area, a robot must be able to extract useful information using its sensorial system despite the presence of noise and imprecision in the sensor data. This information must be adapted to aid the robot to perform the task it has assigned.

In indoor navigation, the robot must reach a destination point departing from an initial position. One the approaches to solve this task consists in using a topological map [13] and a behaviour-based approach [1, 2, 4]. For that purpose, it is necessary to have perceptual models that allow the robot to detect distinguished places of the environment either to create a topological map or to navigate properly in it. In previous works [3] we have developed a fuzzy perceptual model based on ultrasound that establishes a belief degree on the existence of typical places of indoor environments like walls, corners, corridors or doors. This model uses fuzzy logic both to design the concepts and to manage the imprecision and vagueness. The aim of this work is to use the information provided by the camera placed on our Nomad 200 mobile robot to establish a new belief degree on the existence of doors in indoor environments. In future works this belief degree, obtained using vision, will be integrated with other values that the robot can obtain applying the fuzzy perceptual model previously developed.

The door-detection problem using vision has been previously treated using different approaches. In the work developed in [7], a pair of neural networks are used to detect door in color images. One of the nets is employed to detect the lateral and vertical bars of the door and the other to detect the corners. The nets receive as input subwindows of the image of size 18x18 centered in each pixel with the hue and saturation components. After the classification process, an analysis of the components found is performed to detect if there is any door present in the image. The system has the disadvantage of requiring a high computational effort in processing each image. Furthermore it can not detect fully opened doors and it is dependent on the color of the doors used for training.

Based on a functionality-based approach, a method for generic object recognition used for robot navigation is presented in [10]. Other related works use neural networks in order to classify the segments of the doors [6], add information provided by other sensors [11] or focus on the door-detection problem in corridors [12].

In this work we present a new method for visual door-detection based on the extraction of the segments of the image and the definition of several fuzzy concepts. The segments of the images are analyzed in order to detect which of them belong to the frame of a door. The fuzzy concepts *Simple Frame* (SF) and *Double Frame* (DF) are defined to differentiate those situations in which the frame edges of a door can be seen. Features of the segments like size, direction or the distance between them are measured and analyzed using fuzzy logic in order establish a membership degree on the defined fuzzy concepts. In a first step, the edges of the image are extracted using Canny [5], then the Hough Transform [9] is calculated to extract the

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main segments of the image [8]. Using fuzzy logic, the relationship between the segments is measured to detect the presence of the concepts SF and DF. The method is able to detect typical doors of indoor environments under variable illumination conditions in grey-level images. The method can detect the doors under strong perspective deformations caused by the two degrees of freedom (DOF) allowed for the camera of our robot. Furthermore, according to our experiments it is suitable for real-time applications in a mobile robot Nomad 200 equipped with a vision system and a laptop.

2 Visual door-detection

In this section it is explained how the visual door-detection process is performed. Our approach is based on the detection of the segments of the image that form part of the frame of a door. Therefore, we look for those segments that form the frame of a door.

When the frame of a door is captured in a image, it can form two edges with its surrounding. On one hand, there is the edge formed by the frame and the wall. On the other hand there is the edge formed by the frame and either its leaf (if their colors are different) or the gap of the door (if it is open). Therefore, based on our experience we have identified two possible cases in which the frame of a door can be detected. First case, only one of the edges of the frame is present. This case has been formally defined by the fuzzy concept *Simple Frame* (SF). Second case, both edges of the frame are present. This case has been formally defined by the fuzzy concept *Double Frame* (DF). Both cases can better been understood by seen Figure 1. Although Figure 1 shows the ideal case in which the segments of the frame are completely vertical and horizontal, it only happens when the camera is completely in front of the door and aligned with the floor. Nevertheless, due to the two DOF that provides the pan-tilt unit over which is placed our camera, the segments will normally appear in different directions and with a different sizes. Our aim is to detect the doors despite these perspective deformations and scale changes.

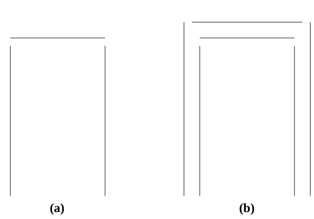


Figure 1: Fuzzy concepts (a) SF and (b) DF

The fuzzy concept *Simple Frame* is used to represent an edge of the frame of a door. It is defined as a pair of vertical segments (belonging to the lateral of a door) joined in its upper part to a horizontal segment (belonging to the upper part of a door). Schematically an SF can be represented as shown in Figure 1(a). In other occasions, when we look at a door it is possible to detect its two frame edges. We model this situation by the fuzzy concept *Double Frame* (DF) that is schematically represented in Figure 1(b).

The detection process starts applying the Canny edge detector [5] on a grey-level image. The result is a binary image $I(x, y)$ where pixels labeled as *true* belong to edges in the original image. In order to ease the notation we assume that the dimensions of the image is NxN. The edge pixels detected are used to compute the Hough Transform [9] and then the segments of the image are extracted [8]. Let us denote the set of extracted segments by $S = \{S^0, S^1, ..., S^n\}$. Each segment is composed by two points $S^i = \{p_0^i, p_1^i\}$, where $p_j^i = (x_j^i, y_j^i)$ (coordinates in the image plane). When the segments are extracted the analysis to detect possible doors is performed. The first step consist in a classification of the segments in order to reduce the computational effort required for the posterior analysis. The classification process is explained in the next section.

2.1 Segment classification

The total number of extracted segment could be high and it is desirable to reduce it and select only those that could belong to the frame of a door. Therefore, an initial classification is performed. Two classes of segments are of interest, the vertical segments that belong to the lateral part of a frame and the horizontal segments that belong to the upper part of the frame. Nevertheless, it is important to remember that we wish to detect the doors under the perspective deformations that makes the segments appear not completely vertical neither horizontal. Therefore, we have defined two fuzzy concepts to represent both cases and manage this deformations. The fuzzy concept *Vertical Segment* (VS) regards to those segments that belong to the lateral frame of a door. The fuzzy concept *Horizontal Segment* (HS) regards to those segments that belong to the upper part of the frame of a door. Both concepts are defined using fuzzy logic as explained below.

If we analyze indoor environments we could see that doors are relatively tall objects. Therefore their vertical segments (VS) are projected with a large and relatively vertical aspect. On the other hand, the horizontal segments of the upper part of the frame (HS) can be projected in a wide range of sizes and orientations around horizontal direction. Nevertheless, we can assume that they are in upper positions of the image. Direction, size and height features of a segment S^i are used to establish its membership degree to the fuzzy concepts VS and HS.

Direction is measured using the linguistic variable $Direction(S^i)$ that has the three possibles values showed in Figure 2(a). The input value for this variable is the direction of the segment calculated by $directionS(S^i)$ as expressed in Equation 1. The variable $directionS(S^i) \in [0, 1]$ is equal to 1 when the angle between the segment S^i and the x axis of the

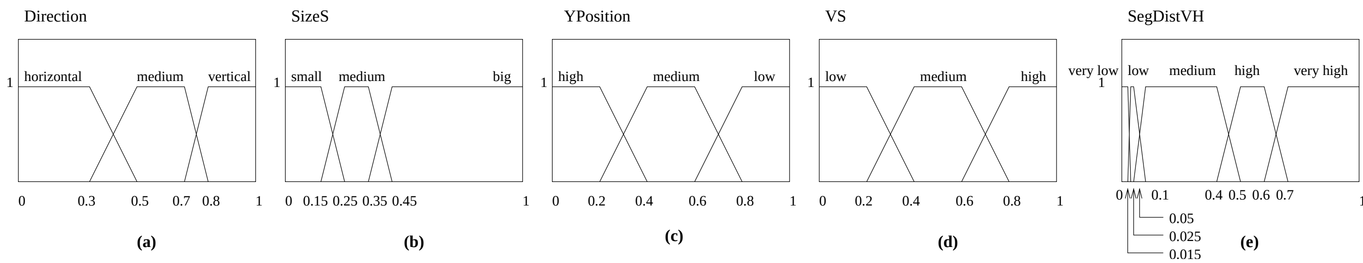


Figure 2: Fuzzy labels for the variables of the system

IF			THEN	
Direction	SizeS	YPosition	VS(S^i)	HS(S^i)
horizontal	small	high	low	high
horizontal	medium	high	low	high
horizontal	big	high	low	high
medium	small	high	low	medium
medium	medium	high	low	high
medium	big	high	low	high
vertical	small		medium	low
vertical	medium		high	low
vertical	big		high	low

Table 1: Rule bases for classification of segments in vertical or horizontal

image is $\frac{\pi}{2}$. On the contrary, $directionS(S^i)$ is equal to 0 when S^i is parallel to the x axis of the image.

$$directionS(S^i) = \frac{2}{\pi} \arctan\left(\frac{|y_1^a - y_0^a|}{|x_1^a - x_0^a|}\right). \qquad (1)$$

The size of the segment is measured using the linguistic variable $SizeS(S^i)$ that has the three possibles values showed in Figure 2(b). The input value of this variable is the size of the segment expressed by $size(S^i) \in [0,1]$ as calculated in Equation 2. The variable $dist(p_0^i, p_1^i)$ in Equation 2 represents the Euclidean distance between the extreme points of S^i and $N\sqrt{2}$ is the maximum possible distance between two points in the image (the diagonal). The variable $size(S^i)$ is equals to 0 when the size of the S^i is 0 and it is equals to 1 when S^i has the size of the diagonal of the image.

$$size(S^i) = \frac{dist(p_0^i, p_1^i)}{N\sqrt{2}}. \qquad (2)$$

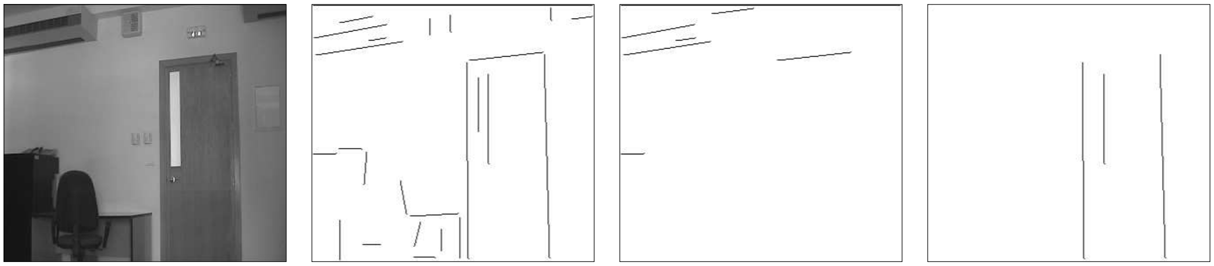
Finally, the height of the segment in the image is measured using the linguistic variable $YPosition(S^i)$. It has the three possible values showed in the Figure 2(c). Its input value, $YPos(S^i) \in [0,1]$, is the position of the middle point of the segment in the vertical axis of the image calculated using Equation 3. Low values indicates that the segment has its middle point in the upper part of the image and vice versa.

$$YPos(S^i) = \frac{y_0^i + y_1^i}{2N}. \qquad (3)$$

The use of these linguistic variables allows us to define the fuzzy concepts VS and HS. The fuzzy sets related to the concept VS are shown in Figure 2(d) and are identical to the fuzzy sets related to the concept HS. The two rule bases shown in Table 1 are used to calculate the membership degree of a segment S^i to the concepts VS and HS in the range $[0,1]$. Both values are calculated by a fuzzy inference process and its corresponding defuzzification. We shall denote the membership degree of a segment S^i to the fuzzy concepts VS and HS by $VS(S^i)$ and $HS(S^i)$ respectively.

Each one of the extracted segment is analyzed and its corresponding membership degrees $VS(S^i)$ and $HS(S^i)$ to the fuzzy concepts VS and HS are calculated. The aim of this process is dual, on one hand to classify the segments into horizontal and vertical segments. On the other hand, to eliminate those segments that, according to its features, does not seem to belong to the frame of a door. Therefore, the values $VS(S^i)$ and $HS(S^i)$ are computed and only those segments whose membership degree to one of the two concepts exceed a certain threshold α_1 are used in the following phases. Those whose membership degrees to the fuzzy concepts VS and HS are below α_1 are considered to have a low possibility of belonging to the frame of a door and thus are removed to speed up the further processing. If S^i is selected for the next phases then it is classified as vertical segment if $VS(S^i) > HS(S^i)$ and horizontal segment in the other case. Let us denote the set of vertical segments selected as $V = \{V^0, ..., V^n / VS(S^i) > \alpha_1 \wedge VS(S^i) > HS(S^i)\}$ and the horizontal one as $H = \{H^0, ..., H^n / HS(S^i) > \alpha_1 \wedge VS(S^i) \leq HS(S^i)\}$. High values of α_1 could make only pass few segments and thus speed up the detection process. Nevertheless, there could be rejected segments that really belong to the frame of a door and thus the door could never be detected. The appropriate value for α_1 is important and has been selected based on the experimentation performed.

Figure 3 shows an example of the classification process with an image of our environment. Figure 3(a) shows an image captured with the camera of our robot.



(a) Original image **(b) All extracted segments** **(c) Horizontal segments** **(d) Vertical segments**

Figure 3: Segment classification process

In Figure 3(b) there are printed all the segments extracted in the image. Figures 3(c) and 3(d) shows the segments classified as horizontal and verticals using the previously commented method. Once the interesting segments has been selected and classified, they are analyzed in order to find if their relationships shows that there is frame of a door.

2.2 Simple Frame Detection

Next step is to analyze if there is any simple frame (SF) in the set of extracted segments. The fuzzy concept SF expresses the idea that there is an horizontal segment (HS) joined to a pair of vertical segments (VS) in its upper part. The fuzzy concepts HS and VS has been previously calculated. Nevertheless, it is yet necessary to analyze if there is a trio of segments (two vertical and one horizontal) whose distances reveals that belongs to a frame. The fuzzy concept *Simple Frame Cohesion* (SFC) is defined for that purpose. SFC expresses if a trio of segments are near enough to be part of the frame of a door. The definition of this concept is explained below.

The process starts selecting for each horizontal segment $H^i \in H$ a pair of vertical segments $\{V^j, V^k\} \in V$ and analyze them. Let us denote the trio by $F^i = \{L^i, Sup^i, R^i\}$, being $L^i \in V$ the leftmost vertical segment, $Sup^i \in H$ the horizontal segment and $R^i \in V$ the rightmost vertical segment of the selected trio.

When a trio F^i is part of a frame, the upper points of the vertical segments L^i and R^ishould be very close to the extreme points of the horizontal one Sup^i. Furthermore, the vertical segments should not be very near. Let us denote Sup^i_l to the leftmost extreme point of the segment Sup^i and Sup^i_r to the rightmost one. Likewise we denote L^i_u to refer to the uppermost extreme point of the segment L^i and similarly R^i_u. There have been defined two linguistic variables that measure the above mentioned distances using these extreme points: $SegDistVH(F^i)$ and $SegDistVV(F^i)$.

$SegDistVH(F^i)$ measures the distance between the vertical segments and the horizontal one and it can have the five possible values represented by the fuzzy sets shown in Figure 2(e) . Its input value $distVH(F^i) \in [0,1]$ is calculated using the Equation 4. The variable $distVH(F^i)$ calculates the maximum of the distances between the upper extreme points of each vertical segment and the horizontal one. If $distVH(F^i)$ is equals to 0 it means that the distance between them is null. On the contrary, if it is equals to 1 it means that the distance between them is the maximum possible, the diagonal.

$$distVH(F^i) = \frac{max\{dist(Sup^i_l, L^i_u), dist(Sup^i_r, R^i_u)\}}{N\sqrt{2}}. \quad (4)$$

In order to evaluate the distance between the vertical segments, the linguistic variable $SegDistVV(F^i)$ is used and its five possibles values are the same that the showed in Figure 2(e). Its input value, $distVV(F^i)$, is calculated using Equation 5. It escalates the distance between the upper points of both vertical segments to the range $[0,1]$.

$$distVV(F^i) = \frac{dist(L^i_u, R^i_u)}{N\sqrt{2}}. \quad (5)$$

Now that these fuzzy variables has been defined it is possible to calculate the membership degree $SFC(F^i) \in [0,1]$ of F^i to the fuzzy concept SFC. It is calculated using a rule base by a fuzzy inference process and its corresponding defuzzification. The fuzzy sets related to the possible values of the concept SFC are identical to those shown in Figure 2(d).

$SFC(F^i)$ indicates that the separation between the segments of F^i is appropriate to belong to a frame, but it does not take into account the corresponding membership degree of each individual segment to the concepts VS and HS. Finally, the membership degree $SF(F^i) \in [0,1]$ of F^i to the fuzzy concept FE is calculated as expressed in Equation 6. $FE(F^i)$ does not only expresses how well the trio is cohered, but also how well its segments accomplish the corresponding fuzzy concepts HS and VS.

$$SF(F^i) = min\{SFC(F^i), VS(L^i), HS(Sup^i), VS(R^i)\}. \quad (6)$$

Only those F^i whose membership degree $SF(F^i)$ exceeds a threshold α_2 are used in the following phase. Let us denote this set as $F = \{F^0, ..., F^n / SF(F^i) > \alpha_2\}$. As in the previous case, the proper selection of

(a) SF (b) DF (c) DF (d) False positive

Figure 4: True and False Positive detections

α_2 is an important issue and it has been selected based on our experimentation. Image 4(a) shows an example of SF detected in a image of our environment.

2.3 Double Frame Detection

In some cases, it is possible to see the two frame edges of a door. For example when the door is seen open from the side that does not contains its leaf, or when the door is closed but the color of its leaf is different from the color of the frame. Therefore, the set of frame edges F selected in the previous phase is analyzed in order to detect if two of them belong to the same door. The fuzzy concept *Double Frame* (DF) evaluates if two frames belong to the same door (see Figure1(b)). The previous phase allows the detection of frames by the concept SF. A new fuzzy concept, *Frame Similarity* (FS), evaluates the degree in which two frames F^i and F^j are parallel and near. The definition of this concept is based on the philosophy employed to create the variables and rule sets of the previously described concepts and due to space limitations it is not explained in this paper. Then, using both concepts (SF and FS) the membership degree of the two frames to the fuzzy concept DF is calculated using fuzzy logic. A threshold α_3 is used, as in the previous cases, to select those pairs whose membership degree to the concept DF is high enough to be considered for a posterior analysis. Figures 4(b) and 4(c) shows examples of CF detected in images of our environment.

The presence in a image of the fuzzy concept DF gives a higher degree of belief on the existence of a door that the detection of a SF. This is because it is more difficult that the projection of an object in the image forms a DF than a SF. Objects like cupboards or paintings can form SF in the images but they are less likely to form a DF. Nevertheless, either the detection SF and CF would be used in a posterior fusion process with the fuzzy perceptual model based on ultrasound. Both informations, the provided by the visual and ultrasound systems, would complement each other to create a global belief degree on the existence of a door in the environment.

3 Experimental Results

In order to test the performance of the system, a database with images of our environment has been created. The image database is composed by 531 images, 390 with doors and the rest without doors. The proposed fuzzy system has a total success of 92% over the database. This value considers either the success in the images with doors and without doors. The *True Positive Fraction* of the initial system is 0.905, it means that the system detects the doors in the 90.5% of the images with doors. The *False Positive Fraction* is 0.035, it means that the system detects false doors only in the 3.5% percent of images that does not contain doors.

Figures 4(a-c) show doors of our environment seen under several positions. The segments belonging to the concepts that the system has detected are superimposed in white. As it can be seen, the method is able to detect typical doors in environments with different illumination conditions and under strong perspective deformations that makes the segments appear not completely vertical neither horizontal. Figure 4(d) shows a false positive detected by the system. They usually are big rectangular objects typical in indoor environments such as cupboards or windows. The inclusion of additional information, like color or ultrasound, could be used for discriminating these cases.

We want to point out that the time consumed by the system in the analysis of each image allows its use for real applications in a mobile robot. The visual processing is performed by the laptop computer added to our Nomad 200 robot. It is a Pentium IV running at $2,4$ Ghz. The experiments show that average time used to compute each image is 160 ms obtaining a frame rate of 6 fps with images of size $320x288$. This frame rate is enough to be used in real applications a mobile robot.

We wish to comment that either the values of the membership functions and the values of $[\alpha_1, ..., \alpha_3]$ have been determined based on the knowledge acquired in the experiments carried out. It could be interesting a procedure for its automatic selection that will be performed in future works.

4 Conclusions and Future work

There has been developed a method for the visual detection of doors based on the analysis of the segments detected in the image. The proposed method is robust to perspective, scale changes and variable illumination conditions. Additionally, it is independent on the dimensions of the image, it uses no color information and it can be employed for real-time application in our robot.

In order to differentiate the several cases in which a door can be seen, there has been defined two concepts using fuzzy logic that are searched in the image: *Simple Frame* and *Double Frame*. The use of fuzzy logic has allowed to classify the segments into *Vertical Segments* and *Horizontal Segments* using a linguistic description. Then, using the classification performed, the spatial relationships between the segments are analyzed to see if there is any *Simple Frame* in the image. Then, the relationship between the frames detected is analyzed looking for *Double Frames*.

The use of fuzzy logic has allowed, on one hand, to limit the search space of the set of possible segments and to define in a natural way fuzzy concepts. On the other hand, it allows to analyze the segments with different directions and size obtaining a high degree of flexibility in the manipulation of the information contained in the images. This flexibility is necessary to take into account the different perspective deformations caused by the two DOF of our camera. Finally, fuzzy logic has allowed to express a belief degree on the existence of a door that will be able to with the belief degree of a previously developed perceptual model based on ultrasound. Therefore, the information provided by one sensor can be complemented by the provided by the other.

The experiments carried out show that the proposed method can detect effectively the door of our environment with a high degree of success (92%). We consider that the method is valid for a great variety of doors commonly present in indoor environments.

A weakness of the method is that as it has been defined requires the three segments of the frame to be present in order to find it. Nevertheless, the experiments carried out shows that in some occasions one of the segments can be hidden. Therefore, as future work, the method will be modified to consider this circumstance and to have the ability of detect partially occluded doors. For that purpose, either the active role of the robot (as an element that can move in the environment) and the additional information provided by the previously developed perceptual model, will be taken into account. Finally, we consider also the automatic selection of the membership functions and the rest of parameters employing some tuning technique.

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