Anti-tailgating

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Introduction

- For automated passenger clearance system (e-Channels)
- It only allows one person entering the echannel at each time
- Current: it needs immigration officer monitoring the e-Channels to avoid tailgating
- More e-Channels will be installed due to increasingly cross-boundary traffic
- Introduce a system to detect the number of people inside the channel for manpower reduction



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- How does the system work?
 - Firstly, install two cameras on the top of e-Channel in parallel



Keep capturing the images of the channel



Image from left camera

Image from right camera

Use computer vision technique to analyze the images

To check how many people inside the channel at the same time

When there are more than one person inside the channel, tailgating occurs

Two main steps

Camera Calibration

To rectified images and make scan lines correspondent

Stereo Matching

To find the location of the correspondence point in right image that matches the point in the left image

Process: Calibration

- In real case, two cameras cannot be installed 100% in parallel
- The scan lines of two images produced are not correspondent
- Data along the scan line is not the same
- Cannot perform stereo matching correctly



Image from left camera Image from right camera

After calibration, images are rectified and the scan lines become correspondent



Objective

• Match with processes and enhance performance of the Stereo Matching.

Placement of Devices





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Improved Calibration

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Rectified Left Image Rectified Right Image

Process: Stereo Matching

- How to analyze the images with stereo matching?
 - Distance exists between 2 cameras
 - 2 images will not cover the same area
 - Along the same scan line, x-coordinate of each points are different in both images



- Search along the scan line in right image so as to find the location of the correspondence point that matches the point in the left image
- Disparity value is found by computing the distance between 2 points.



- Object that nears the cameras, its locations in 2 images will have a greater distance => larger disparity value
- After finding the disparity values for whole image, assemble them into a disparity map
- Intensity values represents the depth of points: intensity of a closer object is higher







- Images contains areas outside the e-Channel
- Region of Interest (ROI) should be set so as to prevent the system analyzing the irrelevant data and to reduce computation time



- Techniques that used to enhance stereo matching performance
 - Normalized Cross-correlation(NCC)
 - Box Filtering Technique
 - Two-Stage Dynamic Programming
 - Multi-level Scheme
 - Rectangular Subregioning

- How to find correspondence between points in 2 images?
- Normalized Cross-correlation(NCC) technique is used
 - This estimate is independent of differences in brightness and contrast of images
 - Measure the similarity of 2 intensity values by calculating the correlation coefficient between 2 points
 - Correlation coefficient value lies between -1 and +1, value that tends to -1 or +1 represents a better match while value that tends to 0 represents a worse match

- For a point in left image that centered at a correlation window with invariant size, NCC value is calculated with the points in right image that along the same scan line
- After a point in right image with the best NCC value is found, the x-coordinate difference between 2 points will be the disparity value



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Calculation of NCC is computationally expensive

Formula:

$$C_{i,j,d} = \frac{\sum_{m=i-K}^{i+K} \sum_{n=j-L}^{j+L} (f_{n})_{n} - \overline{f} (g_{m+d,n} - \overline{g})}{\left(\sum_{m=i-K}^{i+K} \sum_{n=j-L}^{j+L} (f_{n,n} - \overline{f})^{2} \times \left(\sum_{m=i-K}^{i+K} \sum_{n=j-L}^{j+L} (g_{m+d,n} - \overline{g})^{2} + \sum_{m=i-K}^{i+K} \sum_{m=j-L}^{j+L} (g_{m+d,n} - \overline{g})^{2} + \sum_{m=i-K}^{i+K} \sum_{m=j-L}^{i+K} \sum_{m=j-L}^{i+K} (g_{m+d,n} - \overline{g})^{2} + \sum_{m=i-K}^{i+K} \sum_{m=j-L}^{i+K} \sum_{m=j-L}^{i+K} (g_{m+d,n} - \overline{g})^{2} + \sum_{m=i-K}^{i+K} \sum_{m=i-K}^{i+K} \sum_{m=j-L}^{i+K} \sum_{m=i-K}^{i+K} (g_{m+d,n} - \overline{g})^{2} + \sum_{m=i-K}^{i+K} \sum_{m=i-K}^{$$

 Retrieve the value of each point in a correlation window many times

- When shifting the correlation window, many points are overlapped
- **Box Filtering Technique** is used to reduce the computation time
- The new value of the shifted window can be obtained by simply adding the new leftmost column and subtracting the old rightmost column



- How to find the best NCC value for each point?
- Repeat the process of correlation calculation for whole image until the correlation window has gone through a disparity search range [-d, +d]
- For each d, a plane of correlation coefficients is produced
- Putting each of these planes together we have a correlation cube



 After obtaining a correlation cube, the best NCC value for each point should be found for producing a disparity map



- Finding the best NCC value for each point separately, discontinuity of disparity value between points may occur
- Two-Stage Dynamic Programming is introduced to find the disparity for each point where discontinuity is factored in.

In 1st stage, it accumulates the NCC values for each slice j in a vertical direction by this formula:

Y(i, j, d) = C(i, j, d) + Y(i - 1, j, d - 1)



Accumulated max NCC values is then obtained

- In 2nd stage, it finds the best path for each ND slice in horizontal direction which contains the max NCC values
- After finding all best paths for different scan lines, a max surface which cut through the correlation cube is then obtained



- Multi-level Scheme is introduced to enhance the speed in stereo matching
- A more reliable disparity map can be obtained with a multi-resolution data structure



- Fast computation: Search range in each level is small
- High reliability: current disparity value refer to the previous one

- Size of correlation cube is MxNxD
- Rectangular Subregioning (RSR) is used to reduce the cube size and memory space for storing NCC values
- It divides the image into a number of subregions according to the disparity values of previous disparity map
- The objective is to obtain large regions with small disparity range and small regions with large disparity range.



- How to implement all techniques when performing stereo matching?
- 1. Build image pyramid with k levels, resize the images proportionally
- 2. Initialize the disparity map as zero for the first level
- 3. Perform stereo matching
 - RSR: segment images into rectangular sub-regions based on current disparity map
 - Calculate NCC values by box filtering and obtain a correlation cube
 - Find the 3D maximum surface by Two-stage dynamic programming
- 4. If level is not 0, propagate and scale up the disparity map to the next level in the pyramid, set k = k-1 and then go to Step 3; If level = 0, stop the stereo matching and use the final disparity map as the result 37

Results





Level of matching	Correlation Window Size	Search Range	Found Disparity Range	Time
3	9 x 9 pixels	[-40, 0]	[-40, -1]	< 1 sec
1 -	9 x 9 pixels	[-40, 0]	[-40, -5]	4 sec





Q&A