Sidewalk Direction Recognition and Multiple Color Sidewalk Area Detection

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Abstract

Sidewalk area detection and direction recognition are important technologies in autonomous robot. In this paper, We propose an algorithm which can recognize the area of the multiple color and pattern sidewalk in single RGB image frame. Also we propose two algorithms which can recognize the direction of sidewalk. Each results of two algorithms are used in cross-evaluation system to get more accurate result. As a result, we could get 92% of accuracy. This algorithms are less accurate then Neural Network approach, however it is fast enough to use in real-time mobile devices. Using this algorithm, we could develop real-time computer vision based walking assistance application for visually impaired.

1. Introduction

As the technology has been developed each day, convenient life for ours is also required. In our society, there are some obstacles that impaired person have to go through in living in dense urban. Walking in sidewalk, as a pedestrian, it's so hard for them to show the way without navigator to help recognizing sidewalk's condition. For this problem, there are Braille Blocks on road, but as you know, the installation of braille block are very low. So they need helper who can help their walking. To solve this problem we want to develop some assistance application for them with the function of giving sidewalk environment information(direction, obstacle etc.). To analyze the environment of sidewalk, we use input image from camera, and analyze it with our computer vision algorithm which proposed in our paper, Sidewalk Area and Direction Recognition algorithm.

GPS Navigator is the best way to recognize the environment of sidewalk, however GPS Navigator doesn't work in indoor. We also wanted to assist visually impaired in indoor. That's the reason why we choose computer vision technique to recognize the sidewalk environment.

Sidewalk area recognition algorithm make a base line data for sidewalk direction recognition algorithm. In previous work, some papers made some approaches to this problem but it could only worked on single color based sidewalk. It means that various pattern, multiple color and noise are not allow for previous work. In the case of South Korea, most of sidewalks are installed with multiple color and pattern. So we need to solve this problem to use our app in various of environment and countries.

Second, sidewalk direction recognition algorithm is the most important part of our app. The purpose of this algorithm is recognize the direction of sidewalk(e.g right or left corner, rounded or curved sidewalk). There are some obstacle recognition and avoidance approaches for autonomous robot, however there was no research for recognize the sidewalk direction from front real-time video. So we need to develop a new approach to this problem. There are lots of input variables, edges which formed from Canny Edge Detector, lines which formed from Hough Line Detector, corner point which formed from Harris Corner Detector and Vanishing point etc. Among those variables, we decide to use line for detect the tendency of degree, and finally recognize the direction.

Direction information is important for visually impaired, however if we gave them a wrong information, we can put them into a dangerous situation. To prevent this situation, we decide to use cross-evaluate system with our algorithms result using two different algorithms which have the same purpose(recognize sidewalk direction). Line's degree dependency based recognition and classified line's graph pattern based recognition are those algorithms.

2. Related Work

The purpose and the method of our sidewalk area detection algorithm are similar with [1]Sidewalk following using color histograms approach. However previous approach just only can detect the single color and simple patterns sidewalk.

Figure 1. The Result of [1] sidewalk following using color histograms's approach in multiple color sidewalk.

As you see Figure 1, it cannot fully detect the sidewalk area, and Figure 1's situation is common in South Korea and other countries. This is our first problem to solve in this paper.

And Sidewalk Direction recognition approach in real-time front video doesn't have related work.

3. Sidewalk Area Detection Algorithm

Sidewalk area detection is one of the most important technique in autonomous robots. So many researcher struggle in this problem using Color-Detection, Neural Network, etc. However, Supervised Neural Network methods need lots of making datas which contain the area of sidewalk to train their model. So it is not easy thing to do. Also Neural Network methods are not enough fast to use in real-time mobile devices. We decide to make an useful color detection algorithm

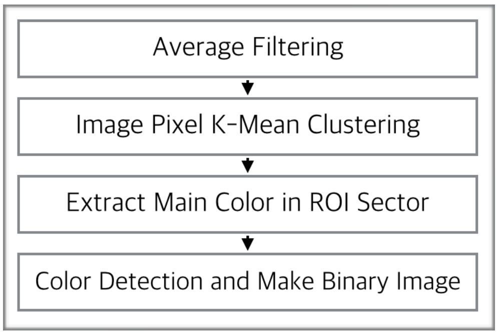

Figure 2. Process of Sidewalk Area Detection Algorithm

Figure 3. Right Image show the result of Average Filter

To reduce noises, we applied Averaging Filter. Figure 3 show you the differences between used or not. Second, we apply the K-Mean Clustering in Input Image. The reason why we apply K-Mean Clustering is to group the similar color. Under Equation shows the equation of K-Mean Clustering.

$$\min_{b,w} \sum_{i}^{n} \sum_{j}^{k} w_{ij} \| x_i - b_j \|_2^2 \; s.t. \sum_{j} w_{ij} = 1, \forall j$$

Simple explain about the K-Mean Clustering, they made the K Group and made cost function with “how much closer with center point of each Group” and the final goal is minimize the cost function. Handling three dimension matrix (RGB Image) is more complicate to express in this paper, so we will just comment under paper [2]Clustering and the continuous k-means algorithm.

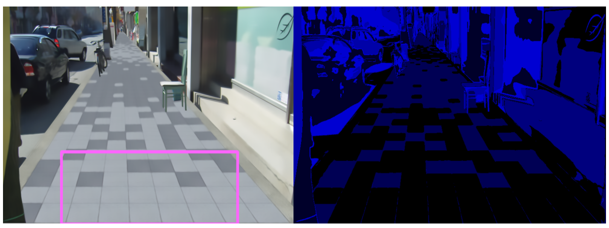

Figure 4. RGB Images K-Mean Clustering Result. In First Image, the pink box is the ROI (Rigon Of Interest) sector .

Next, we will extract the sidewalk’s color pattern in ROI(Region of Interest) . In Figure 4, the pink rectangle is the ROI sector. Using the ROI, we can extract the samples of the sidewalk colors and make target color for color detection.

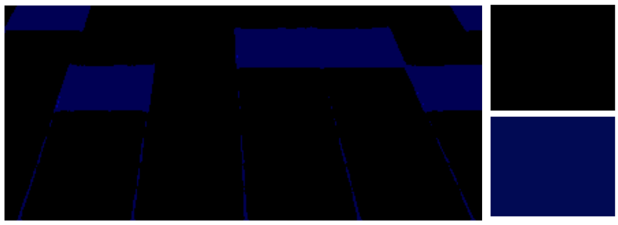

Figure 5. Extract Result of ROI(Region Of Interest)’s Main Color Pattern

Figure 5. shows the two main colors, but it alway’s change in the various situation. Usually the sidewalk is consisted with 1~6 colors. So we apply K-mean Clustering when it initialize, and evaluate suitability to determine the K value. So even if the colors are various, we could recognize the size of main main color.

Figure 6: Compare the previous work and our algorithms result.

After we extract the main color form ROI, we could detect the area of sidewalk using And-OR calculation. Compare the extracted main color and whole clustered pixel of image. Above image shows the result of our algorithm. As you can see, previous problem (single color only detectable) could be solved using our algorithm. Finally we could detect the total area of sidewalk very successfully.

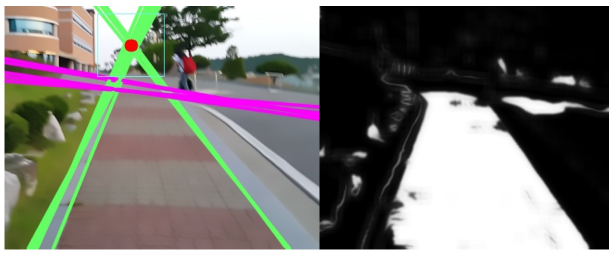

Figure 7. It could successfully detect the whole sidewalk area even if has a multiple color. And second image use the Average Filter.

As you can see, even if the sidewalk has a multiple color or pattern, our algorithm can detect the full area of sidewalk. Using this algorithm, we could detect the vanishing point of sidewalk more accurately(Vanishing point is just a sample, not a important in after paper context).

However, there is some critical point of this algorithm. If user is not located in the sidewalk, than ROI sector will extract the wrong sample. It means that our algorithm only can detect the area when the ROI is on the sidewalk area. This is our homework, which has to make sidewalk detection algorithm without ROI sector. And I think it could be possible with using Neural Networks method.

4-1 Sidewalk Direction Recognition Approach with tendency of lines

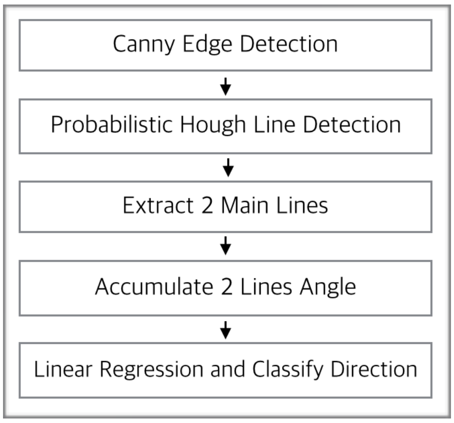

Figure 8. Process of Sidewalk Direction Recognition : Approach with tendency of lines.

Sidewalk Area Detection's result is our input data. First of all, we applied Canny Detection to find contours of the images. Second, we used Probabilistic Hough Transform to get lines of the images. Figure 9 shows preprocessing result.

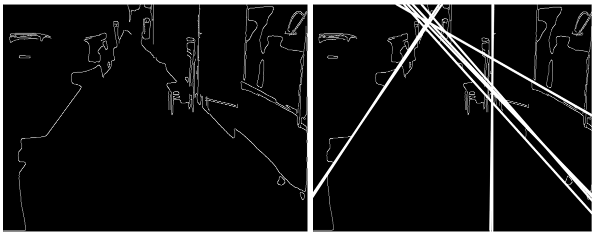

Figure 9. The Result of Canny Detector and Hough Line Detector.

First, we suggest that sidewalk's border be refer with input image's tendency. As pedestrian is walking along road, the view of road must have some tendency. And it is likely to match with sidewalk's border. Second, result lines should be long and exclusive for each other. If slope of two lines are two close, it means that there are no considerable possibilities of becoming border as two lines are approximately same. Third, to become meaningful input, line's size should be big. If ones size is too small, it can be actually some noise or another object's line. So, we applied some linear regression method that contains line's slope and length as variable.

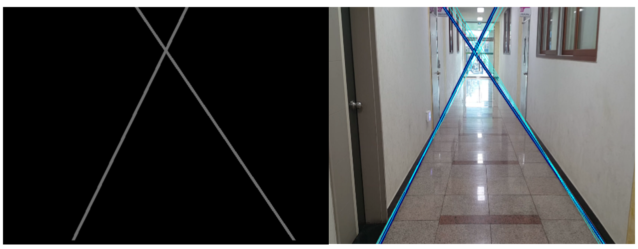

Figure 10. Pair of line which was extracted from cost function.

The result of algorithm is pair of line. So, we need to convert line's reliability not only of them, but with some other line. To give them more accuracy, we set some adopted parameter and evaluated them. Now we set the loss function of two line. In constructing loss function, we calculate variance of matrix fill with data of loss functions. If algorithm's result are correct, its mount should be aroused.

Also, we adopt linear regression method. We get implicit derivatives of function by weighting parameter that adjusts length factor to get minimum variance of loss function's result. Parameters are easily changed to improve its quality. We coordinate the parameter to suit with input data.

$$A_{ij}=\beta((l_i+l_j)2-l)+D(m_i,m_j) \quad (3)$$

$$S(\beta)=Var(A_{ij}) \quad (4)$$

We set the P as average of matrix A. P is related to parameter and represent average of data in matrix A. So, function S is shown at this form of by calculating deviation.

$$S(\beta)=\sum_{i=0}^{n}\sum_{j=0}^{n}(A_{ij}-P)^2 \quad (5)$$

Now, we get implicit derivative of S by parameter. And variables x, y, X, Y are shown as following equations.

$$\frac{\partial S(\beta)}{\partial \beta}=2\frac{2}{n^2}\sum_{i=0}^{n}\sum_{j=0}^{n}(nL-L_{sum})^2\beta+(nL-L_{sum})(Mn-M_{sum})=0 \quad (6)$$

$$L=(l_i+l_j)^2-l, \quad M=D(m_i,m_j) \quad (7)$$

$$L_{sum}=\sum_{i=1}^{n}\sum_{j=1}^{n}L, \quad M_{sum}=\sum_{i=1}^{n}\sum_{j=1}^{n}M \quad (8)$$

Equation (7) present implicit derivative of loss function. To get critical value of it, we can set parameter as related to input data only. And if needed, we can change parameter to get more quality. After calculating it, we can finally set the loss function.

Now, we should define function D to get result of S. While D get two function as variable, we can assume that two line's average angle is close to pedestrian's direction and result of linear regression method. So we define function D as this form.

$$D(m_i,m_j)=-\left|tan\left(\frac{arctan^{-1}(m_i)+arctan^{-1}(m_j)}{2}\right)-m_{avg}\right| \quad (9)$$

In short, we search the slope of all lines by using linear regression method. By adjusting ours, we can develop useful loss function between two lines. This function's parameter are needed to be set before the function is called. But, the parameters are calculated by linear regression method. Although There are some necessary to be changed by image's width and height, we resize it's size. So, in our method weighting parameter beta is calculating like this.

$$\beta = \frac{\sum\sum(M_{sum}-Mn^2)(n^2L-L_{sum})}{\sum\sum(n^2L-L_{sum})^2} \quad (10)$$

In the usual circumstances, we get the parameter beta between 0.015 and 0.020. After applying method that calculate line's reliability with tendency of image, we use linear regression to reduce some trivial errors by simple vibration of user. We use OLS(Ordinary Least Square) method and some RANSAC(Random Sample Consensus) to get line's tendency. In this process, we can get our direction that can be assumed by our previous path model and know whether our path is fit in sidewalk.

Figure 11. Pair of lines which extracted from regression method in matrix which accumulated pairs of lines.

The algorithm's time complexity is mostly influenced by situation which affect linear vector's size. And it is estimated to square of n by big O notation. By using some regression method, we just obtain it's time complexity mostly manufactured by which regression models to take. If we choose Theil-Sen Estimator or Gradient Descendant and so on that refers to more complicated regression model, we have to give up getting real-time processing. Thus, we choose just simple and strong model that compute our algorithm.

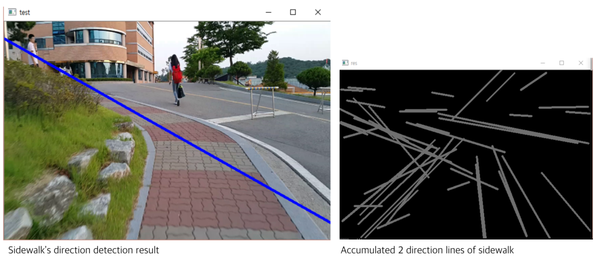

Figure 12. Left image shows the tendency of sidewalk direction which extracted from final result of our algorithm

In real-time detection, there can be some unknown situation that damage our result's reliability. So, we finally use some linear regression method in combination of direction and confidence of each result. Adjusting this method, we assure that result show the direction of frame. There are some point that accuracy and performance time of algorithm needed to be compromised. Especially in realtime processing, performance time must be reduced to get meaningful result. So, there are many ways to deal with such that problems. But, we suggested that it is better to use simple algorithm and integrate with regression or some method is more efficient than using complex algorithm structure to define each frame. It is more economical and change it's elapsed-time more easily and suitable.

4-2 Sidewalk Direction Recognition Approach with graph pattern

Second method for recognizing direction is approach with graph pattern. In this method, we will classify lines according to slope of lines and watch the graph which shows the changes of classified lines. Figure 13 shows the process of our approach. Using all lines tendency and graph pattern recognition are the differences between first method and this one. Two method's cross evaluation helps to make more accurate classification.

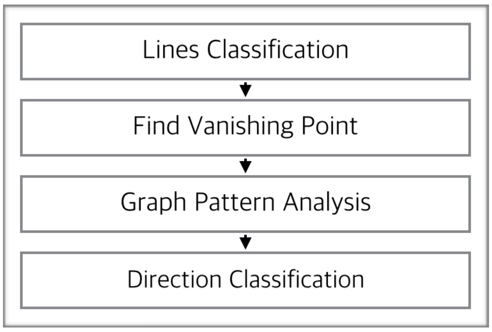

Figure 13. The process of sidewalk direction recognition : approach with graph pattern

First of all, we classified the lines according to slop. Input lines are extracted from Hough Line Detector. And classification condition followed the Figure 14 condition.

$$0<\theta<20 \ \text{ and } \ 155<\theta<180\text{: Vertical Line}$$
$$20<\theta<60\text{: Right Sidewalk Border}$$
$$60<\theta<85\text{: Right Direction Vector}$$
$$85<\theta<95\text{: Horizon Line}$$
$$95<\theta<115\text{: Left Direction Vector}$$
$$115<\theta<155\text{: Left Sidewalk Border}$$

Figure 14. Line Classification Condition

Figure 15. images shows the classification result. Green lines mean right and left sidewalk border lines. And purple lines mean the direction vector. Lastly, white lines means horizon lines. We used Polar System to express lines data. Polar System contains (r,theta) values not (x1,y1,x2,y2). So we can classify lines more easily.

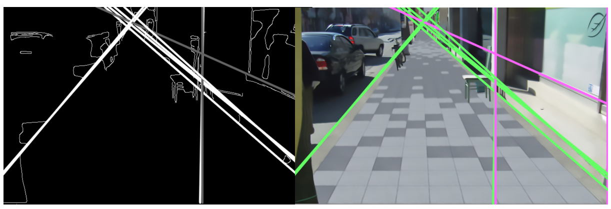

Figure 15. Left image shows the hough line detection result, Right image shows the classification result.

After classification proecces, we made some graph which express the changes of each category. This graph accumulate each classified lines size for 30 frames to see the pattern. And we walked various of sidewalk environment especially in corner situation.

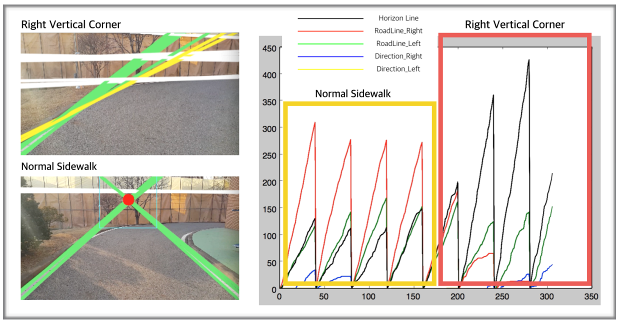

Figure 16. The graph shows the changes which normal sidewalk move to right vertical corner situation.

The images of Figure 16 show the normal and right vertical corner and graph pattern with each direction situation. As you can see there are some differences in graph. If the normal sidewalk are change to the right vertical corner, horizon lines(black lines) size was rapidly increased in graph

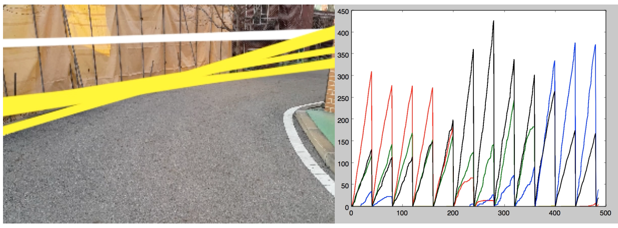

Figure 17. After Figure 16 situation, right curved corner situation happened. And Right Direction Vectors are rapidly increased.

When we turned right to corner, you could meet the right curved sidewalk. Then, the size of right direction vector are rapidly increased and the size of horizon line are decreased. Using this basics which was formed from experience, we can make hypothesis. In vertical corner situation, horizon lines are increase rapidly and the same direction vector are increase also. And if curved corner situation, direction vector increase rapidly and be a biggest in graph. This is just hypothesis which constructed by experience. It could be wrong. So we should proof our hypothesis with some experiment.

Vertical **Right** Corner Decision-Condition

$$if\ \ biggest\ =\ \sum horizon\quad \sum left\ >\ 2\sum right$$

Vertical **Left** Corner Decision-Condition

$$if\ \ biggest\ =\ \sum horizon\quad \sum right\ >\ 2\sum left$$

Bended **Left** Corner Decision-Condition

$$if\ \ biggest\ =\ \sum right\_direction\ \ and\ \ second\ =\ \sum vertical$$

Bended **Left** Corner Decision-Condition

$$if\ \ biggest\ =\ \sum left\_direction\ \ and\ \ second\ =\ \sum vertical$$

Figure 18. Simple formula of hypothesis which can recognize the sidewalk graph pattern

So we made simple formula to describe our hypothesis. And we applied these formulas in another test videos. Result of the test was successful. Figure 19 shows the result of the test

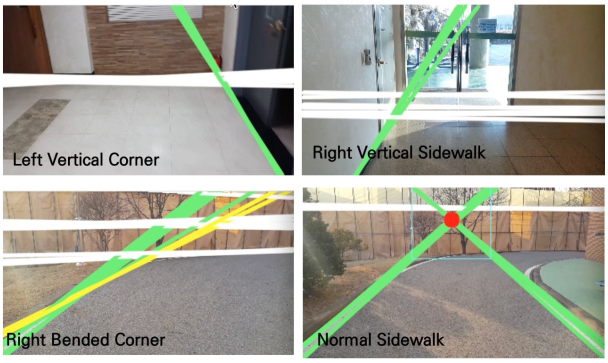

Figure 19.The result of algorithm which applied the hypothesis. The direction which was recognized from our algorithm are printed on the bottom of the image.

5. Test

If the results of 'approach with tendency of lines' and 'approach with graph pattern' are same, we make a direction detected event. To get accuracy of our algorithm, we used specific estimate system. First, we gave the realtime video and print the result of sidewalk direction recognition. Second, we compare the result of algorithm with the real direction Figure 20 shows our the evaluate system.

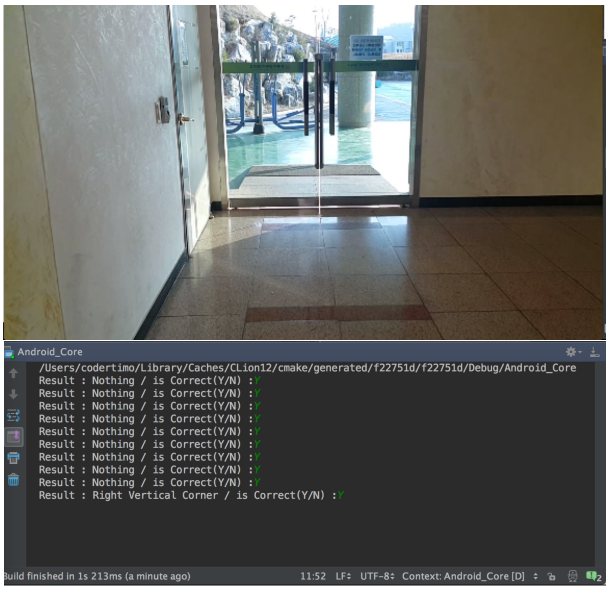

Figure 20. Algorithm evaluate system. System shows the result of algorithm and subject input the real direction.

As a result, we got 92% of accuracy in this test. We used 32 test videos, and 40 different circumstances of sidewalk. Approach with line tendency got 83% of accuracy and approach with graph pattern got 90% of accuracy. This result are full enough to make the walking assistance application for visually impaired which is our main goal.

6. Conclusion

We made sidewalk area detection algorithm and sidewalk direction recognition algorithm. Sidewalk area detection algorithm solve the problem which cannot detect the full area of the sidewalk which has multiple color. And we could made the sidewalk direction recognition algorithm for the first time.

Especially, sidewalk direction recognition algorithm used two different algorithm. If both of results are same, we made an event that the direction information has detected.

Using evaluation system, we could get the accuracies of our algorithms. As a result, our algorithm to 92% of accuracy .

We applied these algorithms in walking assistance application for visually impaired. Also we hope that our research can help the field of autonomous robot

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