Constrained optimisation for plane based stereo

Shahnawaz Ahmed, Miles Hansard, Andrea Cavallaro

Published in:
IEEE Transactions on Image Processing, 2018

Centre for Intelligent Sensing
Queen Mary University of London

Problem

Find depth of a scene

Stereo Vision

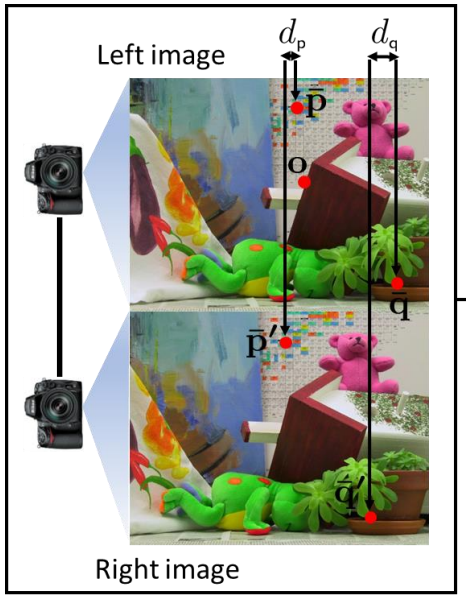
- Estimate depth using two views of the scene
  - Cameras are separated by a horizontal shift

Left image

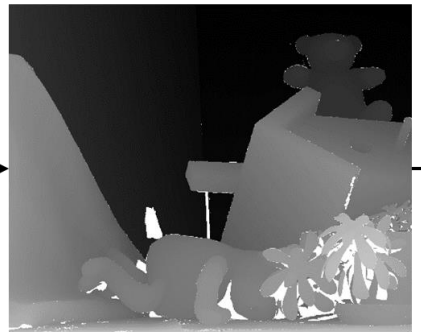
Right image

Disparity

- Horizontal difference between corresponding pixels
- Disparity space (x, y, d)
  - (x, y) : pixel position
  - d : disparity
- Disparity is inversely proportional to depth



Stereo matching

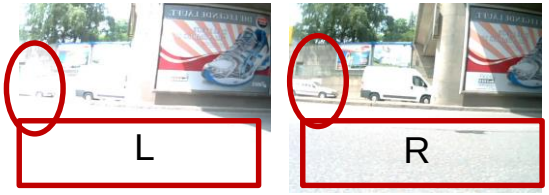


Disparity map

3D view

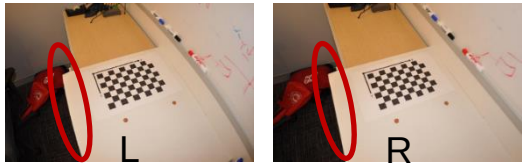
Challenges

- Photometric Variations



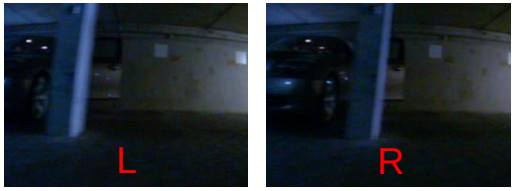
- Specularities

- Lens distortion



- Occlusion

- Image Sensor Noise



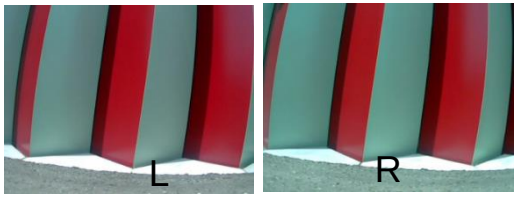
- Textureless Regions

- Reflections

- Transparency

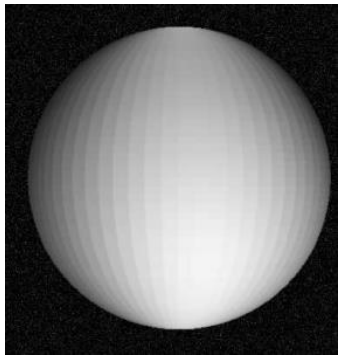
- Foreshortening and the Uniqueness Constraint

- Repetitive Structures and Textures

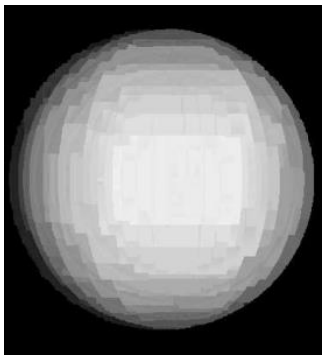


Limitations of Stereo Matching

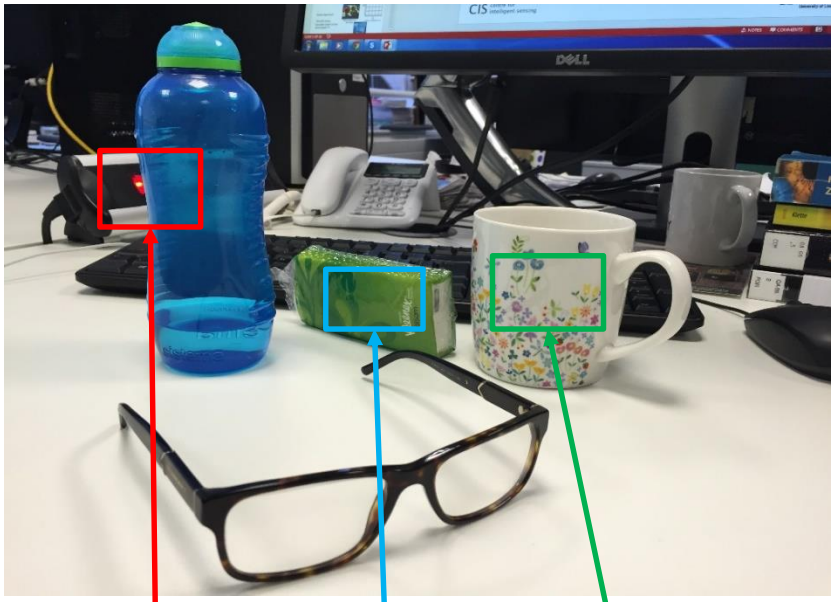
- Assumes all pixels within a patch have constant disparity
  - Assumption does not hold in real world scenarios
  - Consequence: Jump in disparity map (staircase effect)



Ground truth

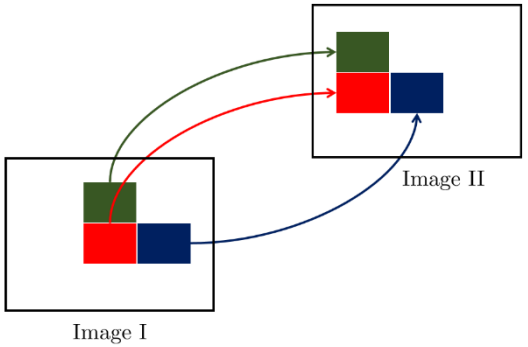


Staircase effect

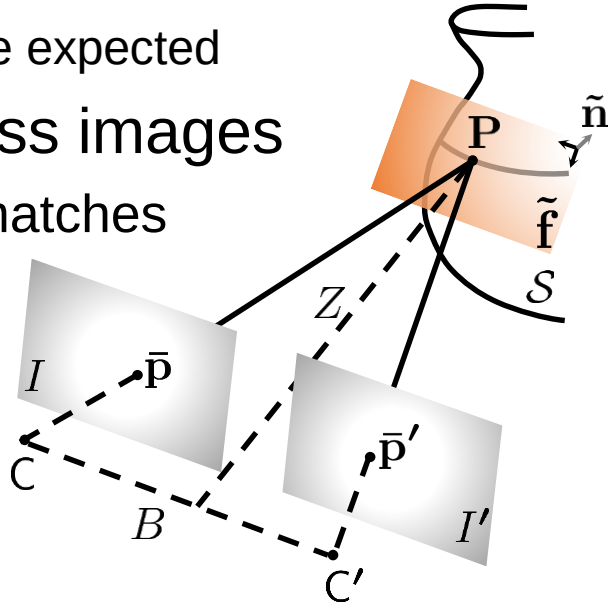


PatchMatch Stereo Framework[1]

- Estimates disparity from planes fitted to each pixel
  - Disparity of a pixel
    - Distance to the plane
  - Disparity space is over-parametrised
    - Three plane parameters
  - Large number of random sampling
    - Some good initial plane estimates are expected
- Propagate planes within and across images
  - Neighbouring pixels have coherent matches



Coherent matches with neighbours



Plane association with pixels

[1] M. Bleyer, C. Rhemann, and C. Rother. PatchMatch Stereo - Stereo Matching with Slanted Support Windows. In *Proc. of BMVC*. 2011.

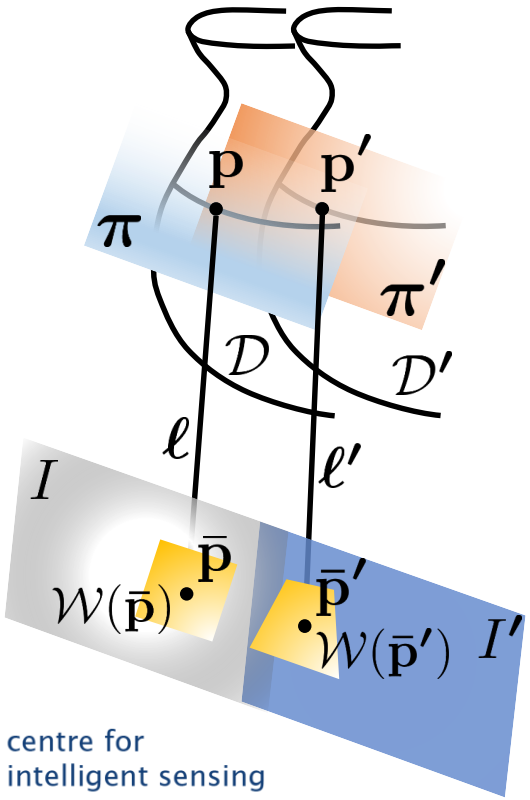
Initialised PatchMatch Stereo

- Primary limitation of PatchMatch Stereo
  - Feasible plane generation not guaranteed during initialisation

- Solution
  - Initialised PatchMatch Stereo (proposed)
    - Uses two geometric constraints to initialise the planes

Initialised PatchMatch Stereo

- Constraint I : Visibility constraint in the disparity space
  - Line of sight vector
    - Vector joining image points and corresponding disparity point
  - Plane should be visible from both line of sight vectors



I, I' : left, right image

$\bar{\mathbf{p}}, \bar{\mathbf{p}}'$: left, right image point

$\mathcal{W}(\bar{\mathbf{p}}), \mathcal{W}(\bar{\mathbf{p}}')$: left, right support window

ℓ, ℓ' : left, right “line of sight” vector

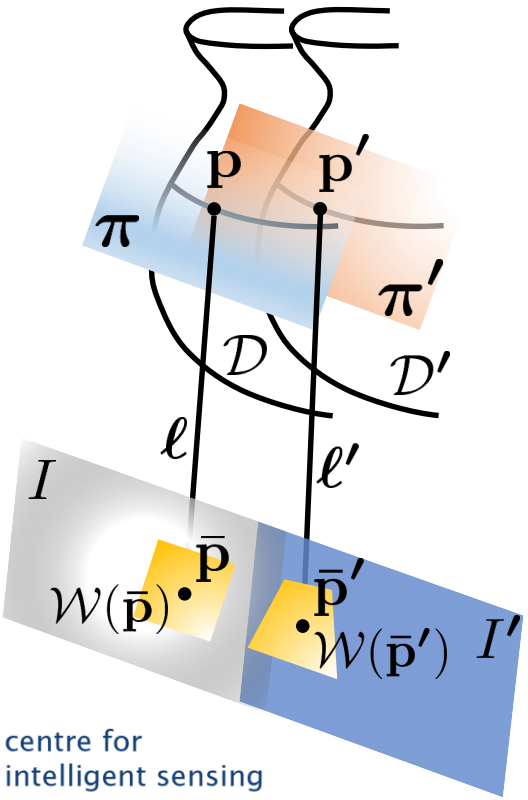
$\mathcal{D}, \mathcal{D}'$: left, right disparity space

$\mathbf{p}, \mathbf{p}'$: corr. point in the left, right disparity space

π, π' : left, right disparity plane

Initialised PatchMatch Stereo

- Constraint II : Disparity Bound Constraint on Support Window
  - Disparity of every pixel inside the support window
    - Lies between allowed disparity limit



I, I' : left, right image

$\bar{\mathbf{p}}, \bar{\mathbf{p}}'$: left, right image point

$\mathcal{W}(\bar{\mathbf{p}}), \mathcal{W}(\bar{\mathbf{p}}')$: left, right support window

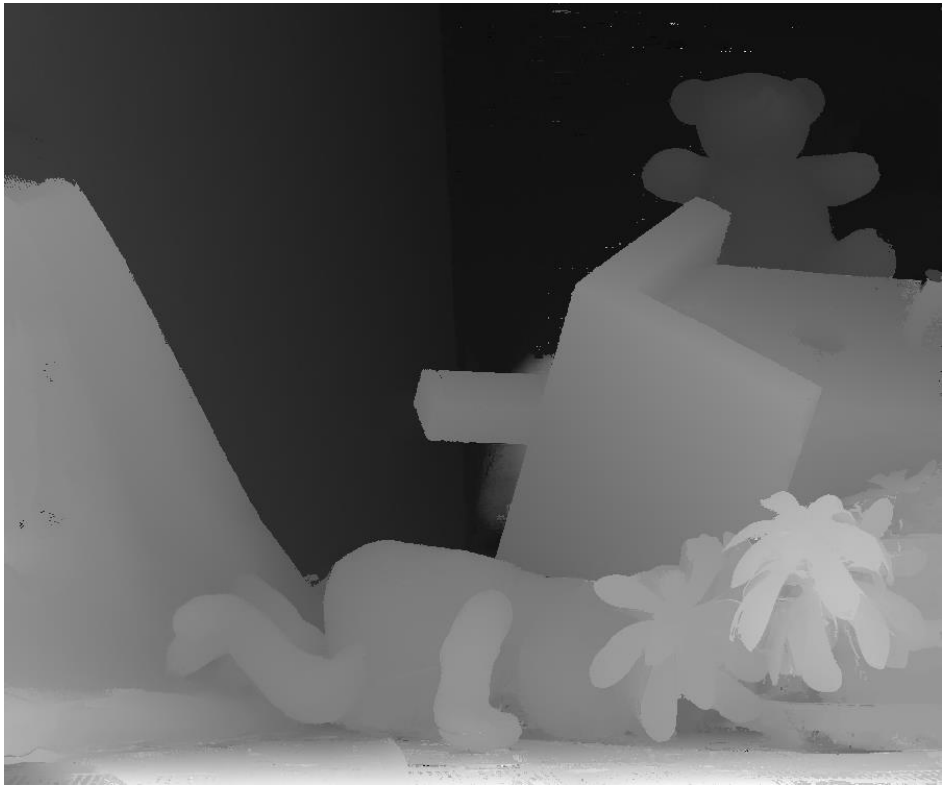
ℓ, ℓ' : left, right “line of sight” vector

$\mathcal{D}, \mathcal{D}'$: left, right disparity space

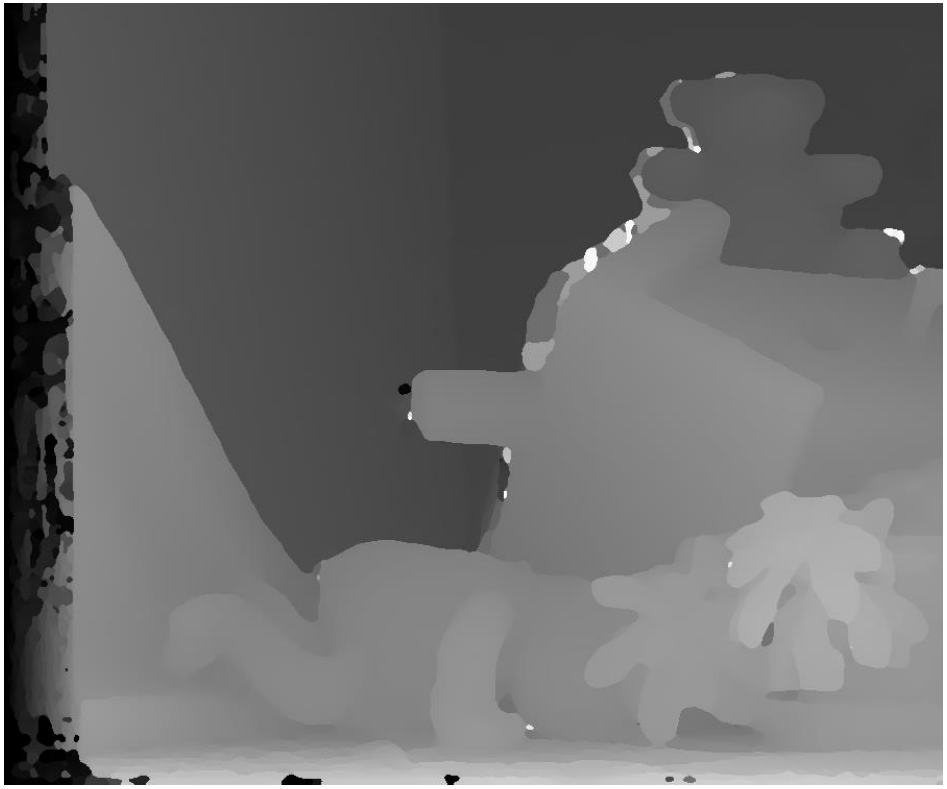
$\mathbf{p}, \mathbf{p}'$: corr. point in the left, right disparity space

π, π' : left, right disparity plane

Results (Disparity Map)



Initialised PatchMatch Stereo



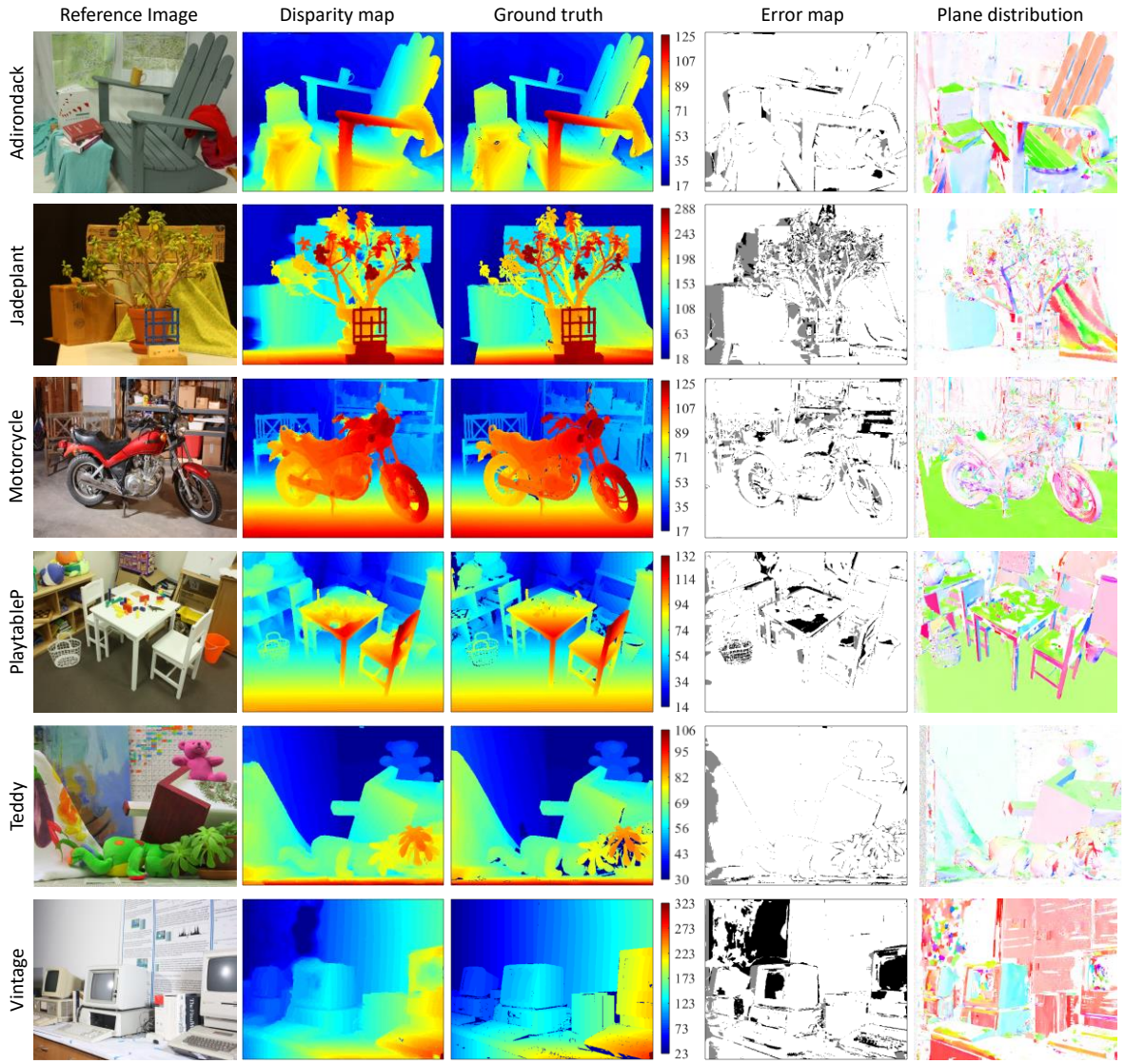
CNN [2]

[2] J. Zbontar and Y. LeCun. PatchMatch Stereo - Stereo Matching by training a convolutional neural network to compare image patches. CoRR, Oct. 2015

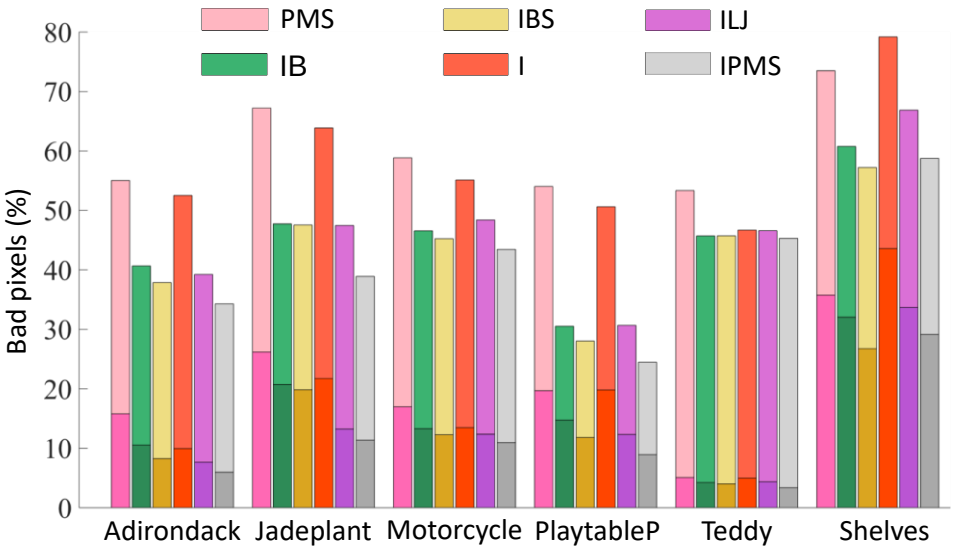
Results (Plane Normal Map)

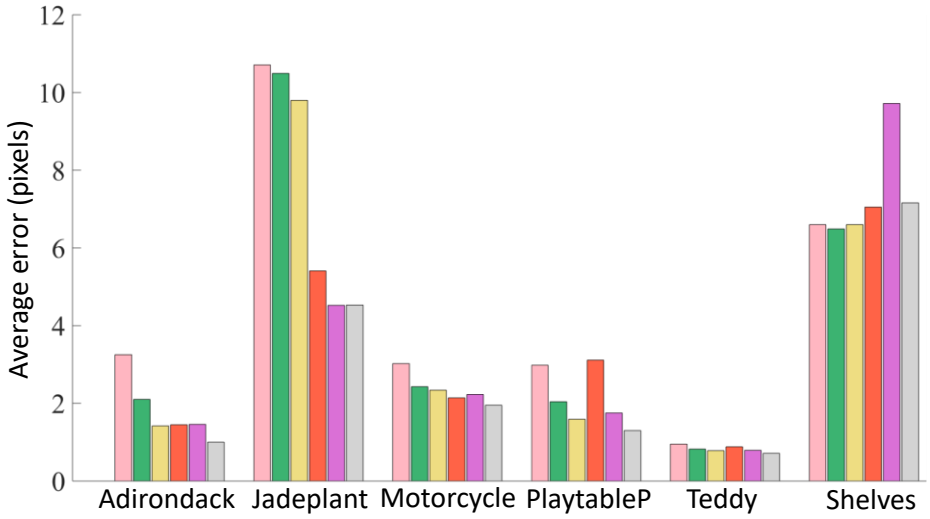
Initialised PatchMatch Stereo

Disparity Map of a Subset of Middlebury Dataset

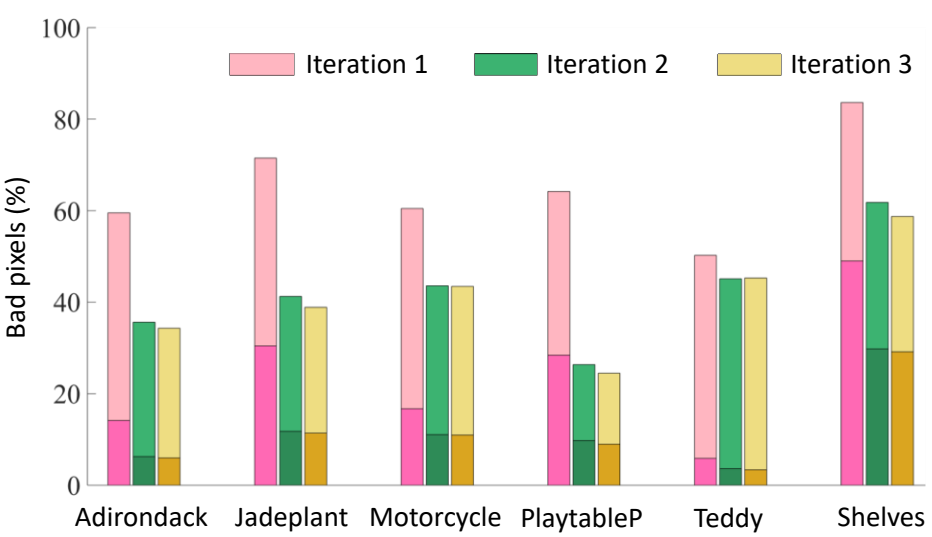


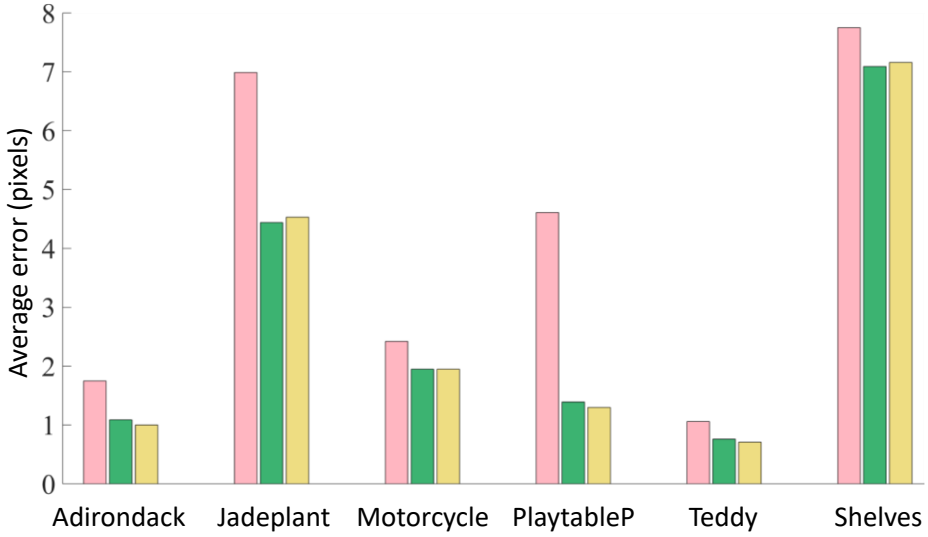
PMS vs IPMS Error Comparison





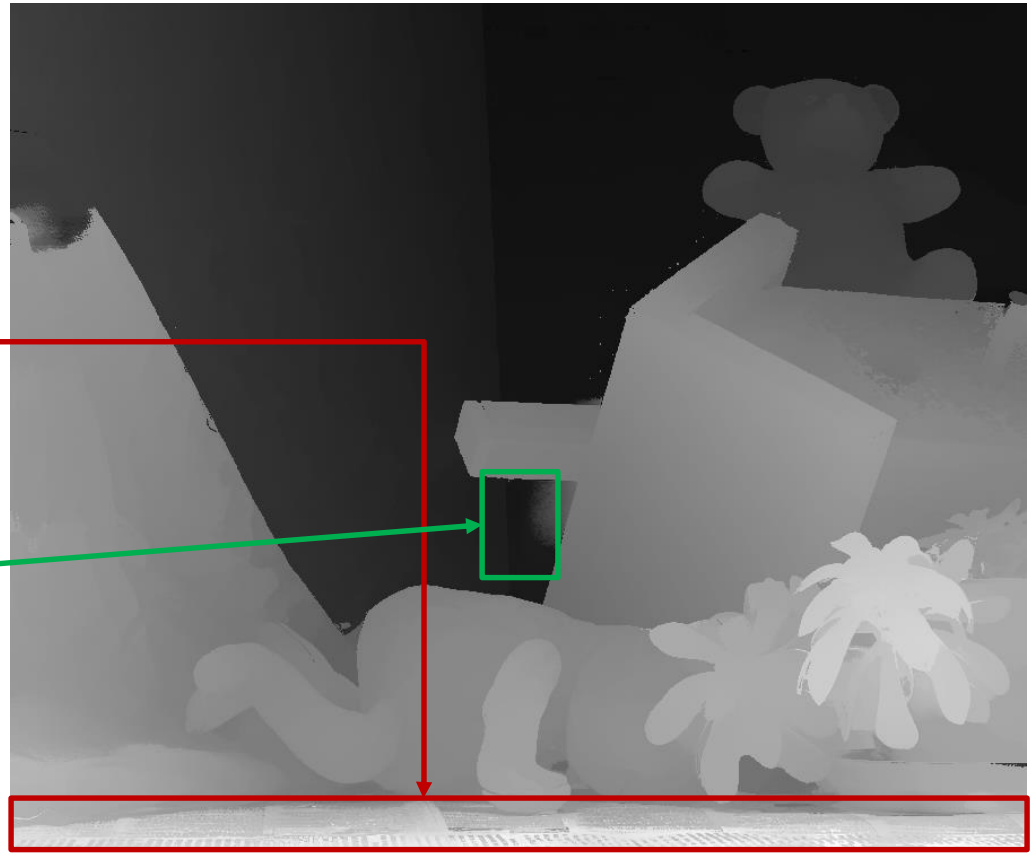
Iterations


Iteration 1
Iteration 2
Iteration 3
Bad pixels (%)
100
80
60
40
20
0
Adirondack
Jadeplant
Motorcycle
PlaytableP
Teddy
Shelves


Average error (pixels)
8
7
6
5
4
3
2
1
0
Adirondack
Jadeplant
Motorcycle
PlaytableP
Teddy
Shelves

Limitations

- High computation time
  - 234 mins (900px*750px)
  - Window size (41px*41px)
- Noisy disparity map
  - Repetitive patterns
  - Low texture regions
- Occlusion



Initialised PatchMatch Stereo

Conclusions

- Introduced a constrained initialisation scheme for plane parameters for PatchMatch Stereo framework
  - Geometrically feasible planes are associated with every pixel
- Converges in two iteration
- Future work
  - Extend the planar model to a quadric