De-ghosting for Gigapixel Snapshot Processing

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Outline

1 Introduction

2 De-ghosting
   - Pipeline
   - Alignment
   - Fusion
   - Illustrations

3 Recap

4 Acknowledgments
**Example Multi-Camera Systems**

- Higher-end performance through lower-end cameras

<table>
<thead>
<tr>
<th>System</th>
<th>Overlap ratio</th>
<th>Purpose</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stanford Multi-Camera Array (mode 1)</td>
<td>~ 90%</td>
<td>high frame-rate video; synthetic aperture</td>
<td>1</td>
</tr>
<tr>
<td>Stanford Multi-Camera Array (mode 2)</td>
<td>~ 50%</td>
<td>high resolution eFOV</td>
<td>1</td>
</tr>
<tr>
<td>AWARE-2</td>
<td>~ 10%</td>
<td>high resolution eFOV</td>
<td>2, 3</td>
</tr>
<tr>
<td>ARGUS-IS</td>
<td>~ 5%</td>
<td>high resolution eFOV</td>
<td>4</td>
</tr>
<tr>
<td>Single-camera sweep over stationary scene</td>
<td>variable</td>
<td>high resolution eFOV</td>
<td>5</td>
</tr>
</tbody>
</table>

**Overlap**

```
A

large
```

```
B

small
```

```
C

D
```

---

AWARE-2 Prototype: 2 Gigapixels, 120° FOV

- Independent focus & exposure
- Gigapixel-resolution snapshots
- Complex configuration on a hemisphere


Gigapixel Imaging Applications

- Survey, query and monitoring of:
  - urban and suburban development\(^1\)
  - wild-life habitats\(^2\)
  - archaeological sites\(^3\)
- Exploration and dynamics of celestial bodies\(^4\)
- Recognition\(^5\)
- Surveillance\(^6\)

\(^5\) L. Gueguen *et al.* *IGARSS*, 2011.
\(^6\) B. Leiningen *et al.* *SPIE* 6981, 2008.
Stitching Software

- GigaPan Stitch\(^1\)
- Autopano Giga\(^2\)
- Microsoft ICE\(^3\)
- Autostitch\(^4\)
- Panorama Tools\(^5\)
- Fiji\(^6\)
- ...

- Challenged by complex, sparse geometry & small, noisy overlap

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1. gigapan.com/
2. autopano.net/
3. research.microsoft.com/en-us/UM/redmond/groups/IVM/ICE/
4. www.cs.bath.ac.uk/brown/autostitch/autostitch.html
5. panotools.sourceforge.net/
FoV Overlap: Small, Sparse, Noisy

Note: AWARE-10 is coming out; see M. Gehm’s talk
FoV Overlap: Small, Sparse, Noisy

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Ghosting & De-ghosting

Both results from the AWARE-2 (monochrome) dataset (AWARE-10 produces color images)

A.S. Iliopoulos, J. Hu, N. Pitsianis, X. Sun, M. Gehm, D. Brady

De-ghosting for Gigapixel Snapshot Processing

Duke, AUTh, Arizona
Ghost Sources

- **Static/systematic:**
  - Deviations from design during manufacturing
  - Displacement in array mounting

- **Transient/scene-dependent:**
  - Variable camera viewpoints
  - Independent camera parameters & settings
De-ghosting: 3 Key Steps

- Pairwise registration
- Global bundle adjustment among multiple images
- Gradient-domain blending
De-ghosting Pipeline

- Raw Images, Flat-fields
- Geometric Alignment
- Feature Extraction
- Reliable Feature Matching
- Global Bundle
- Gradient Merging
- Global Bundle Fusion
- Mosaic
- Gradient Integration
- Pixel-wise Operator
- Laplacian Solver
- Block Operator

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Pairwise Registration

- SIFT
  - computation-intensive
  - SiftGPU by C.C. Wu

- Geometric configuration
  - anchor points

- GeCo-RANSAC
  - reliable control points
  - preconditioning
  - Global Bundle Adjustment

1. http://cs.unc.edu/~ccwu/siftgpu
Bundle Adjustment

- Adhere to geometric configuration

\[
\begin{align*}
\text{(variational form 1)} & \quad \min_{\{H_i\}} \sum_{i} \sum_{j \neq \emptyset} w_{ij} \left\| x_{k,i}^T H_i - x_{k,j}^T H_j \right\|_2^2 \\
\text{(variational form 2)} & \quad \min_{H} \left\| W E x H \right\|_2^2
\end{align*}
\]

- Fix a reference frame \( R \):

\[
L_{\bar{R}} H_{\bar{R}} = B_{R}
\]

\( L \) is the Laplace operator and \( W \) is a weight matrix.
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Gradient Re-projection

- Place & compute gradients on the mosaic canvas
  - Pack images into non-overlapping pairs

- Custom CUDA kernels
  - Transformation back-projection; interpolation
  - Binary image erosion to remove spurious gradient border

- Speed-up by packing & GPU: 40x
Gradient-domain Blending

- Maintains high-frequency information
- Smooths intensity seams
- Invariant to camera sensor bias
- Computation-intensive integration

\[ \nabla I(x) = \sum_{x \in I_i} w_i(x) \nabla I_i(x) \]

\[ I = G \ast \text{div}(\nabla I) \]

- Green’s function \((G)\) is approximated via a convolution pyramid.¹
- **Speed-up** by algorithm, memory streaming, **GPU: 30x**

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Illustrations II
Illustrations IV
Illustrations V
Illustrations VI
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Recap

- Unconventional projective layout:
  - Sparse, Small and Noisy overlaps among multiple FoVs
- Combine static spatial/geometric knowledge and scene-dependent parameters & features
- Computation-intensive steps enabled by GPU
- Potential other applications include:
  - Sparse and adaptive sampling in video data
  - Individual tracking among a crowd
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References


References II


References III


References IV


