Spacetime Stereo: Shape Recovery for Dynamic Scenes


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**Introduction**

**Goal:** stereo reconstruction for scenes with abruptly changing appearance but smoothly changing geometry.

**Problem:** applying standard stereo algorithms frame by frame results in temporally inconsistent and noisy/over-smoothed shapes.

**Solution:** match sequence to sequence, yielding temporally consistent and spatially accurate reconstruction.

**Spacetime Stereo Metrics and Algorithms**

We extend traditional 2D window matching in image plane to 3D window matching in video volume.

**Static cases:**

- A fronto-parallel surface
- An oblique surface

**Moving case:**

- An oblique surface

<table>
<thead>
<tr>
<th>t=0,1,2</th>
<th>t=2</th>
<th>t=0</th>
<th>t=1</th>
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<tbody>
<tr>
<td>L</td>
<td>R</td>
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Solve for x shift.  
Solve for x shift, x scale, y shear.  
Solve for x shift, x scale, y shear, t shear.

Standard stereo matching algorithms can be adapted to use spacetime window metric.

We use Dynamic Programming (DP) for initialization and Lucas-Kanade (LK) for subpixel refinement.

**Related work**

**Structured light:** [Sato87][Kanade91][Curless95][Pulli98][Bouguet98][Hall-Holt01]

- Idea: illuminate scenes with special time-varying light patterns encoding correspondences
- Limitation: previous methods do not fully exploit temporal information for moving scenes.

**Motion Stereo:** [Vedula99][Mandelbaum99][Tao01][Zhang01][Carceroni01][Strecha02]

- Idea: compute stereo correspondence and optical flow simultaneously
- Limitation: lighting, shadowing, and texture variations violate brightness constancy

**Sequence to Sequence alignment:** [CaspI00]

- Idea: register two video sequences with a global transformation
- Limitation: it works only for concentric camera motion or planar objects

*We generalize stereo matching to incorporate arbitrary appearance variations to estimate depth more accurately at each pixel in each frame. Our technique applies a form of sequence to sequence alignment for a spacetime window around each pixel in the video. In the same proceedings, Davis et al. [03] also propose using a similar spacetime stereo framework for static scenes. Our primary motivation is to recover moving scenes.*
Results

Outdoor scene: waterfall

Structured light: facial deformation

Structured light: bending arm

Discussion

For a diffuse surface moving under static ambient light, the spacetime window a-b-c over t=0,1,2 is equivalent to a larger spatial one f-b-g at t=1.

Future work

• Adaptive windows for spacetime stereo
• Graph cut and belief propagation implementations
• Linear dynamic models for temporal disparity variation
• Reconstruction for full human body in motion
• Other applications:
  - shape from insects?
  - shape from weathering?
  - landscape from waving plants?