A Novel Color Coherence Vector Based Obstacle Detection Algorithm for Textured Environments

Ajay Mittal and Sanjeev Sofat

***Abstract*—This paper presents a novel obstacle detection algorithm that makes use of color information and color coherence vectors for robust obstacle detection. The algorithm makes use of color cue to classify a pixel in an image as an obstacle or a path. Color is one of the prominent image features. Color information is readily available as input from a color camera. Our algorithm makes use of coherence vectors for representation and matching instead of histograms. A color histogram provides no spatial information. It merely describes the color information present in an image. Color coherence vectors represent pixels as either coherent or incoherent. Color coherence vectors prevent coherent pixels from getting matched with incoherent pixels. The color histogram cannot make such fine distinction. The algorithm is tested with a challenging indoor and outdoor image set. Test results show that our algorithm performs better than available color based obstacle detection approaches.**

***Index Terms*—Obstacle detection, appearance based obstacle detection, color coherence vector, vision aid.**

I. Introduction

To get the perception of the environment around them, humans depends upon five senses – vision, hearing, smell, touch and taste. Out of these, vision is undoubtedly the one that people depend upon the most for the performance of their everyday activities. Most people cannot even imagine what life would be if they lose it- unable to read, requiring assistance for daily activities and difficulty in recognizing near and dear ones. This is however, a hardcore reality for nearly 45 million people worldwide, who are blind [1]. A further 135 million people have severely impaired vision in both the eyes and additional 100 million people suffer from monocular vision loss [2]. These visually impaired people experience serious difficulties in leading an independent life due to the reduced perception of the environment. Most of them confront serious difficulties in mobility and navigation when they find themselves in new environment. Obstacle detection is one of the major problems to be solved to ensure safe navigation for visually impaired users.

In this paper, a novel algorithm for obstacle detection is proposed that makes use of color cue and color coherence vectors for robust obstacle detection. The algorithm detects obstacles based on the appearance of individual pixels. Whether an individual pixel belongs to an obstacle or a navigable path is determined by a color classifier. The color classifier makes use of color information which is readily available as input in a color image. Color is one of the prominent image features and easy to process. Our approach makes use of coherence vectors [3] instead of histogram for color representation and matching. The coherence vectors are better than histograms as they incorporate spatial information. Moreover, our approach does not have any learning requirement prior to the use of classifier.

The rest of the paper is organized as follows: Section II presents a survey of the related work. Section III presents the assumptions and the steps involved in the proposed algorithm. Section III-A – III-D elucidates the steps involved in the algorithm. Section IV presents and discusses the experimental results. The conclusion is drawn in Section V.

II. Related Work

In context of navigation for a visually impaired user, obstacle can be defined as "anything that stops the progression of the user and/or requires the modification of his/her posture.” The visually impaired people have been greatly relying on the use of white cane to detect obstacles during navigation. White cane is a low cost, versatile navigation aid used by the visually impaired to get the information about the obstacles in the form of tactile response. However, white cane has an inherent disadvantage that the information about the objects only within its reach can be obtained. It cannot be used to obtain the information about the obstacles beyond it reach and hence cannot help the user in board route planning.

Extensive research has been carried out for developing Electronic Travel Aids (ETAs) for the visually impaired. ETAs are electronic devices developed to assist the visually impaired for autonomous navigation [4]. They make use of sensors to measure some attribute of the world in order to detect obstacles. Based on the type of energy sensed, the sensors used by ETAs are classified as- active sensors and passive sensors. Active sensors require energy from an input source other than what is being sensed to illuminate the scene. This energy is reflected by the objects present in the scene and is used to provide information about them. Popular active sensors used for obstacle detection include LASER, RADAR, LIDAR and ultrasonic sensors. The main advantage of active sensors is their ability to measure distance and speed of the target object in bad weather and poor lighting conditions. The major disadvantages of these sensors are interference with the environment, difficult interpretation of output signals, high power consumption, high acquisition price, poor resolution and incapability to detect small obstacles. Passive sensors sense the naturally available energy to determine obstacles in a path. The CMOS and CCD sensors are

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common passive sensors used to register images. These sensors are used in vision-based systems for obstacle detection. The major advantages of using passive sensors for obstacle detection are low power consumption, low cost and no interference with environment.

Vision based obstacle detection systems are further classified as range-based systems and appearance-based systems. Range-based systems detect obstacles on the basis of disparity calculations [5] – [7], range data [8] and ground plane estimation [9]. All range-based systems make use of computationally expensive complex algorithms and have difficulty detecting small or flat objects on the ground. Reliable detection of these objects requires high measurement accuracy and thus precise calibration. Appearance-based systems detect the obstacles by making use of color [10], texture [11] and shape features. Color information is computationally cheap to learn and process. While small objects are difficult to detect in range based system due to their poor angular resolution, they can in many cases be easily detected with color vision.

III. Methodology

This work concerns a vision system that has a single low cost web camera mounted on a headgear worn by the user. This vision system has the task of detecting obstacles and recognizing safe navigable areas in an image grabbed by the worn camera. The system consists of two parts- storing ground representation in form of color coherence vectors and a classifier. The classifier compares a patch of pixels in the acquired images with the stored ground representation to decide if a patch is a path or an obstacle. The system makes the following assumptions that are reasonable for a variety of indoor environments:

1) Ground plane is flat
2) Obstacles differ in appearance from the ground, protrude out from the ground plane and there are no overhanging obstacles
3) Initially, a small area ahead of the user is free from obstacles

The work assumes that the ground plane is flat and is free from steps, stairs and ramps. Steps, stairs and ramps can be better detected by making use of range based stereo vision instead of appearance based monocular vision. The second assumption allows us to distinguish obstacles from the ground and estimate the distance of obstacles from the user. If the first two assumptions are satisfied then, the distance is monotonically increasing function of the pixel height in the image.

The algorithm consists of steps listed below and shown in Fig. 1.

1) Image enhancement
2) Transformation to HSI color space
3) Color representation of reference area in form of coherence vectors
4) Comparison of an image patch with reference vectors for obstacle detection

A. Image Enhancement

The input image is filtered with a 5×5 Gaussian filter to reduce the noise level. This eliminates the small variations between the neighboring pixels.

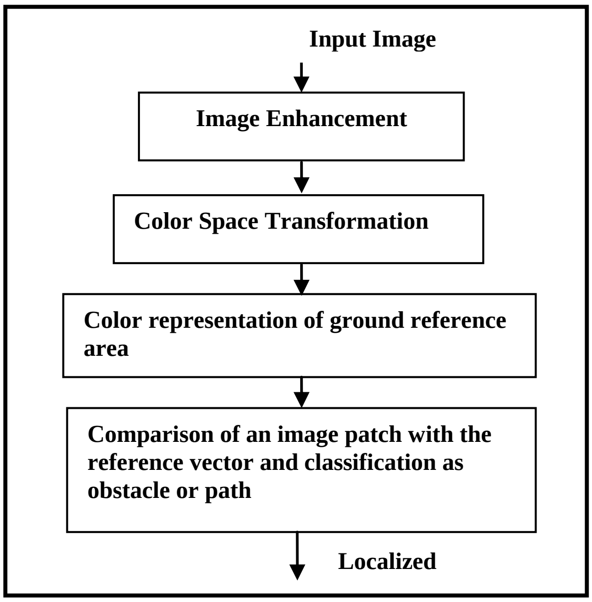


Fig. 1. Algorithmic steps

B. Color Space Transformation

The filtered RGB values are transformed to HSI color space. In HIS color space, the intensity is decoupled from the color information described by the hue and saturation. Hue and saturation responds closely to the way human perceives the color. The hue is more meaningful when saturation approaches 1 and less meaningful when saturation approaches 0 or when intensity approaches 0 or 1. Hence, hue is only assigned a meaningful value if the corresponding saturation is above a minimum value and the intensity lies between a particular range of values. The RGB color space can be transformed into HSI color space by making use of the transformations given in the equations (1)-(3):

$$I = (R + G + B\ ) / 3 \tag{1}$$

$$H=cos^{-1}((1/2((R-G)+(R-B)))/((R-G)^2+(R-B)(G-B)^{1/2})) \tag{2}$$

$$S=1 - (3\times min(R,G,B)/ (R+G+B)) \tag{3}$$

This step desensitizes the following steps of the algorithm to illumination changes.

C. Color Representation of Reference Area

The representation of the trapezoidal reference area (assumed to be free from obstacles) in the front of the user is stored in form of CCVs. The computation of CCV [3] is similar to the computation of a color histogram. The color space is discretized into n bins. All the pixels within a given color bin are classified as coherent or incoherent. A coherent pixel is a part of a large group of pixels of the same color, while an incoherent pixel is not. The pixel groups can be determined by computing connected components. A connected component C is a maximal set of pixels such that for any two pixels p and $p' \in C$, there is a path in C between p and p'. A path between p and p' in C can be defined as sequence of pixels $p, p_1, p_2, \ldots, p_n, p'$ such that each pixel p_i is in C and any two sequential pixels p_i, p_{i+1} are adjacent to each other. Two pixels are said to be adjacent if one pixel is among the eight neighbors of the other. The time complexity of computing connected components is proved to be linear.

A pixel is coherent if the size of its connected component exceeds a fixed threshold value τ; otherwise pixel is incoherent. For a given color bin, some of the pixels within that color bin will be coherent and some will be incoherent.

For a color bin j, let the number of coherent pixels be α_j and the number of incoherent pixels be β_j. Thus, the total number of pixels in the color bin j is $\alpha_j + \beta_j$. So, the color histogram would summarize an image as $<\alpha_1 + \beta_1, \ldots, \alpha_n + \beta_n>$ while the color coherence vector summarizes the image as $<(\alpha_1, \beta_1), \ldots, (\alpha_n, \beta_n)>$, where (α_j, β_j) is a coherence pair for j^{th} bin.

The main advantage of using color coherence vector for the representation is their ability to prevent coherent pixels getting matched with incoherent pixels. Hence, CCVs can make fine distinction than color histograms. Thus, our CCV based obstacle detection method clearly outperforms histogram based obstacle detection methods especially in case of textured environments.

D. Classification

Let G and G' be the CCV's of the image I and I'. Let the number of coherent pixels in color bin j be α_j (for I) and α'_j (for I'). Similarly, let the number of incoherent pixels in color bin j be β_j (for I) and β'_j (for I'). Comparison of the images based on the histograms would compute $\Delta H = \sum_{j=1}^{n} |(\alpha j + \beta j) - (\alpha' j + \beta' j)|$ while the comparison of images based on CCVs will compute $\Delta G = \sum_{j=1}^{n} |(\alpha j - \alpha'_j + (\beta_j - \beta'_j)$. Observe that a given color bin j can contain same number of pixels in I and I', i.e. $\alpha_j + \beta_j = \alpha'_j + \beta'_j$ but these pixels may be entirely coherent in I and entirely incoherent in I'. In such case, $\beta_j = \alpha'_j = 0$ and $\Delta H = 0$ while ΔG will be large.

Our color classifier makes use of CCVs and classifies a pixel patch as path or obstacle. A patch is classified as path if its color coherence vectors match with that of reference area with a high threshold value i.e. small ΔG value. The comparison can also be done by using squared differences instead of absolute differences in the definition of ΔG.

IV. Results and Discussions

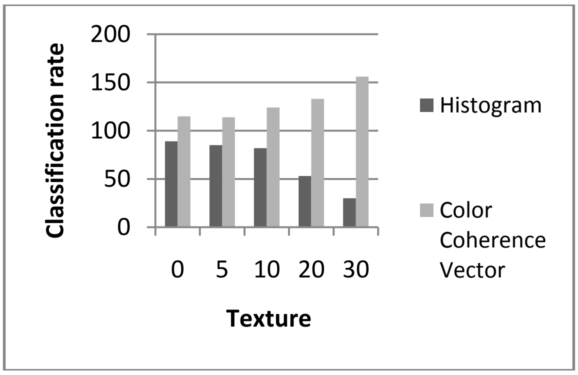
The proposed algorithm and color histogram based approach is tested on an image set of 80 indoor and outdoor images grabbed from Microsoft Live-cam VX-1000. Figure 2 shows a sample of the test data set. Figure 3 shows the results of the algorithm when applied on sample set. The comparison of our algorithm with histogram based approach is shown in Fig. 4.

(a) (b) (c)

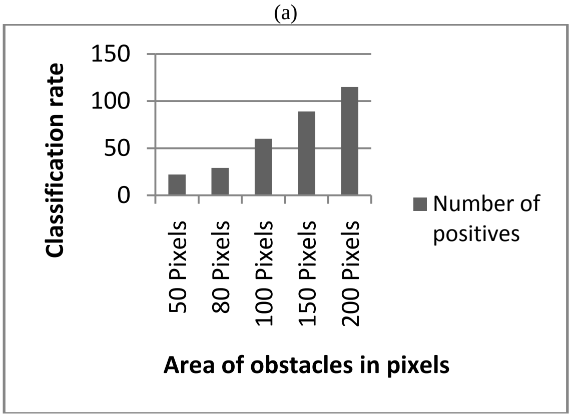
Fig. 2. Sample of test images used for the evaluation of algorithm: (a) Image of indoor environment (b)-(c) Images of outdoor environment.

(a) (b) (c)

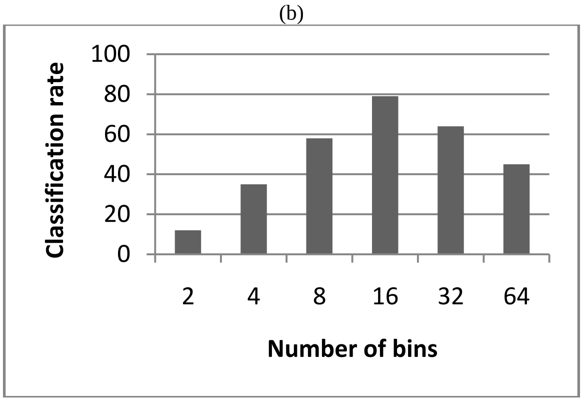
Fig. 3. Classification of a pixel in an image as obstacle or path. Pixels classified as path are shown in black and pixels classified as obstacle are shown in white.



(a)



(b)



(c)

Fig. 4. (a) Performance of the algorithm as compared to histogram based approach in textured environment. (b) Classification of the algorithm for obstacles of different sizes. (c) Effect of number of bins on the performance of the algorithm.

Test results shows that the algorithm performs comparable to the histogram based approach for non-textured environment but outperforms for the textured environments. This behavior is attributed to the ability of color coherence vectors to encode spatial information while histograms are unable to make such fine distinction. Fig. 4(b) illustrates that the algorithm shows significant improvement in detecting obstacles of small size as compared to histogram based approach in relation to the obstacle size. It is found that the algorithm fails to detect obstacles of very small size in large number of cases but these cases are difficult even for human.

Fig. 4(c) illustrates the performance of the algorithm in relation to the number of used color bins. It is found that the detection rate increases by increasing the number of color bin till a certain level and then it starts decreasing.

V. Conclusion

An efficient algorithm for obstacle detection that makes use of color cue and color coherence vector is presented. The algorithm is used in guidance system for visually impaired and helps them in navigating both indoor and outdoor environments. The algorithm makes use of color coherence vectors which can be computed in linear time. The color coherence vector matching is computationally inexpensive and hence the algorithm has good efficiency. Moreover, the algorithm does not have any learning requirements.

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