Non-Uniform Hierarchical Pyramid Stereo for Large Images

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Overview

- Introduction.
- Classical pyramids.
- Error classification.
- Dealing with errors.
- The algorithm.
- Experimental results.
- Conclusion.
- Pyramidal schemes have been introduced to deal with high resolution images.
- Pyramidal schemes suffer from error propagation.
- We want to minimize error propagation between pyramid levels.
Introduction

Pixel based stereo

For each pixel in the left image we try to find the corresponding pixel in the right image.

The resulting displacement for that pixel (disparity) represents the distance between the object and the reference camera.
- $L_0$ is solved first.
- $L_1$ is then solved using the result of $L_0$ as an initialization.
- $L_2$ is then solved using the result of $L_1$ as an initialization.
- There can be more than 3 levels.
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Introduction  Taxonomy

pixel based stereo

pyramidal  full size [Scharstein et al. 2001]

approximate  exact  exact  approximate

approximate by level  exact by level
(X, Y) plane is the disparity map with block size $B_s$.

Axis $D$ is the disparity to assign over a range $Dr$ and disparity step $Ds$. 
Simultaneously increase the spatial and disparity resolution while reducing the disparity range.

- level 0 is over the full disparity range (absolute mode).
- level 1,2 is over an interval around the previous solution (relative mode).
Two kinds of error:

(A-C) Smooth surface error (can be recovered by classic pyramid).

(D-F) Discontinuity localization error (cannot be recovered by classic pyramid).
Increase spatial resolution at large discontinuities.

- A depth discontinuity is large if it is greater than a threshold.
- Keep subdividing until border localization is at one pixel resolution.
- The increase of the solution space is small.
Dealing with error

- Increase spatial and disparity resolutions simultaneously.
- Use relative mode to keep solution space under control.
- Prevent large discontinuity error from reappearing.
Dealing with error  smooth surface error

Absolute mode  reduce $B_s$, $D_s$, and $D_r$  final solution

reduce $B_s$ at large discontinuity
Disparity map in the solution space represented as a cut in a graph.

Finds sharp depth discontinuity.

Features an arbitrary neighborhood structure independent of the epipolar constraint.
Smoothing edge have a “cost” proportional to the contact surface.

Regularity of the graph allows an memory efficient implementation.
Our goal is to demonstrate the usefulness of Non-Uniform decomposition.

- A simple cost function based on block matching and SSD is used.
- There is no explicit modeling of occlusion.
- There is no adaptive smoothing.
The algorithm

Limitations

Too coarse initial grid or too large threshold value can have a significant impact on the quality of the final solution.

- missing large depth discontinuities.
- pixelized smooth surfaces.
Not all depth discontinuity errors are removed in the absolute phase.

During the relative phase, extra iterations could be needed to get rid of them.
• Resolution $512 \times 512$ and 64 disparity steps (17 millions nodes).

• Running time is about 10 sec on AMD Athlon 1.4Ghz.

• 200 000 elementary operations (100 million for the full size problem solved by Max-flow).
Non-Uniform and Uniform have the same running time.

MRSS [C.Sun, 99] uses Non-Uniform decomposition in order to speed-up computation but does not model large discontinuities.
Experimental Results

Tea-Pot

- Courtesy of Jean-Yves Bouguet.
- Resolution $2048 \times 1536$.
- 400 disparity step.
- $400^{3145728}$ possible configuration.
- Graph size over a billion nodes.
- Important occlusion zones.
- Specular components.
- Texture less slanted surface.
Cox algorithm was used for the dynamic programming.
Ground Truth is obtained by structured light (Jean-Yves Bouguet).
Experimental Results

- Courtesy of Bill Hoff.
- Resolution of $256 \times 256$.
- 18 disparity step.
- Highly textured.
- Exposure variation between images.
- Sharp contours.
Experimental Results

MRRS  Max–Flow  N–U Pyramid

- 9.4 million elementary operations for Max-flow.
- .57 million elementary operations for Non-Uniform pyramid.
A pyramid scheme that alternates the computational effort between border localization and surface smoothness.

- Stability and efficiency of pyramid scheme.
- Border localization typical of exact approaches.
- We extend Maximum-flow to allow solving very large problems efficiently while preserving the quality of the solution.
A pyramid scheme that is guaranteed to find the exact solution of the original full-size problem.

Adaptive and automatic determination of the smoothing factor and threshold value.