Computational Photography

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http://www.cs.pdx.edu/~fliu/courses/cs510/

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Last Time

- Video Stabilization
  - Video stabilization pipeline
Today

- More on Video Stabilization
  - 3D Video Stabilization
  - Subspace Video Stabilization

- Final Project Presentation
  - In class, June 5 and 7
Video Stabilization Pipeline

Input → Trajectory Estimation → Motion Mode Estimation → Motion Plan → Video Transform → Output

Further Improvement

I. Scene points are sometimes poorly distributed
II. The set of feature point changes over time
Poor distribution of scene points
Poor distribution of scene points
No feature points
Pre-Warping

Input frame
Pre-Warping
Pre-Warping

Pre-warping + content-preserving warping
Pre-Warping

Method:
Pre-warp input using a best-fitting homography

Result:
✓ Regions with sufficient feature points: Content-preserving warping dominates
✓ Regions without sufficient feature points: Pre-warping gives a good approximation
Result of content-preserving warping with pre-warping
Video Stabilization Pipeline

Input → Trajectory Estimation → Motion Mode Estimation → Motion Plan → Video Transform → Output

Further Improvement

I. Scene points are sometimes poorly distributed
II. The set of feature point changes over time
Temporal Coherence

Input video & points

Output points
Temporal Coherence
Temporal Coherence

Fade-in/out the weight of the data constraint over time
Result of fade-in/out the weight
Question 1: How about Moving Objects?

- No reconstructed 3D points
- Warp follows surrounding background points

- Not correct! But...
  - ✓ Viewpoint shifts are small
  - ✓ Motion clouds the issue
  - ✓ Don’t notice exact occlusion relationships
Question 2: How Is Novel View Synthesis?

Camera position                     Output points
Novel View Synthesis
Novel View Synthesis
Novel View Synthesis
Results & Comparisons

**INPUT**

**OUR OUTPUT**
Results & Comparisons

Input

Our Output
Limitation

- Requires running **structure-from-motion**
  - Slow & memory-intensive
  - More brittle than simple point tracking
    - Need enough parallax
    - Difficult to deal with zooming
    - Vulnerable to artifacts in videos
  - Requires static regions to lock onto
Our 3D Video Stabilization Method

Input → Trajectory Estimation → Motion Model Estimation → Motion Plan → Video Transform → Output

3D reconstruction via structure from motion

Content-preserving warp
Video Stabilization Pipeline

Input → Trajectory Estimation → Motion Model Estimation → Motion Plan → Video Transform → Output

- 3D reconstruction via structure from motion
- Content-preserving warp
Subspace video stabilization
[Liu et al., ACM Transactions on Graphics ‘11]
Video Stabilization Pipeline

Input → Trajectory Estimation → Motion Model Estimation → Motion Smooth → Video Transform → Output

- smooth feature trajectories
- Content-preserving warp
Video Stabilization Pipeline

Input → Trajectory Estimation → Motion Model Estimation → Motion Smooth → Video Transform → Output

- smooth feature trajectories
- Content-preserving warp
Low-pass Filter Input Trajectories
Low-pass Filter Input Trajectories

Input image
Low-pass Filter Input Trajectories

Result of filtering
Low-pass Filter Input Trajectories

Result of filtering
Low-pass Filtering Trajectories

![Graph showing x coordinate over time with two input curves: input 1 (blue dotted line) and input 2 (green dotted line).]
Low-pass Filtering Trajectories

- x coordinate
- time
- Filter

Graph showing two input trajectories:
- Blue dashed line: input 1
- Green dashed line: input 2
Low-pass Filtering Trajectories

![Diagram showing x coordinate vs time with different filter kernel support]
Constraints

- Homography of 2D methods
  - Restrictive
  - Cannot model 3D feature motion
- Reconstructed 3D model of 3D methods
  - Difficult to estimate
Affine Camera

Track feature points

Input trajectory matrix $M$

Scene matrix $C$

Camera matrix $E$
The trajectory matrix of a rigid scene imaged by a moving camera over a short period of time should approximately lie in a low-dimensional subspace.

The trajectory matrix of a rigid scene imaged by a moving camera over a short period of time should approximately lie in a low-dimensional subspace.

Subspace Stabilization Overview

Track feature points
Subspace Stabilization Overview

Track feature points

Input trajectory matrix $M$
Subspace Stabilization Overview

Track feature points

Input trajectory matrix $\mathbf{M}$

Coefficient matrix $\mathbf{C}$

Eigen trajectory matrix $\mathbf{E}$
Subspace Stabilization Overview

Track feature points → Input trajectory matrix \( M \) → Coefficient matrix \( C \) → Eigen trajectory matrix \( E \) → Filter

Smooth eigen trajectory matrix
Subspace Stabilization Overview

- Track feature points
- Input trajectory matrix $M$
- Smooth trajectory matrix
- Coefficient matrix $C$
- Eigen trajectory matrix $E$
- Filter
- Smooth eigen trajectory matrix
Low-pass Filtering Trajectories

Naïve filtering

Subspace filtering
Low-pass Filtering Trajectories

Naïve filtering

Subspace filtering
Naïve filtering

Subspace filtering
Matrix Factorization

Track feature points

Input trajectory matrix

Coefficient matrix

Eigen trajectory matrix

Matrix factorization
Incomplete matrix factorization

- **Iterative methods** [Buchanan and Fitzgibbon 05, Chen 2008]
  - Accurate
  - Time-consuming and not streamable
    - Difficult to handle long videos.

- **Moving factorization**
  - A variation of incremental factorization methods
  - Greedy method and less accurate
    - But, good enough for stabilization
  - Efficient and streamable
Factorization accuracy

- Testing data: 70 videos
  - Resized to 640 x 360

- Moving factorization
  - Error: 0.08 to 0.26 pixels

- Iterative factorization
  - ¼ of moving factorization errors on average
Result: A Long Video

Input

Our result
Comparison with Our 3D Method

Input

3D

Our result
Demo

Input

Our result
Limitations

- Aggressive stabilization leads to aggressive cropping
- Need reasonably long feature trajectories
A subspace method for smoothing the feature trajectory

A content-preserving warping method for video transformation

Contribution 1

Contribution 2
Impact

- Selected as one of the five Top Videos of 2009 by *New Scientist*

- *Warp Stabilizer* in After Effects CS5.5 and Premiere CS 6.0 is largely based on our research
Next Time

Final Project Presentation