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;</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>synthetic aperture</td>
<td></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

- large
- small

A | B | 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\(^6\)

---

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

---

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

Note: AWARE-10 is coming out; see M. Gehm’s talk
Outline

1 Introduction

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

3 Recap

4 Acknowledgments
Ghosting & De-ghosting

Ghosted image

De-ghosted using our pipeline

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

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

A.S. Iliopoulos, J. Hu, N. Pitsianis, X. Sun, M. Gehm, D. Brady
Duke, AUTh, Arizona
De-ghosting for Gigapixel Snapshot Processing
De-ghosting Pipeline

- Raw Images, Flat-fields
- Geometric Alignment
- Approximate Overlapping Regions
- Feature Extraction
- Reliable Feature Matching
- Global Bundle
- Gradient Re-projection
- Gradient Merging
- Gradient Integration
- Mosaic

A.S. Iliopoulos, J. Hu, N. Pitsianis, X. Sun, M. Gehm, D. Brady
Duke, AUTh, Arizona
Pairwise Registration

**Speed-up by algorithm & GPU:**

\[ >1000x! \]

*computation-intensive* SiftGPU by C.C. Wu\(^1\)

**Sparse, Small, Noisy overlapping regions**

**Geometric configuration**

**anchor points**

**Global Bundle Adjustment**

**GeCo-RANSAC**

**reliable control points**

**preconditioning**

**“broken”**

**ghosted**

1. [http://cs.unc.edu/~ccwu/siftgpu](http://cs.unc.edu/~ccwu/siftgpu)
Bundle Adjustment

- Adhere to geometric configuration

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

- Fix a reference frame \( R \):

\[
\text{(normal/Laplace equation)} \quad L_{\bar{R}} H_{\bar{R}} = B_R
\]

strong overlap

weak overlap
Outline

1 Introduction

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

3 Recap

4 Acknowledgments
Gradient Re-projection

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

- 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**

---

Outline

1. Introduction

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

3. Recap

4. Acknowledgments
Illustrations IV
Illustrations V
Illustrations VI
Outline

1 Introduction

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

3 Recap

4 Acknowledgments
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
Acknowledgments

Lars Nyland
Adjunct Associate Professor, UNC
& Compute Architect, NVIDIA

Esteban Vera Rojas
Research Associate, UA

Changchang Wu
Software Engineer, Google

Steve Feller
AWARE Project Manager, Duke

Daniel Marks
Associate Research Professor, Duke
Acknowledgments II

- NVIDIA academic research equipment support to Duke & AUTh
- Marie Curie International Reintegration Program, EU
- National Science Foundation (CCF), USA
- Defense Advanced Research Projects Agency HR0011-10-C-0073
Thank you!
References I


References III


References IV


