

Disparity Determination in Stereo Vision

Lu Sang, Michael Haberl, Raphael Ullmann

22.07.2017

Overview

Problem Description

Algorithms

Results

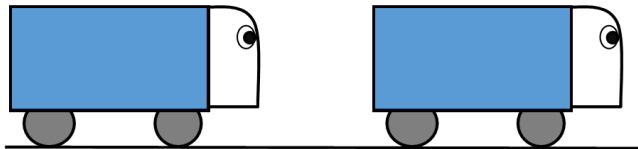
Overview

Problem Description

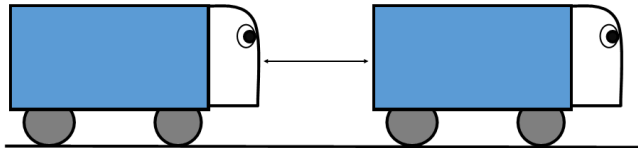
Algorithms

Results

Problem Description



Problem Description



Problem Description

- What is the distance to an object?
- How to determine the distance by 2D images?

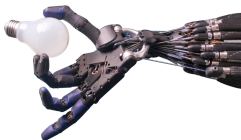
¹<https://upload.wikimedia.org/wikipedia/commons/4/49/Roboterhand.mit.Gluehbirne.png>

Problem Description

- What is the distance to an object?
- How to determine the distance by 2D images?

Applications

- Autonomous driving
- Robotics
- Object recognition



Stereo Cameras



Corresponding Pixels



Figure: Left Picture [1]



Figure: Right Picture

Corresponding Pixels



Figure: Left Picture [1]



Figure: Right Picture

Corresponding Pixels



Figure: Left Picture [1]

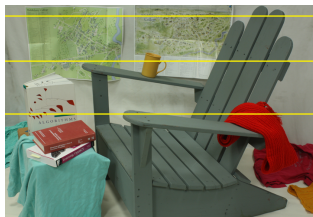


Figure: Right Picture

- 1 Calculate for the pixels in the left image costs in the right image

Corresponding Pixels



Figure: Left Picture [1]

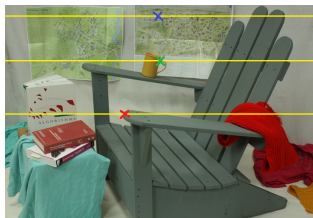
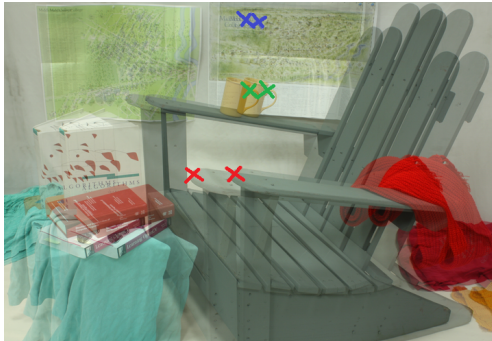


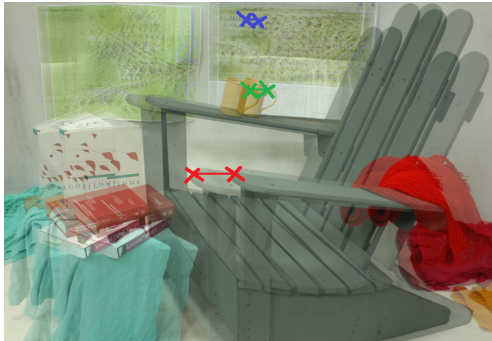
Figure: Right Picture

- 1 Calculate for the pixels in the left image costs in the right image
- 2 Pixel with minimal cost is the corresponding pixel

Disparity



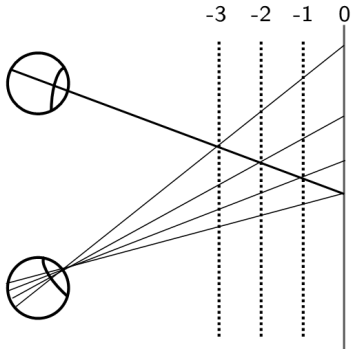
Disparity



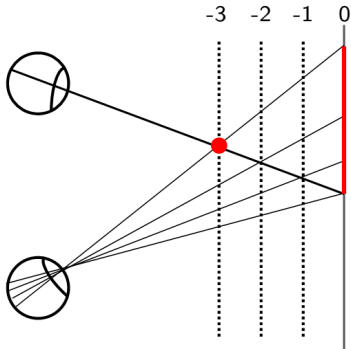
Disparity

Pixel distance of related pixels.

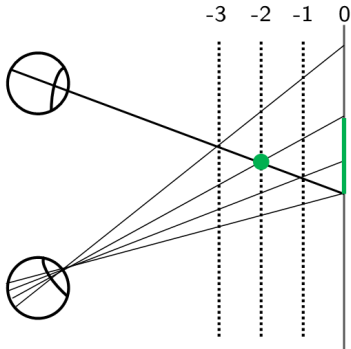
Getting distance from Disparity



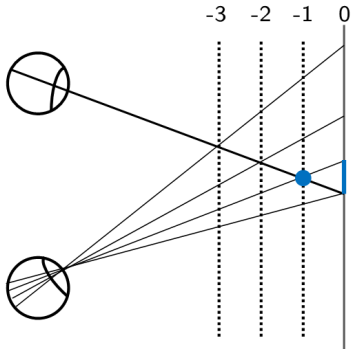
Getting distance from Disparity

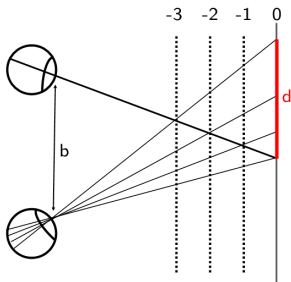


Getting distance from Disparity



Getting distance from Disparity





Distance

$$z = \frac{f \cdot b}{d}$$

- Distance z
- Focal length of the camera f
- Disparity d

Overview

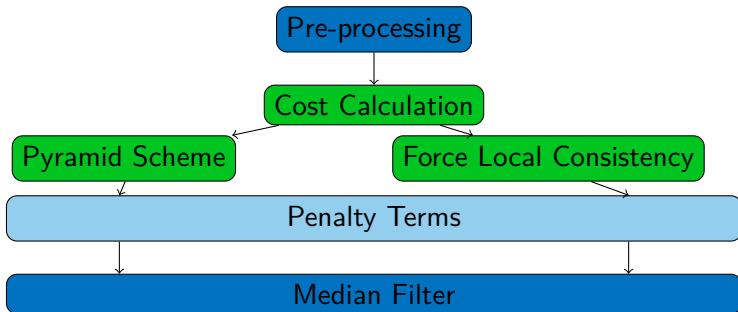


Problem Description

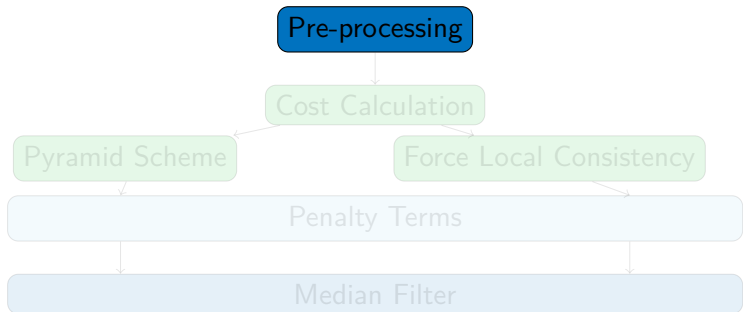
Algorithms

Results

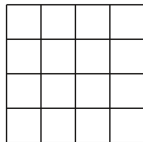
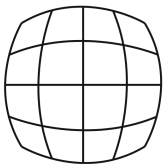
Overview



Overview



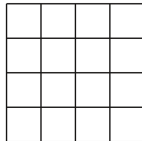
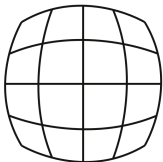
Pre-processing: Undistortion



Original Picture

Undistorted Picture

Pre-processing: Undistortion

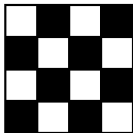
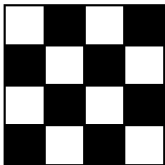


Original Picture

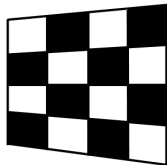
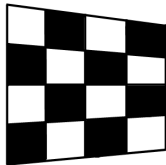
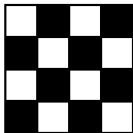
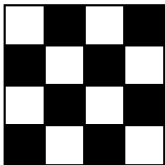


Undistorted Picture

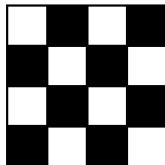
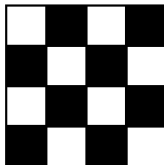
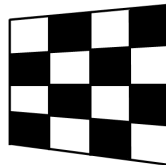
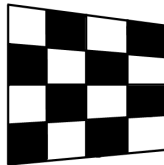
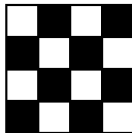
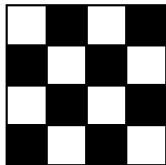
Pre-processing: Rectification



Pre-processing: Rectification



Pre-processing: Rectification



Pre-processing: Rectification



Left Picture

Right Picture

Pre-processing: Rectification



Left Picture

Right Picture

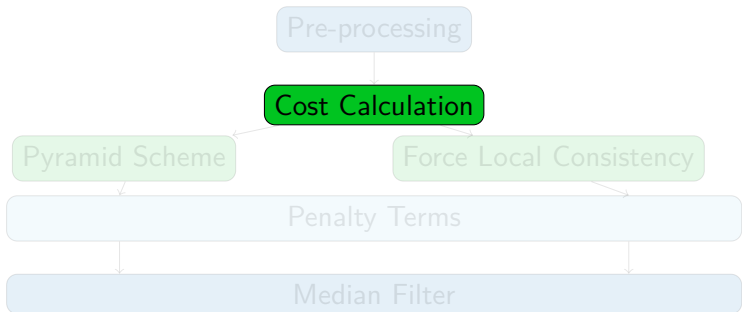


Energy Function

$$\operatorname{argmin}_d C(p, d) + S(p, d)$$

- Cost $C(p, d)$ for every pixel p and disparities $d = 1, \dots, D$
- Regularization $S(p, d)$
 - E.g. penalty for deviation of neighbouring pixels

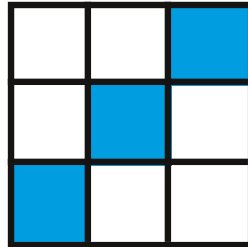
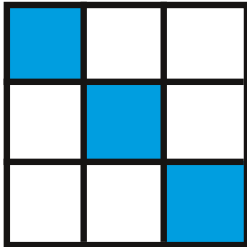
Overview



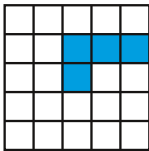
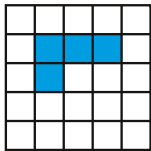
Cost Calculation: Comparing Windows



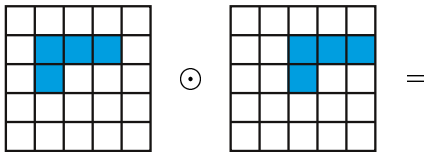
Cost Calculation: Comparing Windows



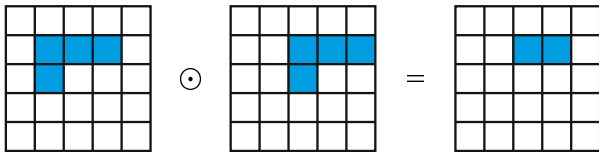
Cost Calculation: Cross Correlation



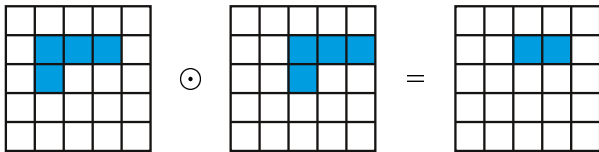
Cost Calculation: Cross Correlation



Cost Calculation: Cross Correlation

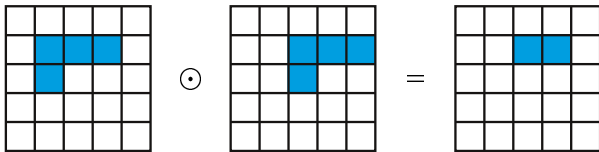


Cost Calculation: Cross Correlation

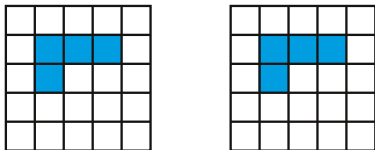


Total sum = 2 \Rightarrow Costs = -2

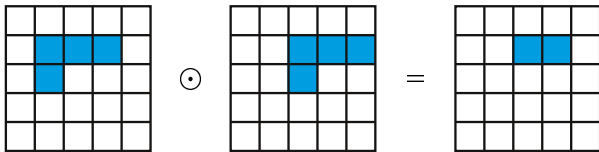
Cost Calculation: Cross Correlation



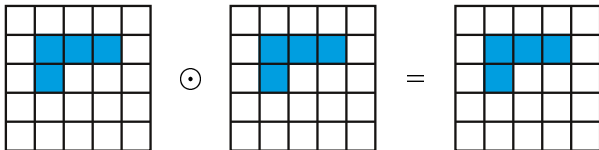
Total sum = 2 \Rightarrow Costs = -2



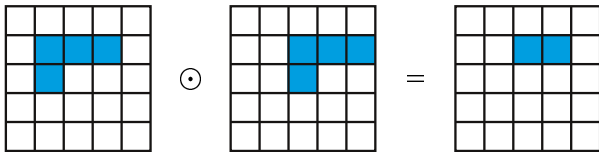
Cost Calculation: Cross Correlation



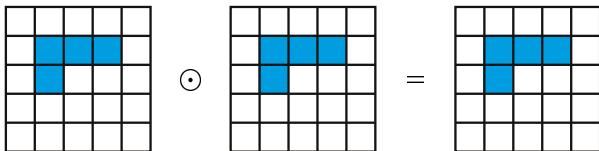
Total sum = 2 \Rightarrow Costs = -2



Cost Calculation: Cross Correlation

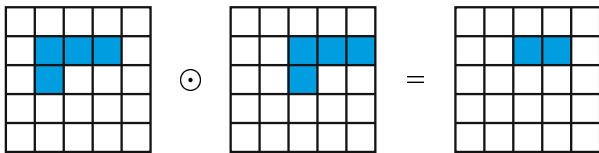


Total sum = 2 \Rightarrow Costs = -2

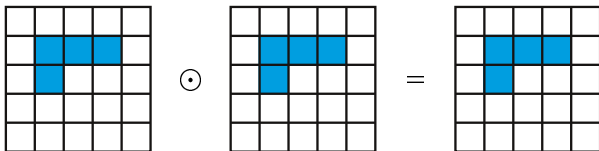


Total sum = 4 \Rightarrow Costs = -4

Cost Calculation: Cross Correlation



Total sum = 2 \Rightarrow Costs = -2



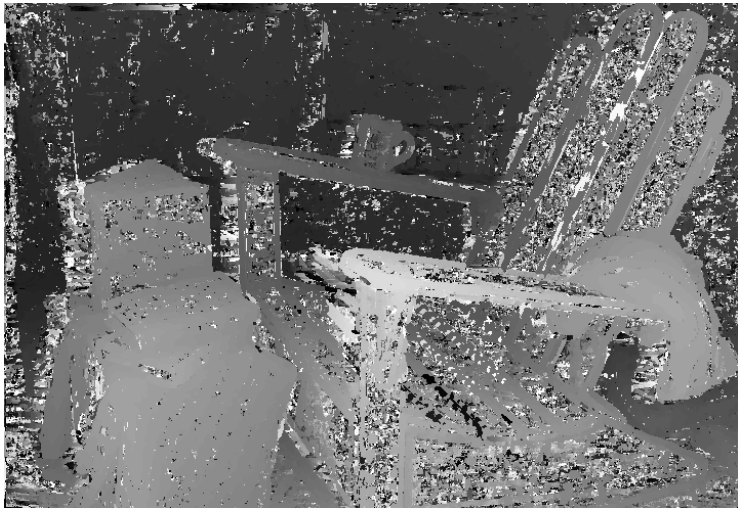
Total sum = 4 \Rightarrow Costs = -4

Normalization and Zero Mean: Values in $[-1, 1]$

Cost Calculation: Result



Cost Calculation: Result



Cost Calculation: Result



- Error Rate of NCC: 33.09%

Test Data



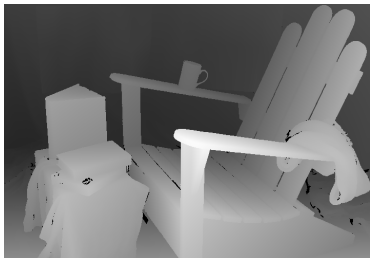
Figure: Left Image



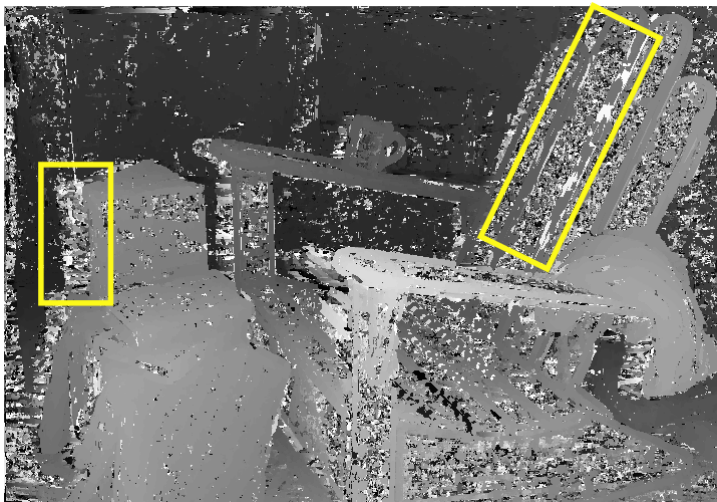
Figure: Right Image



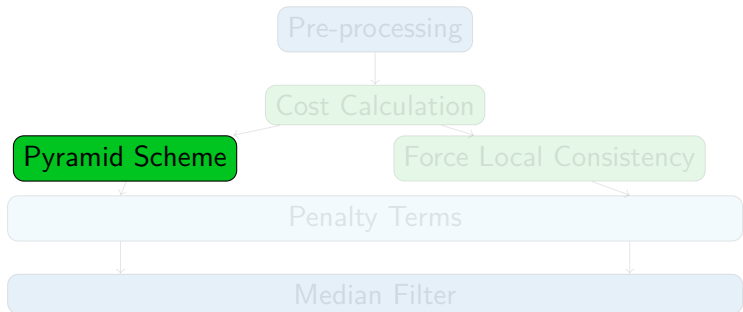
- Middlebury Dataset
- Ground Truth
- Leaderboard



Algorithm Defect



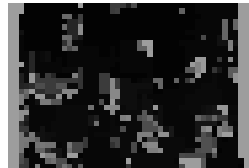
Overview



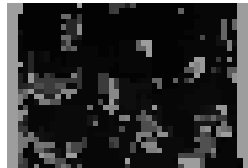
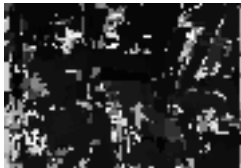
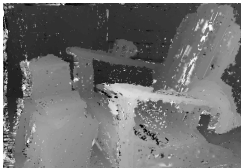
Pyramid Scheme



Pyramid Scheme



Pyramid Scheme



Pyramid Scheme: Results

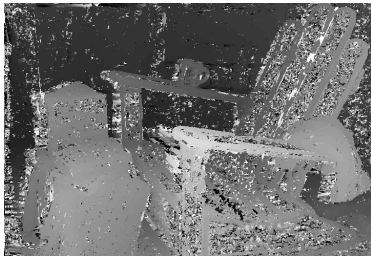


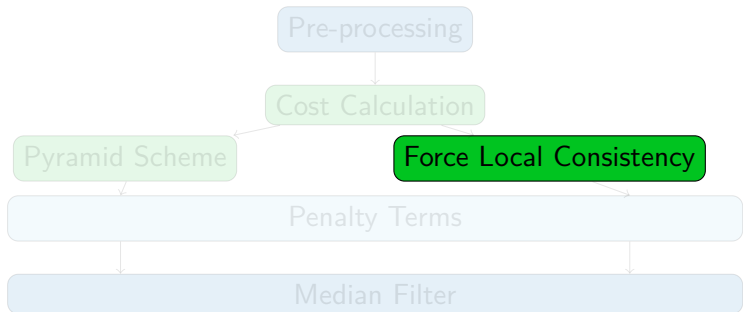
Figure: Results of NCC



Figure: Results of Pyramid Scheme

- Error Rate of NCC: 33.09%
- Error Rate of Pyramid Scheme: 28.1%

Overview



Force Local Consistency



- Interpret Cross Correlation as confidence indicator
- Use only pixels with high confidence
- Replace low confidence by values with high confidence in the window

Force Local Consistency: Confidence Map

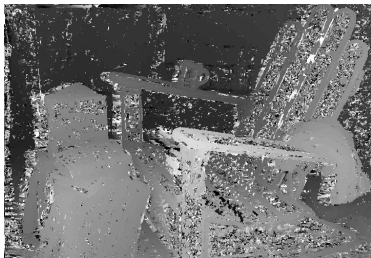


Figure: Results of NCC

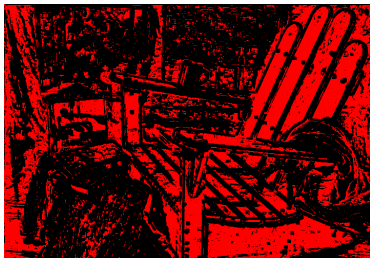
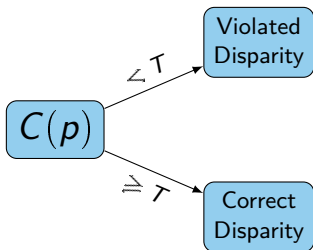


Figure: Confidence Map

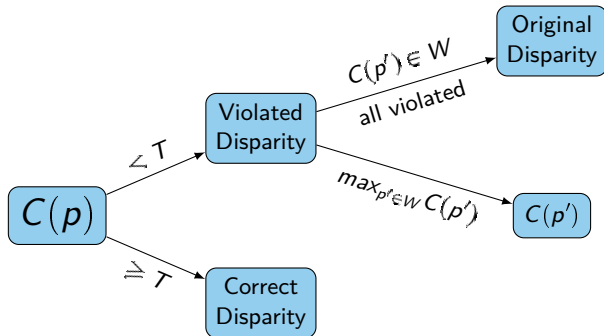
- Black point: trustworthy pixel with correct disparity ($C(p) \geq T$).
- Red point: unreliable pixel with violated disparity ($C(p) < T$).

Force Local Consistency



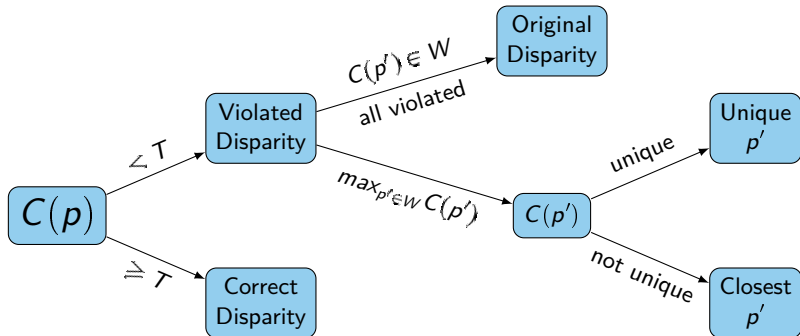
- 1 Mark all violated pixels.

Force Local Consistency



- 1 Mark all violated pixels.
- 2 Find the pixel with max NCC coefficient.

Force Local Consistency



- 1 Mark all violated pixels.
- 2 Find the pixel with max NCC coefficient.
- 3 Replace the disparity value by using the disparity of new pixel.

Force Local Consistency: Results

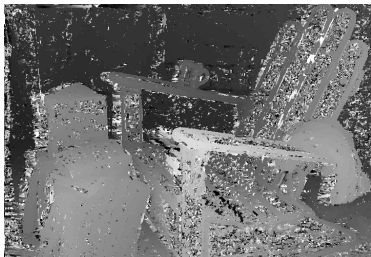


Figure: Results of NCC

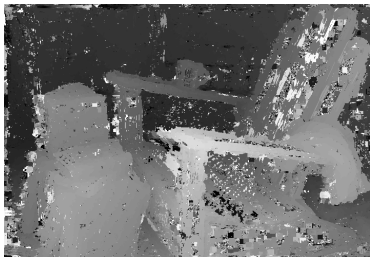
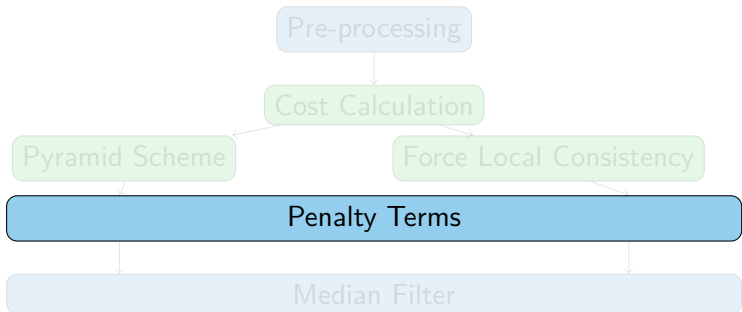


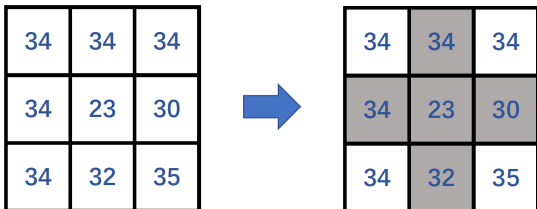
Figure: Results of FLC

- Error Rate of NCC: 33.09%
- Error Rate of FLC: 26.90%

Overview



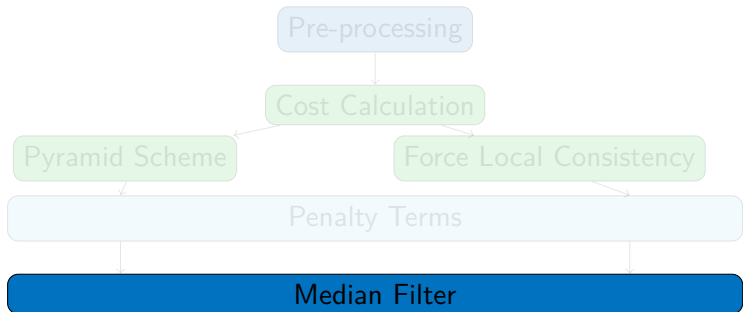
Local Penalty



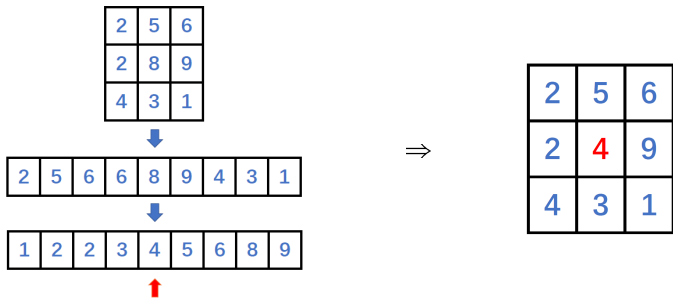
Local Penalty

- 1 Smoothness check
- 2 Search four directions
- 3 Punish on NCC coefficient
- 4 Iterate

Overview



Post Processing: Median Filter



Final Results



Figure: Results of FLC



Figure: After Post-processing

- Error Rate of FLC: 26.90%
- Error Rate of FLC + Median filter: 21.10%

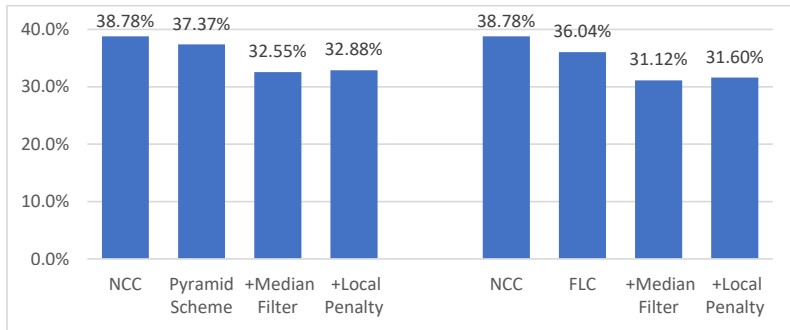
Overview

Problem Description

Algorithms

Results

Results: Average Error Rates



Own Pictures



Figure: Left Image



Figure: Pyramid Scheme
+ Median Filter

Own Pictures

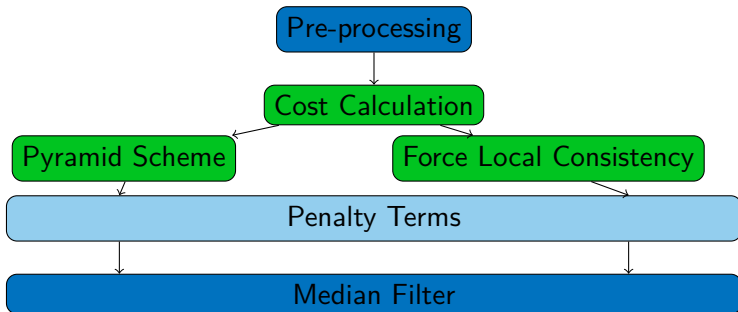


Figure: Left Image



Figure: Pyramid Scheme
+ Median Filter

Summary



Failed Approaches

- Disparity Calculation:
 - Cost Aggregation
 - Gradient Guided Weighted Match
 - Neural Network
- Disparity Refinement
 - Local Interpolation
 - Cubic Plane Interpolation
 - Segment Penalty
- Post-processing
 - Bilateral Filter
 - Gradient Guided Mask Filter

Failed Approaches

- Disparity Calculation:
 - Cost Aggregation
 - Gradient Guided Weighted Match
 - Neural Network
- Disparity Refinement
 - Local Interpolation
 - Cubic Plane Interpolation
 - Segment Penalty
- Post-processing
 - Bilateral Filter
 - Gradient Guided Mask Filter

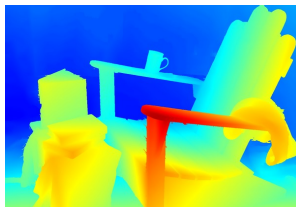
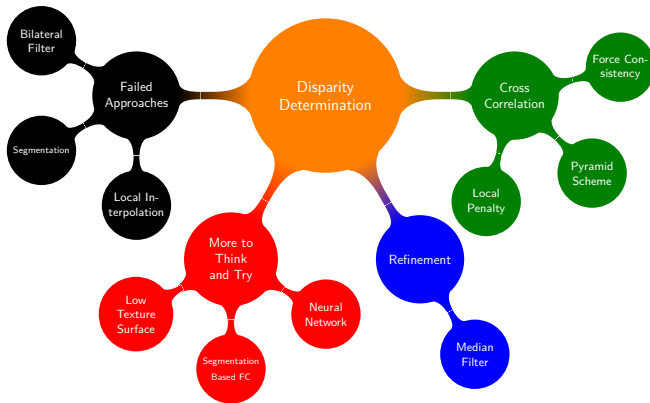


Figure: Disparity Image using Neural Networks

Thanks!



Sources

- [1] D. Scharstein, H. Hirschmüller, Y. Kitajima, G. Krathwohl, N. Nestic, X. Wang, and P. Westling. High-resolution stereo datasets with subpixel-accurate ground truth. In German Conference on Pattern Recognition (GCPR 2014), Münster, Germany, September 2014