Anti-tailgating

Supervisor: Dr. Kenneth Wong
Students: Ying Chun Ching, Lai King Cheuk

Contents

- Introduction
- Main processes
  - Calibration
  - Stereo Matching
- Results
- Q&A

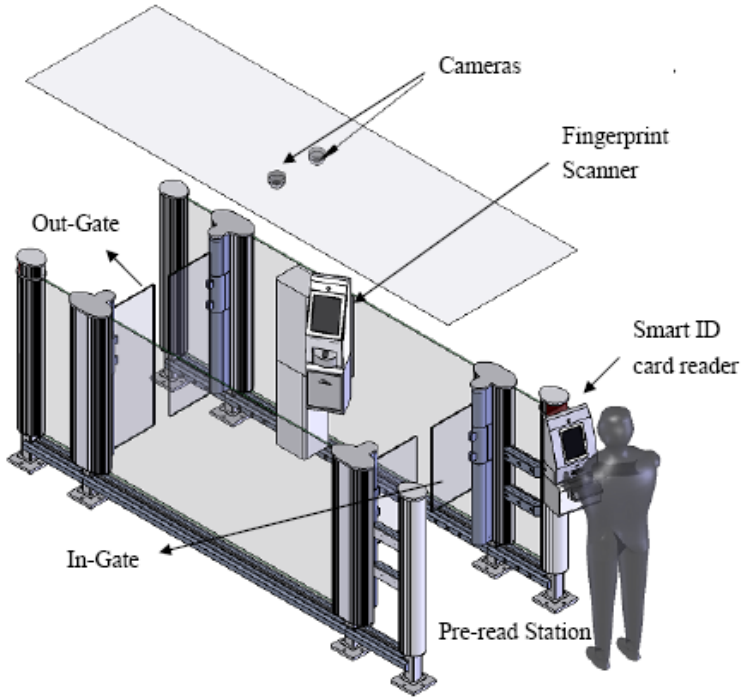
Introduction

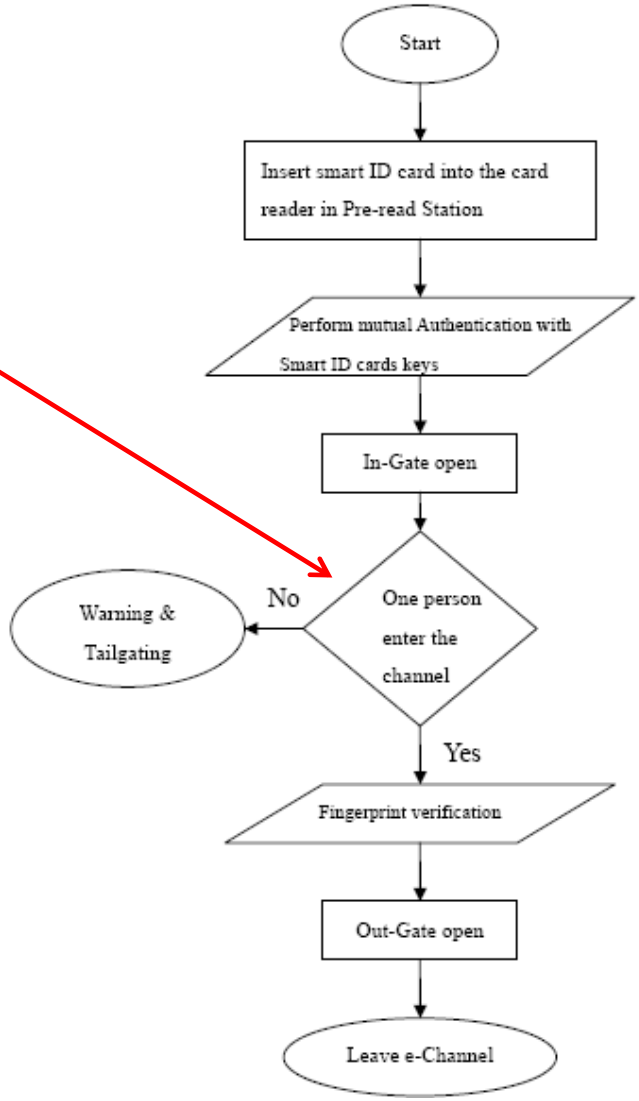
- For automated passenger clearance system (e-Channels)
- It only allows one person entering the e-channel at each time
- Current: it needs immigration officer monitoring the e-Channels to avoid tail-gating
- More e-Channels will be installed due to increasingly cross-boundary traffic
- Introduce a system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

Introduction (con't)

Workflow of e-Channel

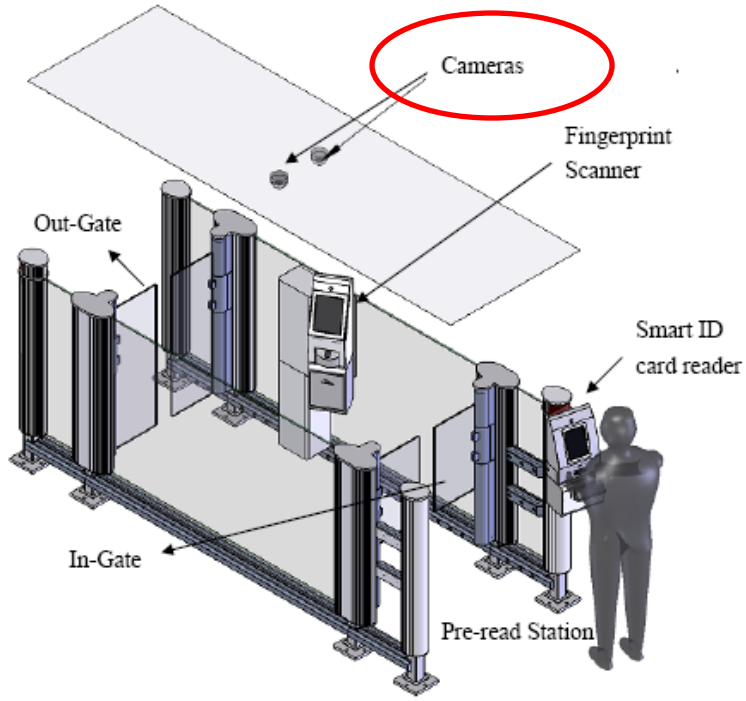
Anti-tailgating system takes place





Introduction (con't)

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



Introduction (con't)

- Keep capturing the images of the channel

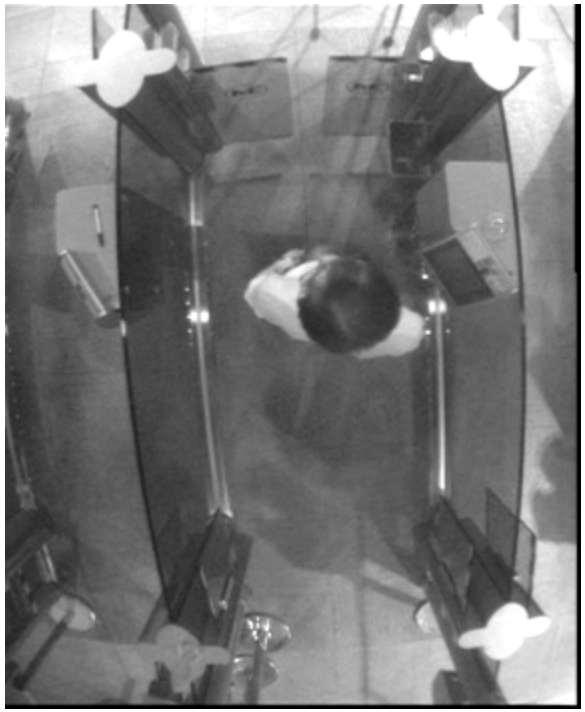


Image from left camera

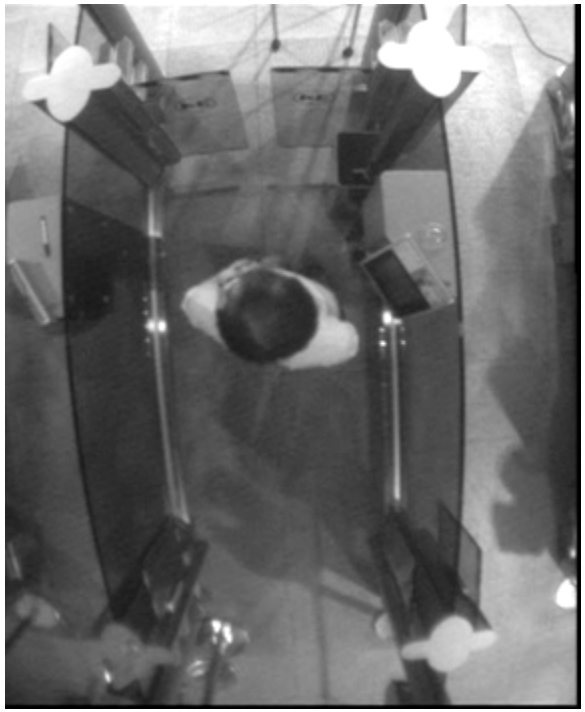


Image from right camera

Introduction (con't)

- 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

Introduction (con't)

- 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

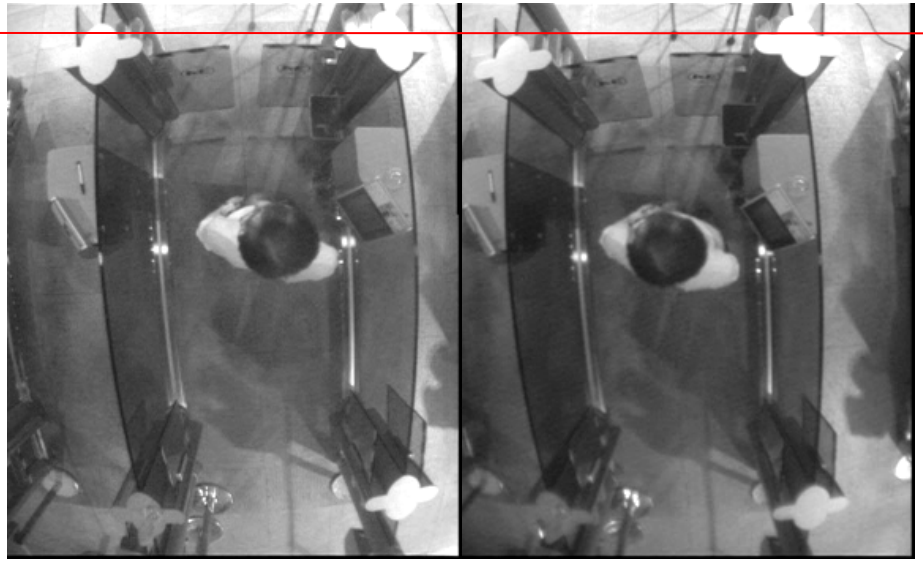
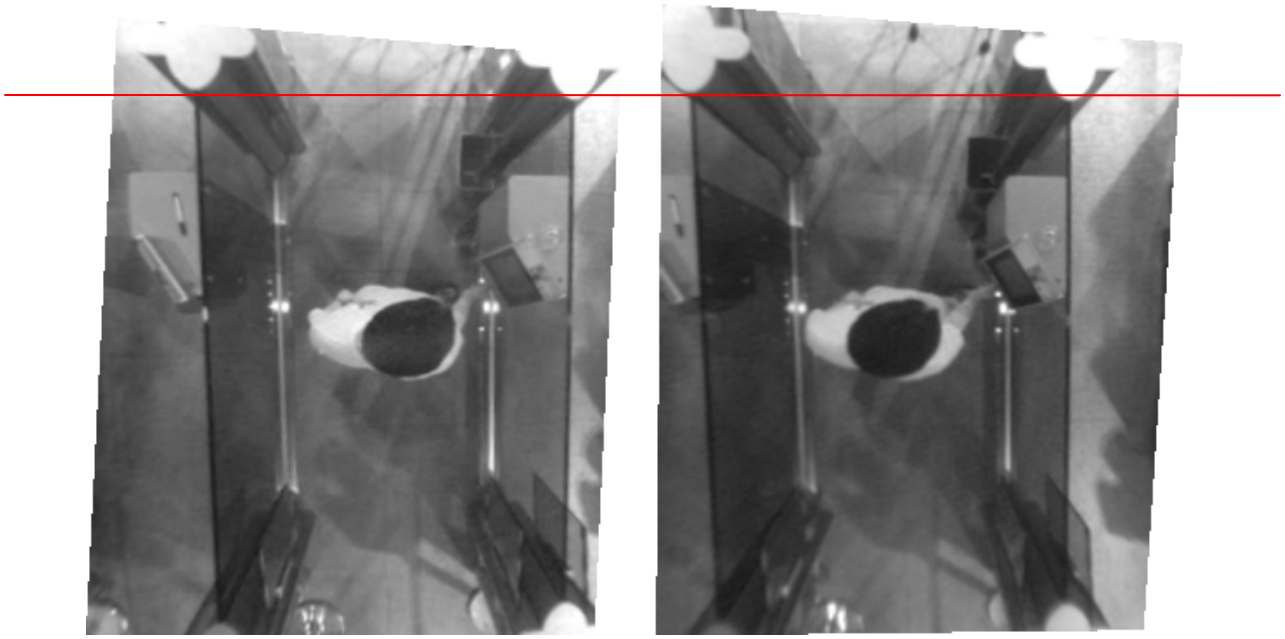


Image from left camera Image from right camera

Process: Calibration (con't)

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



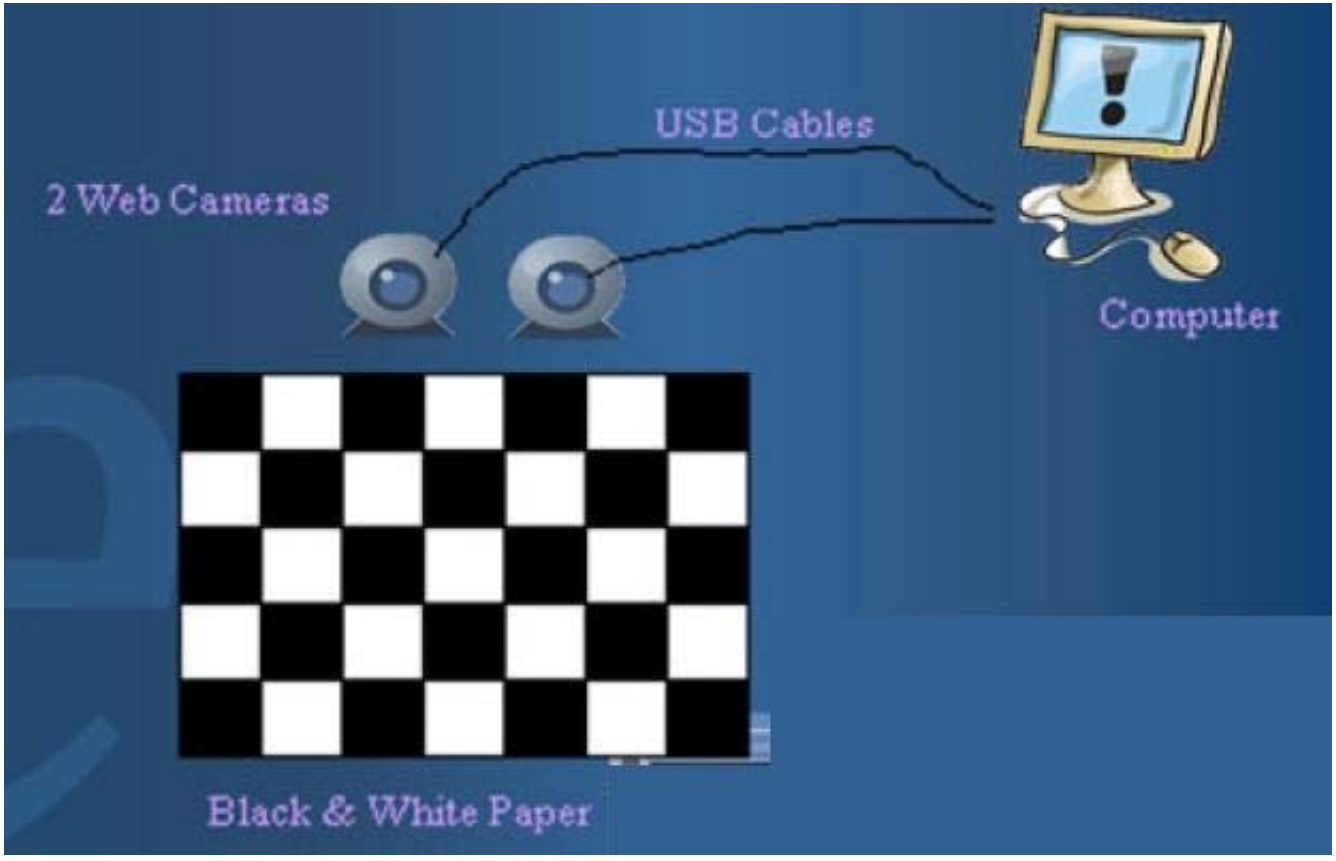
Process: Calibration (con’t)

Objective

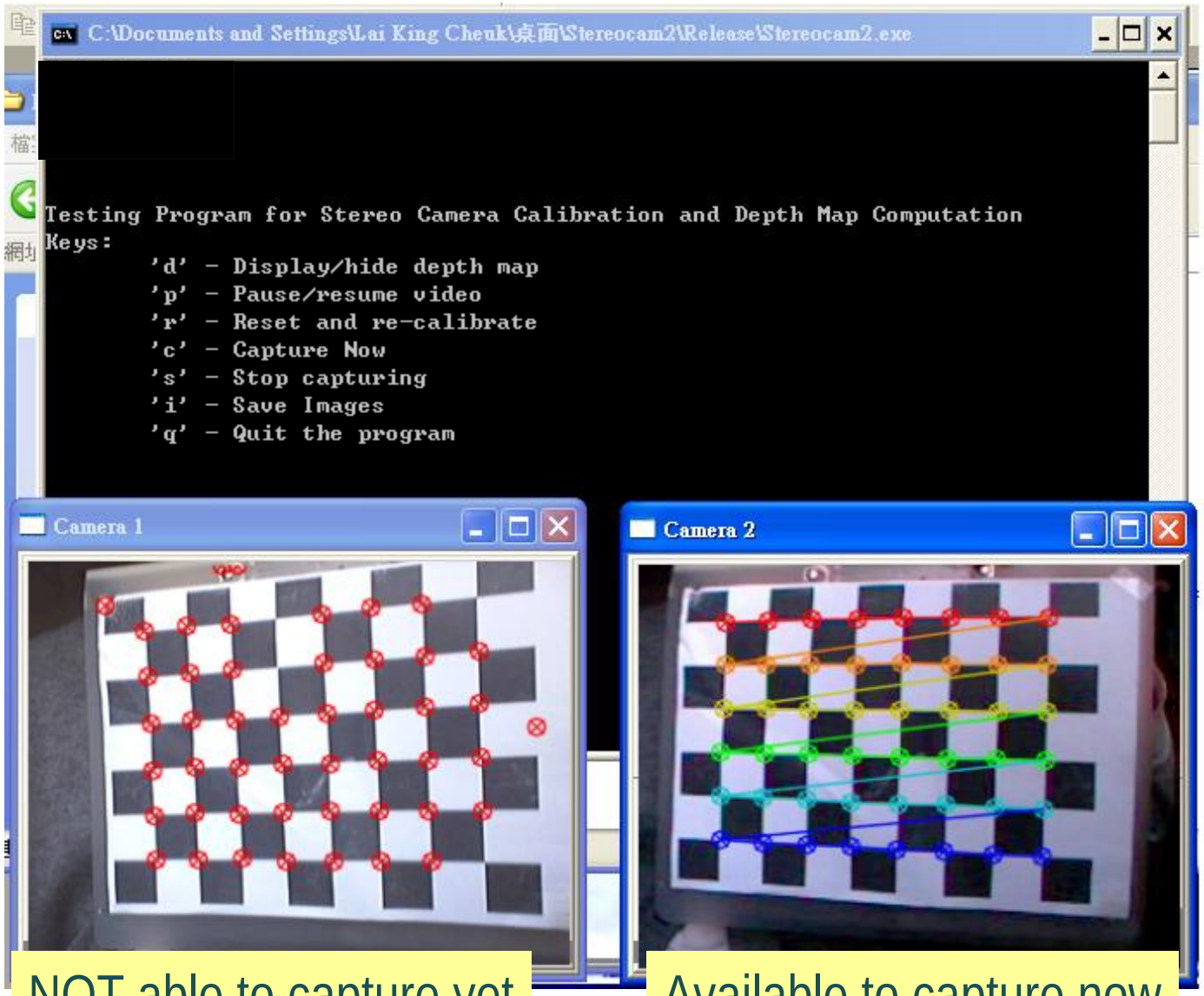
- Match with processes and enhance performance of the Stereo Matching.

Process: Calibration (con’t)

Placement of Devices



Process: Calibration (con't)



NOT able to capture yet

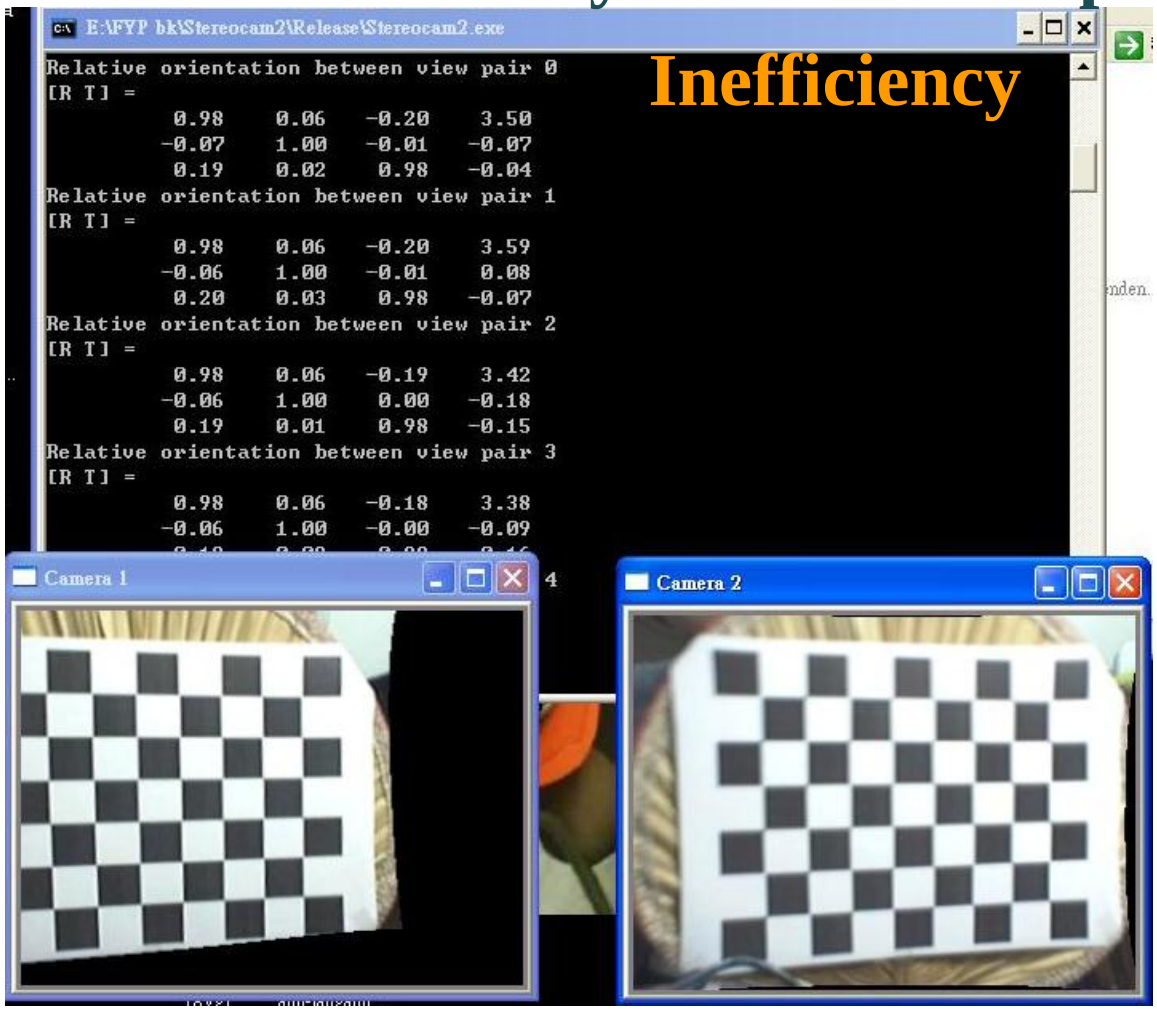
Available to capture now

Process: Calibration (con't)

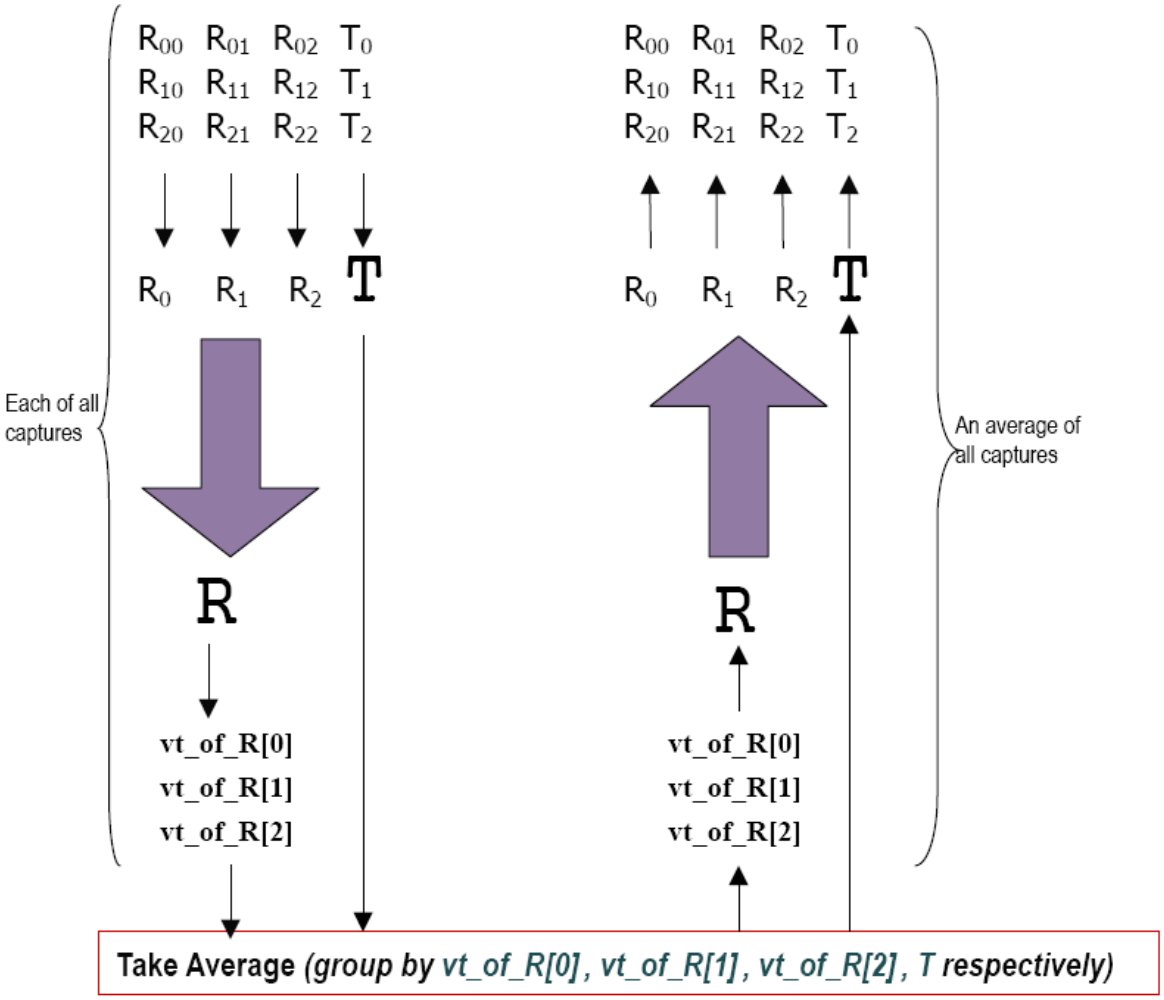
Original Program

Only 10 times of captures

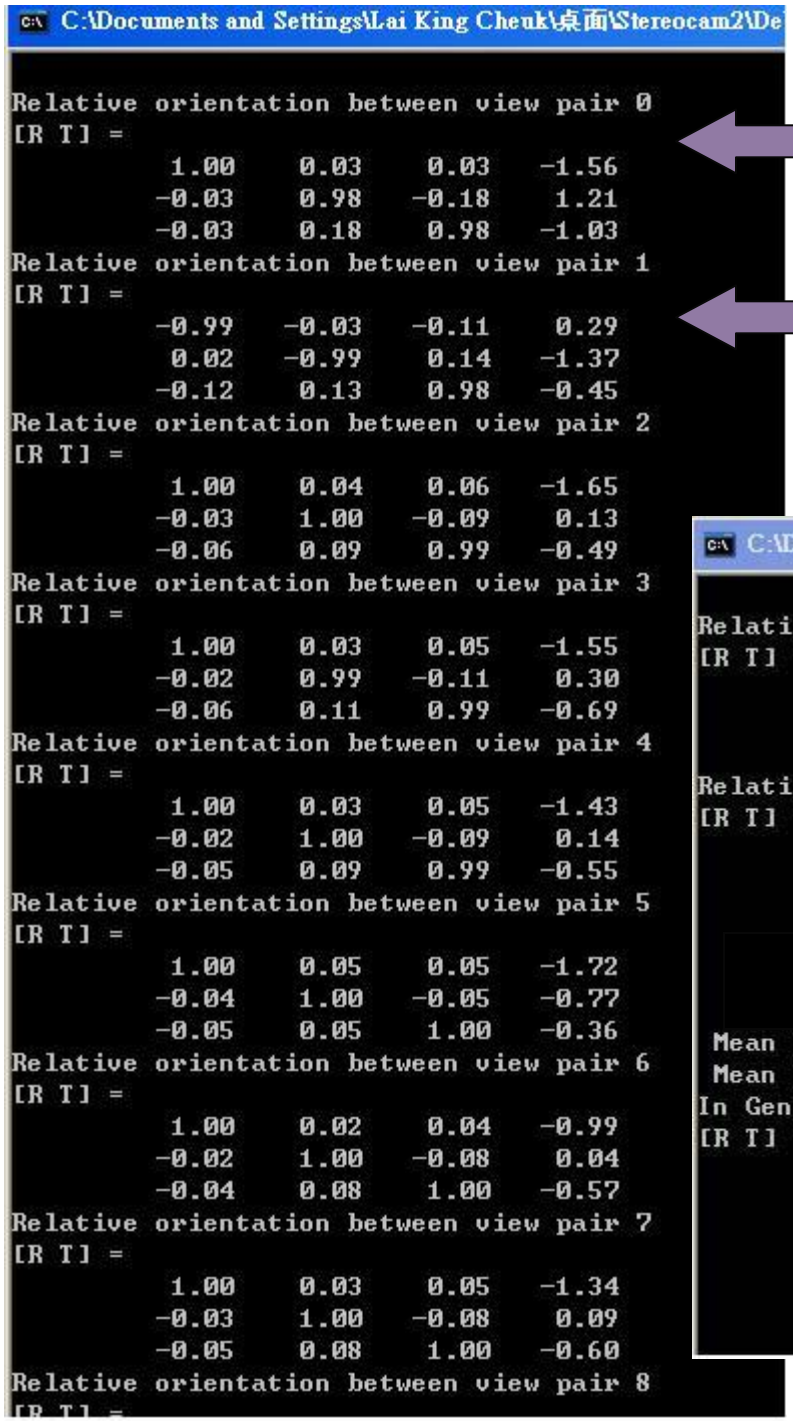
Inefficiency



Process: Calibration (con't)



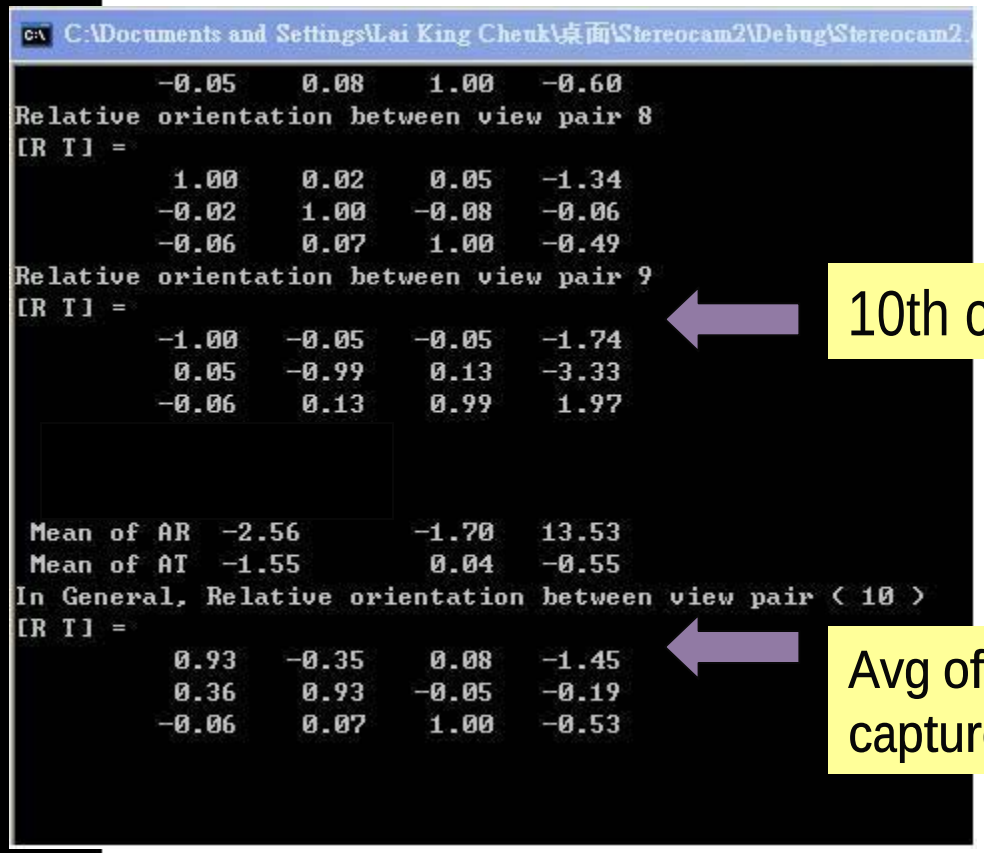
Calibration Improvement Concept



1st capture

2nd capture

and so on…

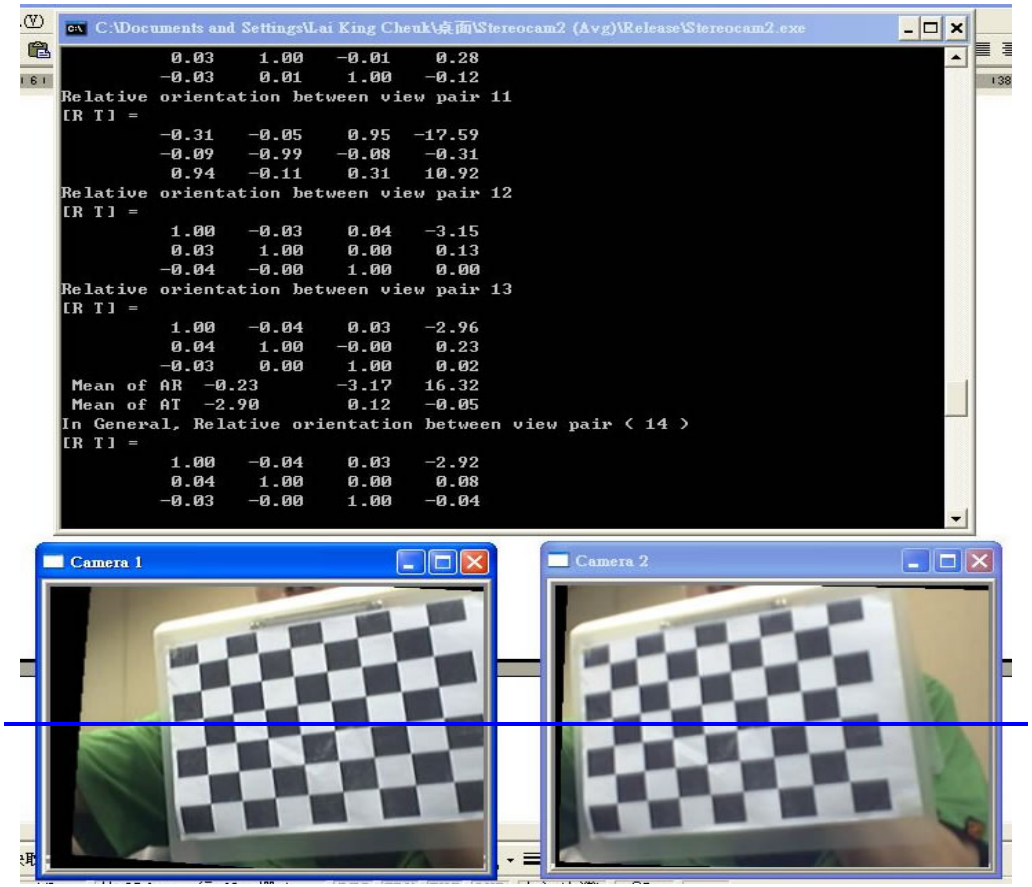


10th capture

Avg of captures

Process: Calibration (con't)

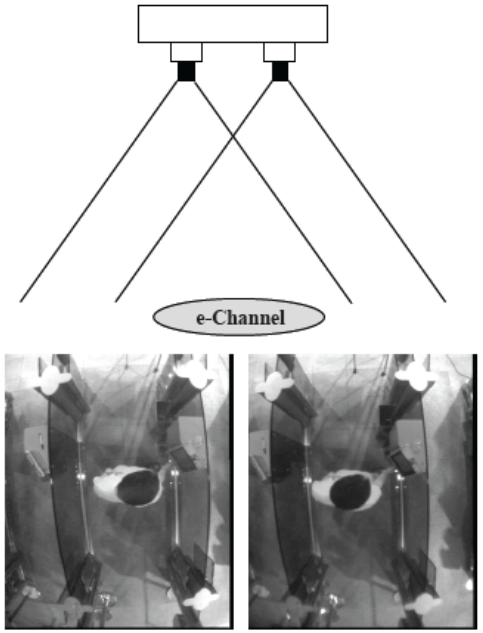
Improved Calibration



Rectified Left Image Rectified Right Image

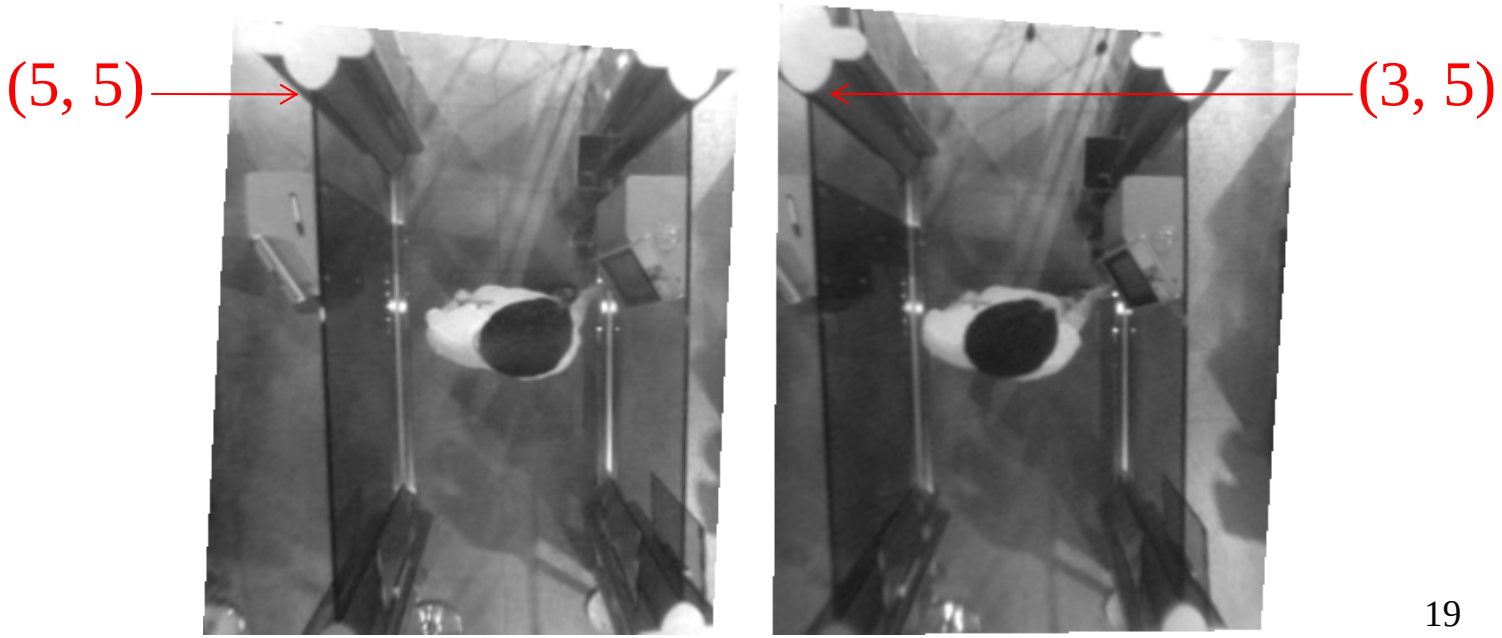
Process: Stereo Matching

- **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



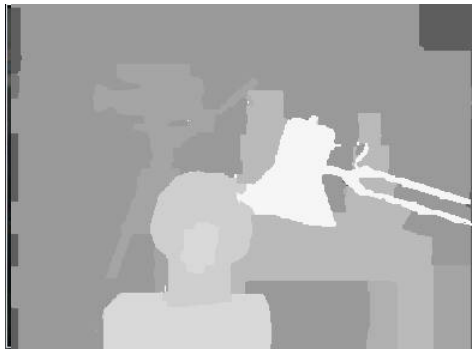
Process: Stereo Matching (Con't)

- 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.



Process: Stereo Matching (Con't)

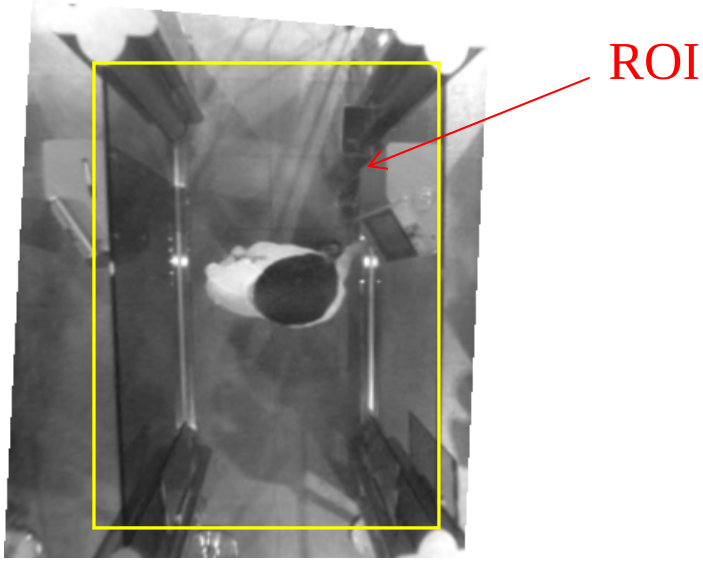
- Object that nears the cameras, its locations in 2 images will have a greater distance => larger disparity value
- After finding the disparity values for whole image, assemble them into a disparity map
- Intensity values represents the depth of points: intensity of a closer object is higher



Process: Stereo Matching (Con't)

- 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



Process: Stereo Matching (Con't)

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

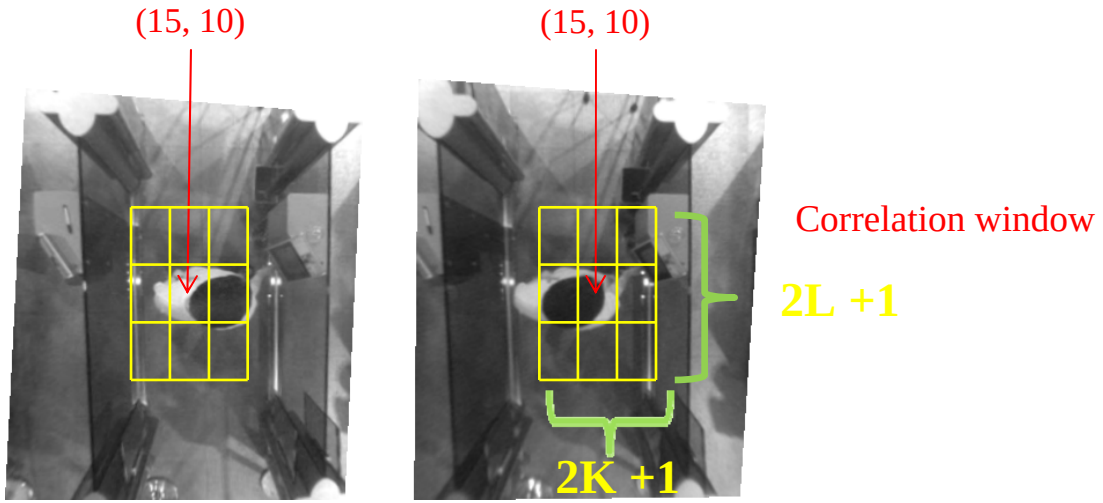
Process: Stereo Matching (Con't)

- **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

Process: Stereo Matching (Con't)

- 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

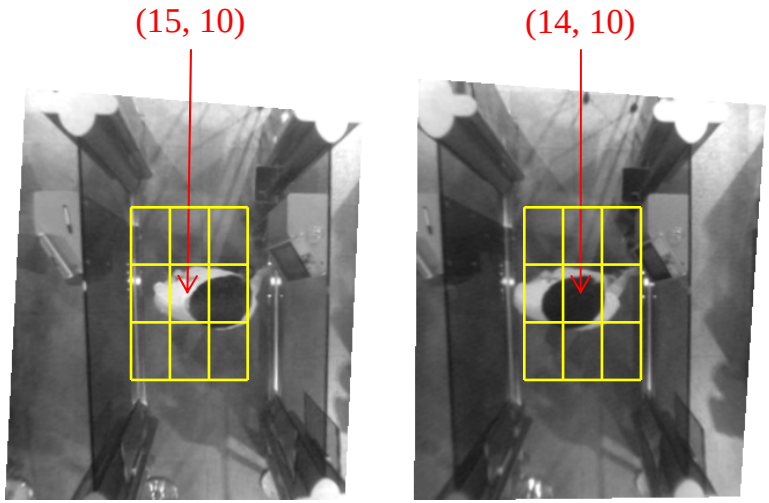
- After a point in right image with the best NCC value is found, the x-coordinate difference between 2 points will be the disparity value



Process: Stereo Matching (Con't)

- 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

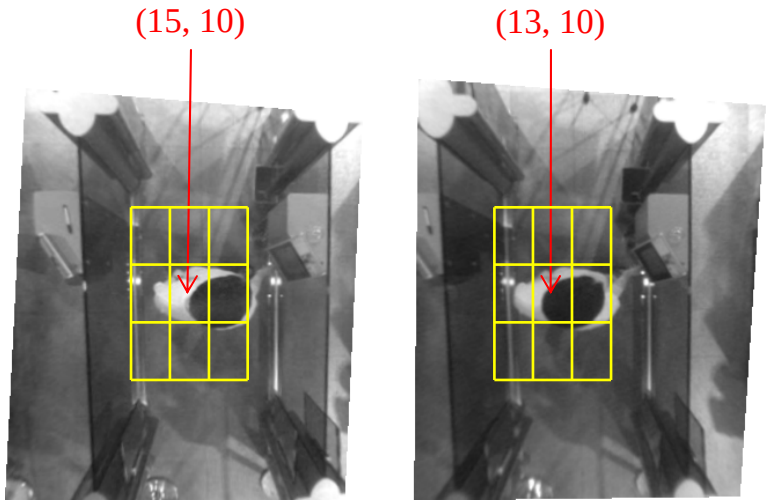
- After a point in right image with the best NCC value is found, the x-coordinate difference between 2 points will be the disparity value



Process: Stereo Matching (Con't)

- 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



Process: Stereo Matching (Con't)

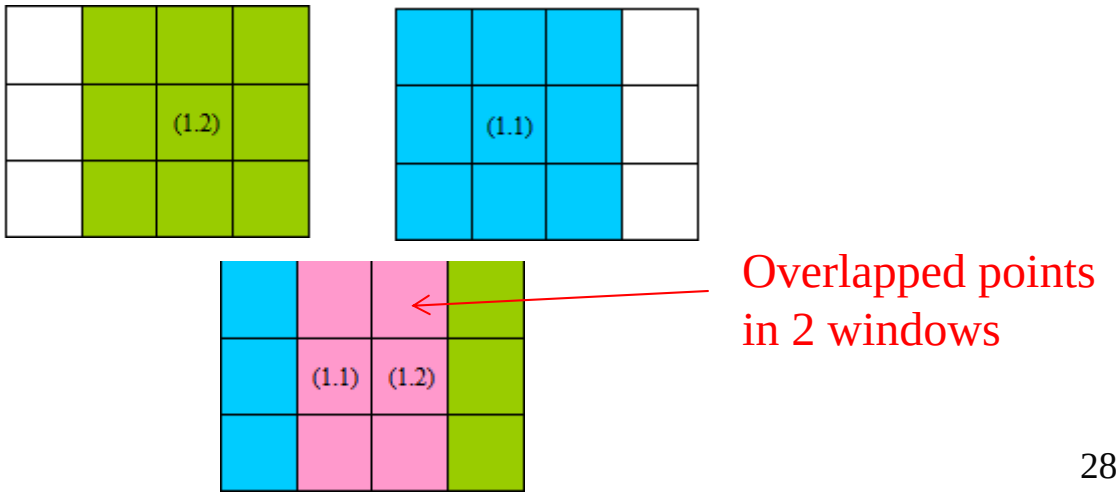
- Calculation of NCC is computationally expensive
- Formula:

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

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

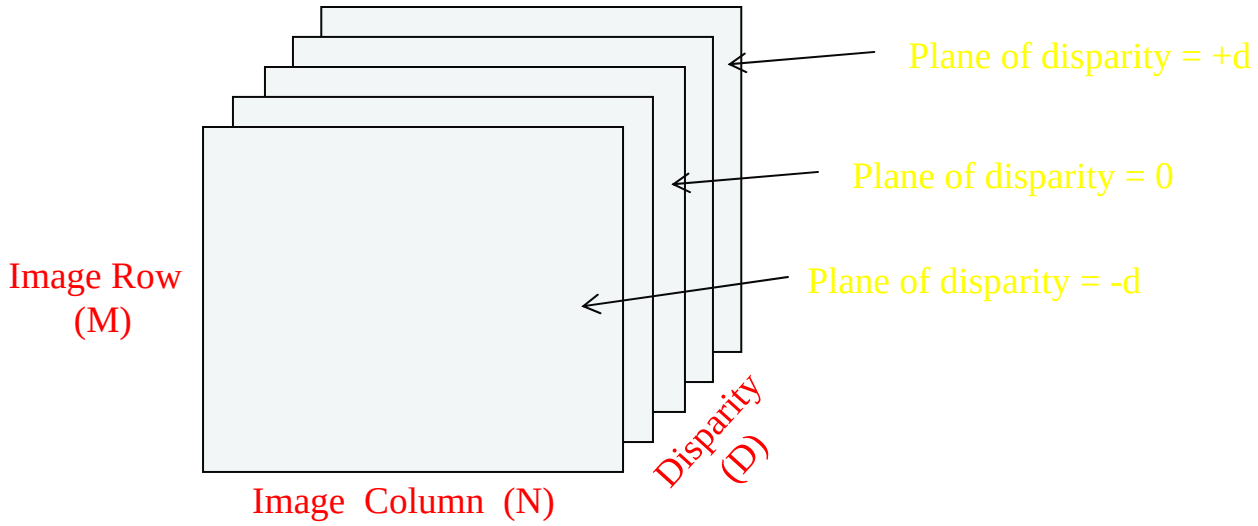
Process: Stereo Matching (Con't)

- 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



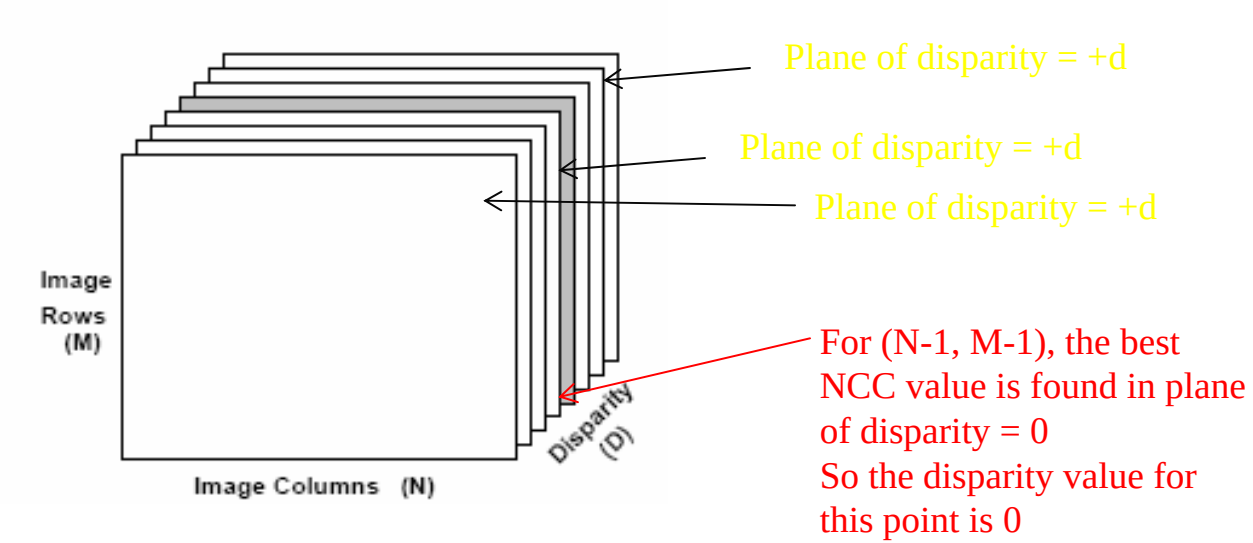
Process: Stereo Matching (Con't)

- **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



Process: Stereo Matching (Con't)

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



Process: Stereo Matching (Con't)

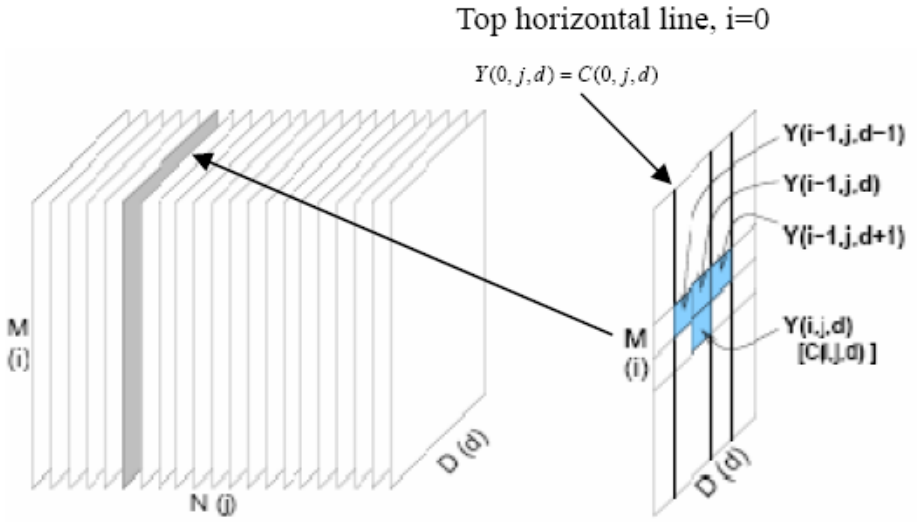
- Finding the best NCC value for each point separately, discontinuity of disparity value between points may occur

- **Two-Stage Dynamic Programming** is introduced to find the disparity for each point where discontinuity is factored in.

Process: Stereo Matching (Con't)

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

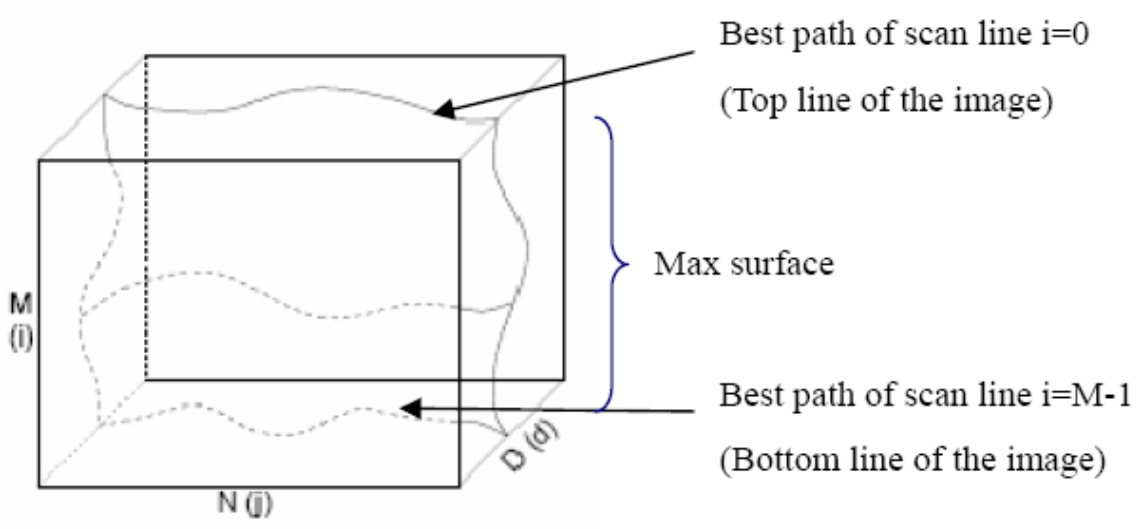
$$Y(i,j,d) = C(i,j,d) + Y(i-1,j,d-1)$$



- Accumulated max NCC values is then obtained

Process: Stereo Matching (Con't)

- 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

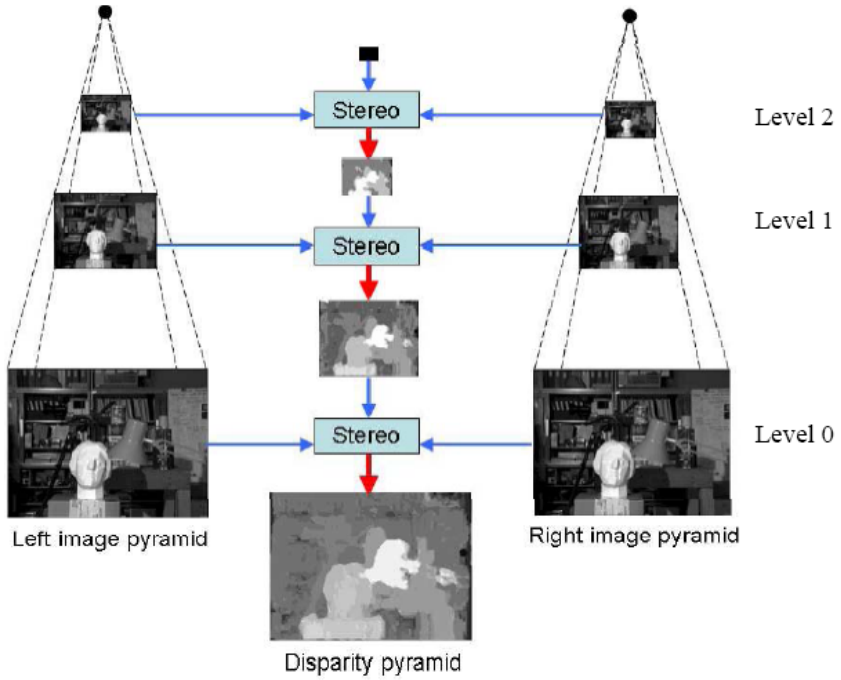


Process: Stereo Matching (Con't)

- **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

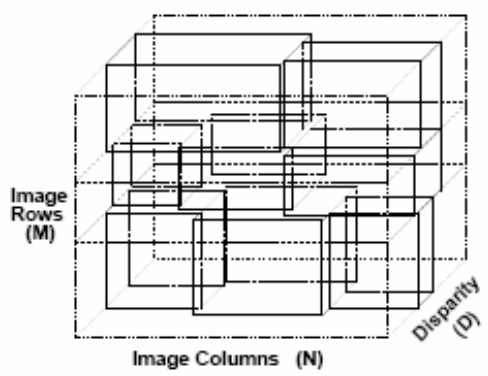
Process: Stereo Matching (Con't)



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

Process: Stereo Matching (Con't)

- 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.

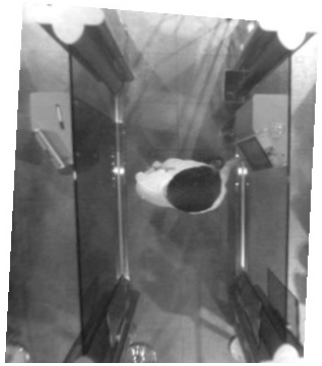


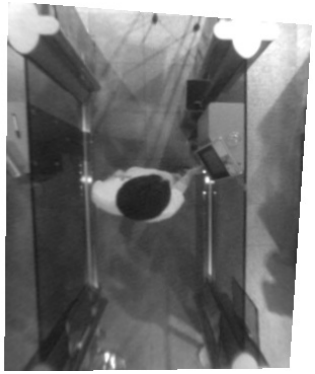
Process: Stereo Matching (Con't)

- **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

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