# Report on: Stairways Detection and Distance Estimation Approach Based on Three Connected Point and Triangular Similarity

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# Abstract

A paramount aspect of human beings has a sense of vision that naturally gifted by God, but some people are not capable to visually perceive things around the environment. They face various types of hindrances such as obstacles, potholes, staircase, pedestrian, vehicles etc. in their daily living and are not able to navigate around by the individuals. This paper presents a novel method of detection of staircase using the unique and natural properties of stair and estimating distance from the camera based on Triangular similarity. In the proposed system, the images of staircase are captured through a webcam and then Gabor filter and Canny edge detector are used initially to alleviate influence of illumination and to detect stair edges respectively. Then, non-candidate and small edges are eliminated and longest horizontal edges are extracted by using linking technique. In the next stage, three connected points are detected from the edge image and increasing horizontal edges are extracted. Finally, vanishing point is calculated for distinguishing from other similar pattern like pedestrian, rail line, etc. The proposed prototype is experimented with a variety of stair images with various conditions and achieves a high accurate result.


## Contents Pages

## List of figures Pages



# 1. Introduction

According to the World Health Organization (WHO), about 253 million people are visually impaired. Among them, around 36 million people are blind and rest 217 million people have various vision impairment. Among the above 80%, people are 50 years aged or above [1].
As the world is progressing at a faster rate, new systems are being developed every day to make sure daily living are getting comfortable in every way possible. But for the people who have physical disabilities, they require more help than ordinary people. So, the technology has come up and trying to provide solutions so that they can live around the society just like normal people. Nowadays, the development of assistive devices for the visually impaired people has become a prominent research area. One of the most important and challenging tasks is developing such systems with a user interface for the people with such physical disabilities while interfacing the sensors in the systems with real-world data.
In the last decade, many works [2] have been done in this field to help the visually impaired people in different directions. Some of the systems are in mobile devices, some for robot applications and the others for the visually impaired people using computer vision technology.

# 2. Previous Work

In the last decade, many works have been done in this field to help the visually impaired people in different directions. Some of systems are in mobile devices, some for robot applications and the others for the visually impaired people using computer vision technology.

Sayed et al. [3] proposed a Multi floor detection system for robotic system so that robot could navigate around the stairs in a building. The system used multiple proximity sensors and RGBD camera to detect both the upward and downward stairs and provide location access inside closed

room. The mainboard running the linux Operating system uses the Several Simultaneous Localization and Mapping (SLAM) algorithms to extract the stairs from the images of the camera. The main components of the model are a dual-core 2.1 GHz CPU and a GPU-CPU hybrid board, both running ROS on Ubuntu14.04. A SICK LMS 2D LiDAR is mounted centrally, and an Xtion Pro Live RGBD camera is placed in the front. The proposed model works very well in the multi-floor building and the system gives access to location as well. Very less complex compared to previous model. But the system fails when there is inconsistent stair size and ambient directly at the camera. Also, the measurement decays a bit when there a is wall directly at the front.

Shuihua wang and Yingli Tian al. [4] developed a staircases and pedestrian crosswalks detection system for blind and visually impaired people to improve travel safeness. The proposed system used computer vision-based method to detect stair-cases and pedestrian crosswalks by using RGBD camera. The system used Hough transform to extract the concurrent parallel lines based on the RGB channels and then Depth channel is used to recognize pedestrian crosswalks, upstairs and downstairs using Support Vector Machine (SVM). The proposed system is lightweight and user friendly and provide accurate information about upstairs and downstairs and pedestrian. However, the system fails to detect in dark and in case of large distance.

Shahrabadi et al. [5] proposed a method to detect of indoor and outdoor staircases for assisting visually impaired during navigation and for autonomous robots. The developed system is used Gaussian function for filtering the frames in order to mitigate the noise and then passes through Canny edge detector to detect wider range of edges in frames. Then Hough transform is applied for horizontal edges detection. Minimum and Maximum distance is applied and if the distance between two edges is between minimum and maximum distance, the edges are kept and edges with smaller distance are discarded. The main components used in the method are camera, processing device. The proposed method is able to detect both indoor and outdoor stairs with different view angles. It works satisfactory even if frame is saturated either by sunshine or contained shadows or in dark place. However, the system gives poor accurate result for detection of staircases about 83%.

However, all these prototypes had major setbacks. In our system we have tried minimize the setbacks of the previous projects.

# 3. Methodology

The working procedure of the proposed framework is discussed in this section. The developed system has six elementary steps which works sequentially one after another. Here, in following Fig. 1, the block diagram is presented.

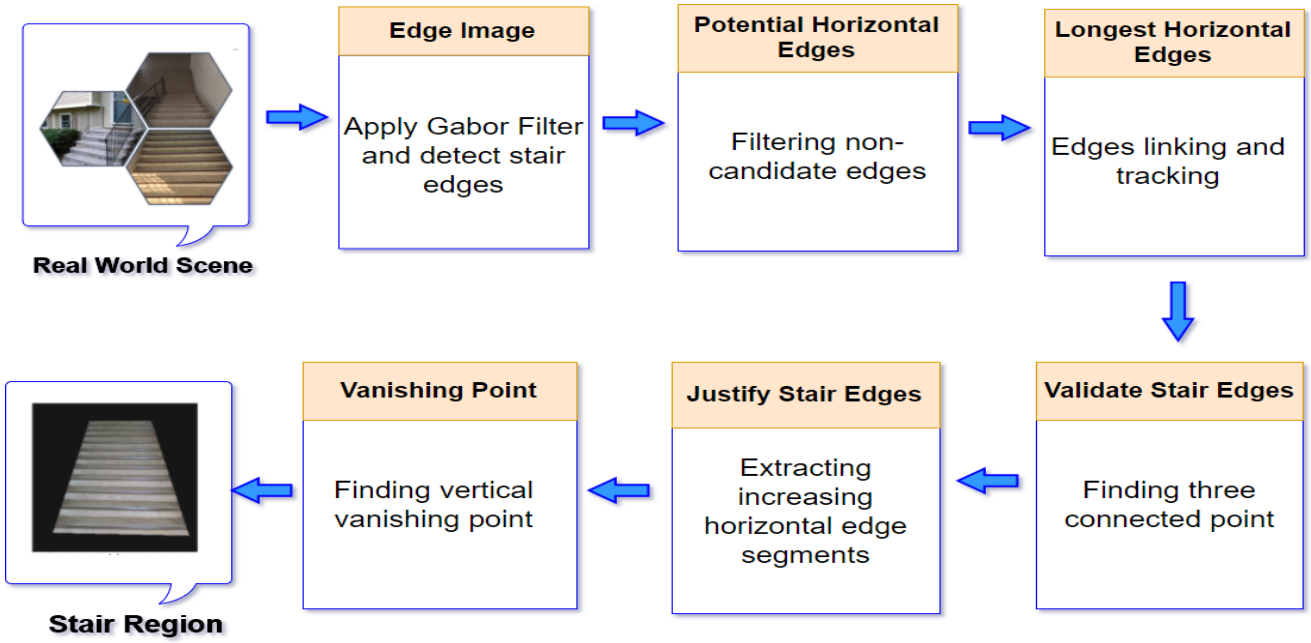



Fig. 1. Block diagram of proposed framework.

The steps are described in followings.

1. Gabor filter is applied on stair image to extract stair edges properly.
2. Non-candidate edges are filtered.
3. Establish links between edges and track.
4. Finding of Three connected points.
5. Horizontal edge segments are extracted being increased.
6. Detect staircase using vertical vanishing point.

## 3.1. Edges detection using Gabor Filter

The Gabor Filter is used for removing noise from stair image. Gabor filters may use with different frequencies and different orientations in different directions have been used to localize and also to extract desired regions from complex images for both gray scale image and color image. As the computational cost of color image is high, color images are converted into gray scale images. Here Gabor filter removes the influence of illumination variety and shadow effect efficiently with reservation of import information (multi-scaled, multi-directional) of stair image and various oriented staircase edges are extracted.

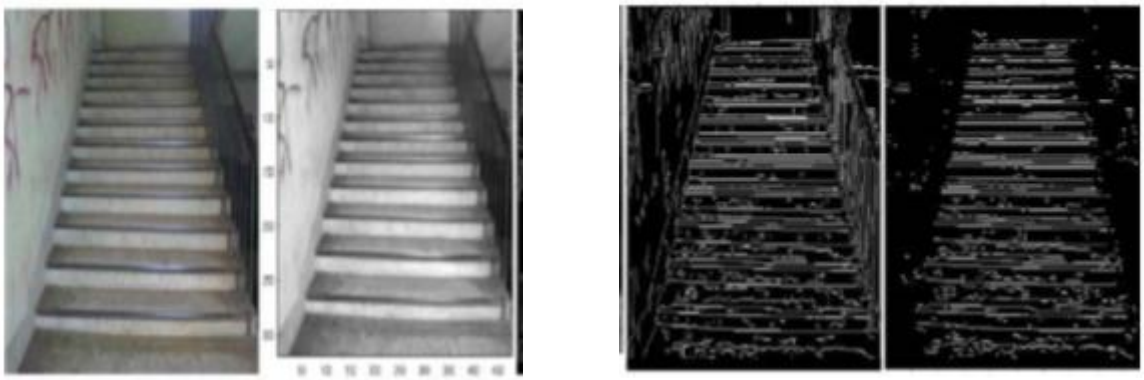
$$g(x, y; \lambda, \theta, \psi, \sigma, \gamma) = \exp\left(-\frac{x'^2 + \gamma^2 y'^2}{2\sigma^2}\right) \cos\left(\frac{2\pi x'}{\lambda} + \psi\right)$$

where,

$$x' = x\cos\theta + y\sin\theta$$

$$y' = -x\sin\theta + y\cos\theta$$

In the given equation, $\lambda$ is wavelength of sinusoidal factor, $\theta$ is the orientation of Gabor function, $\pi$ represents the phase offset, $\sigma$ describes the *sd* i.e. standard deviation of Gaussian envelope, and then $\gamma$ specifies the ellipticity of Gabor function.
Canny edge detector, an edge detector operator, is used to extract the edges from the gray scale image. Here is an illustration of Gabor filter and Canny edge detector in Fig. 2(b) and 2(c) respectively.



(a) (b) (c) (d)

Fig. 2. (a) stair image, (b) Gabor filtered image, (c) Canny edge image, and (d) horizontal edge image: All images from Khaliluzzaman et al. [6]

## 3.2. Filtering non-candidate edges

It is noticed that, the image in Fig. 1(d), there are different types of edges like small, large, horizontal, vertical, noise edge etc. A THRESHOLD_LINE is used to remove small edges and discontinuous edges that are not needed. Here is the procedure of small edges elimination.

Small edge elimination procedure

```
for i =1 to No_of_edge
    If   length (i) > THRESHOLD_LINE then
         Preserve the edge i pixels
    else
         Eliminate the edge i pixels
    end if
end for
```

Here, length (i) is the length of edge i and THRESHOLD_LINE = max (length (i)) /6.

This method also reduces the time for edge linking. Nevertheless, there exist some edges which are not part of the parallel edges known as non-candidate edges. Below, in Fig. 2(a) and 2(b), the illustration of filtering small and non-candidate edges respectively.

## 3.3. Edge linking and tracking

In this stage, the image contains only long horizontal edges of staircase. As, there may possible small gaps or breaks at some places in long horizontal edges for various reason, so, they must be filled up. Then the procedure of edge linking will be applied. The edge linking procedure is described as follows.

Two edges $i$ and $j$ are merged if they are satisfied the conditions as follows. If $y_r(i)$ - $y_l(j) < T$ and $x_l(j) > x_r(i)$ then $i$ and $j$ are merged by the point $(x_r(i), y_r(i))$ and $(x_l(j), y_l(j))$. If $y_l(i) - y_r(j) < T$ and $x_l(i) > x_r(j)$ then $i$ and $j$ are merged by the point $(x_r(j), y_r(j))$ and $(x_l(i), y_l(i))$. Where, $x_r$, $x_l$, $y_r$, $y_l$ are $x$ and $y$ right and left end point coordinate of edge $i$ and $j$. In following Fig. 3, here is an illustration.

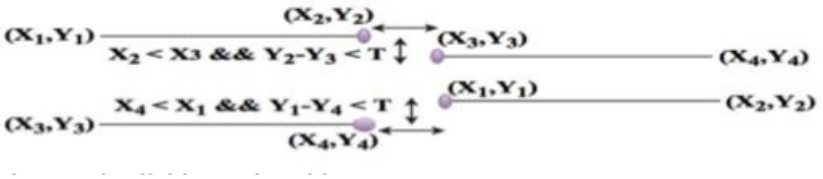



Fig. 3. Edge linking and tracking: Image from Khaliluzzaman et al. [6]

The result after applying edge linking & tracking method in an image is illustrated in Fig. 4(c). And Finally, those edges whose length are less than T (Threshold) are removed from the image shown in Fig. 4(d).

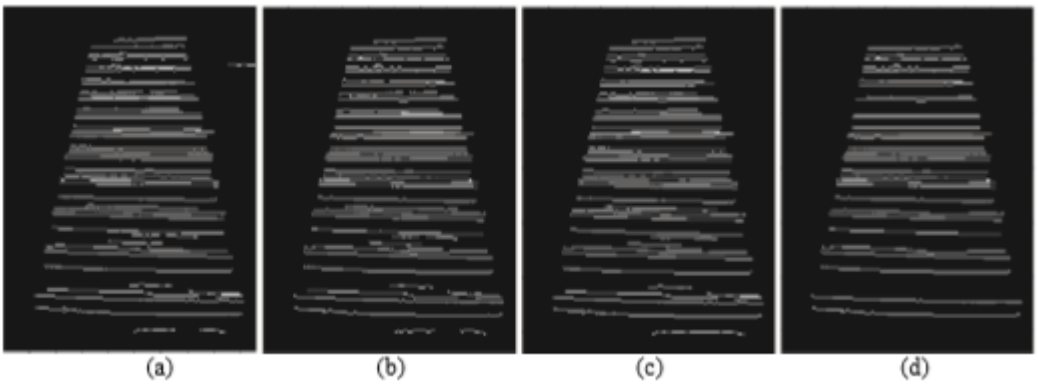
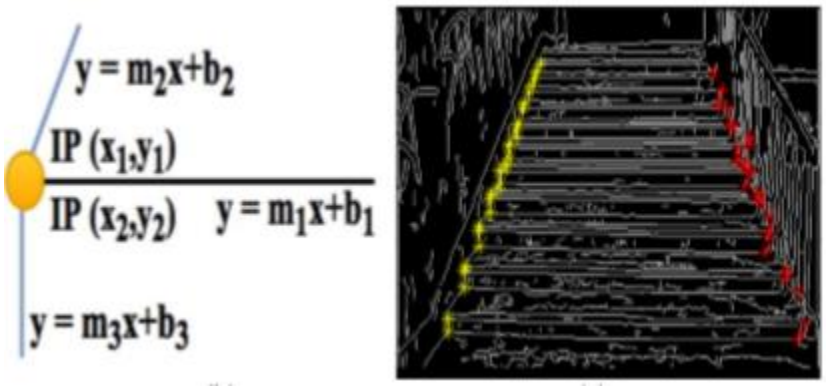



Fig. 4. (a) elimination of small edges, (b) elimination of non-candidate edges, (c) edge linking, (d) potential longest horizontal edges: All images from Khaliluzzaman et al. [6]

## 3.4. Finding TCP (three connected points)

We know that, the unique and important property of staircase, which is, the beginning point and ending point of the stairs step's horizontal edges intersect with two vertical edge points. Again, the canny edge image is used from where the n horizontal edges are extracted also contain vertical edges. Here in followings, is an illustration of TCP. The process of finding TCP is demonstrated in following Fig. 5.




(a) (b)

Fig. 5. (a) procedure of calculating TCP, (b) TCP in the edge image: All images from Khaliluzzaman et al. [6]

## 3.5. Extracting increasing horizontal edge segments

In this stage, the longest increasing horizontal edge is extracted from long horizontal n edges which are found in the section D and using Three-Connected-Point (TCP). As, in case of the stairs with parallel arrangement, the stair step consecutively appears in an increasing order from top to bottom, which is very unique and important feature of staircase.

## 3.6. Calculating vertical vanishing point

In this section, the Vanishing Point (VP), an imaginary point, is calculated from the increasing horizontal edge segments. Vanishing Point can be described as two handrails intersection point of a staircase. Some staircase does not have either both handrails or one handrail. For this reason, two virtual handrails may construct to calculate VP. But the pedestrian and rail way line have edges as like as stairs, positive y coordinate value of VP distinguishes these images from stair image. On the other hand, TCP criterion is not satisfied in case of pedestrian. The calculation of VP is illustrated in following Fig. 3(c).

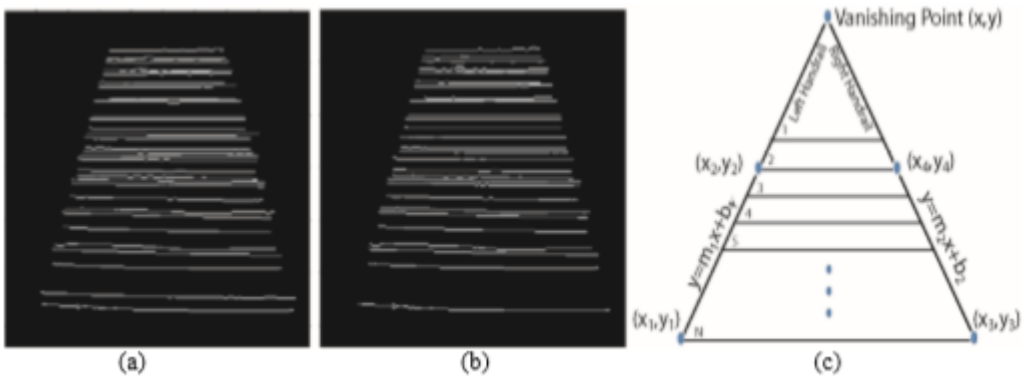



Fig. 6. (a) longest horizontal edge segment, (b) longest increasing horizontal edge segment, (c) estimating vertical vanishing point: All images from Khaliluzzaman et al. [6]

# 4. Estimating distance from Camera to Stair

Two cameras are used to measure the distance from staircase to camera. At first, from the camera at O', the ending point and beginning point of the staircase's first step is estimated. $A'(x1, y1)$ and B'(x2,y2) are the estimated points for this case. So, the distance between these two points is A'B' = $\sqrt{(x1-x2)^2+(y1-y2)^2}$. C is the center point between A' and B'. Another camera is placed at the position O from where the distance of the first step of staircase is estimated. The ending point and beginning point of the staircase's first step is estimated A and B respectively. The following Fig. 7. is an estimation of distance between camera and stairs.

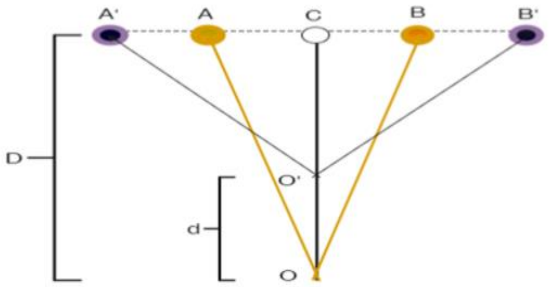



Fig. 7. The proposed framework for estimating distance from the camera: Image from Khaliluzzaman et al. [6]

It is noticed that $ACO$ and $A'CO$ triangles are similar. So, we can write $CO' \propto \frac{1}{CA'}$ and $CO \propto \frac{1}{CA}$. Hence,

$$\frac{OC}{A'C} = \frac{O'C}{AC} \qquad where\ OC = D, O'C = D - d$$

$$\frac{D}{A'C} = \frac{D-d}{AC}$$

$$D = \frac{d}{1-\frac{AC}{A'C}}$$

$$D = \frac{d}{1-\alpha}$$

Here α is the ratio between $AC$ and $AC'$. $D$ and $d$ are the distance between second camera to stair and first camera to stair respectively.

# 5. Experimental Results

The experiment is done on Intel Core i3 @2.5 GHz processor with 4GB RAM. They resized all the images with 480x320. It was done using MATLAB environment. The proposed system works both in indoor and outdoor stair type with normal and uneven environment condition. 40 out of 41 images were detected correctly in case of indoor stair type which was 97.56% accurate. In case of outdoor stair type, 58 out of 60 images were detected correctly which has 96.67% accurate. So, in total the system had achieved an accuracy of 97.12% as it was correctly detected 98 (40+58) out of 101 (41+60) images. Here it is illustrated in the following table 1.

**Table 1.** Detection accuracy at different environmental conditions.

| Stair type | Environment condition | Total images | Correctly detected | Detection accuracy (%) |
|---|---|---|---|---|
| **Indoor** | Normal and uneven illumination | 41 | 40 | 97.56 |
| **Outdoor** | Normal and uneven illumination | 60 | 58 | 96.67 |

The distance estimation from camera to staircase, in this case the developed system produces an high accuracy, is show in the following table 2.

**Table 2.** Distance estimating using proposed framework.

| SL No | Actual distance from first camera (m) | Estimated distance (m) | Absolute error (m) | Accuracy (%) | Run times |
|---|---|---|---|---|---|
| 1 | 4.5 | 4.46 | 0.04 | 99.11 | 0.073 |
| 2 | 6.0 | 5.87 | 0.13 | 97.83 | 0.073 |
| 3 | 9.25 | 8.98 | 0.23 | 97.08 | 0.075 |

# 7. Conclusion

In this paper, a prototype has been developed for extracting stair region from a staircase image and distance estimation from the camera to staircase automatically except any prior information about the location of the stairs at all. Some natural and unique properties of staircase are used to develop this framework. This model was trailed successfully by a different staircase images with various styles and a variety of illumination conditions. All the stair images are captured with a height of less than two meters from the ground. The proposed system detectes stair regions of these staircase images with an acceptable accuracy. The distance estimation from the camera to the staircase is also produce an accuracy of 97.61%. The proposed framework can only detect the traditional

staircases with usual shapes not give so much response for other stair such as spiral stair, etc. As the proposed framework is only work for usual shape stairs and upstairs, this work will be extended for detection of the staircase region with unusual shapes and implemented to detect the staircase region from downstairs in future. And the accuracy and estimated distance will be focused on.

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