Real-time Facial Animation

Hao Li
ILM

Mark Pauly
EPFL
High-End 3D Scanning
High-End 3D Scanning
Low-Cost Passive Scanning (AGI soft)

 stereo pair
Low-Cost Passive Scanning (AGI soft)

stereo pair

3D scan
Low-Cost Active Scanning + Temporal Upsampling

Microsoft Kinect & Kinect Fusion
Rigging & Animation
Rigging & Animation
Typical Facial Animation Workflow in Industry
Typical Facial Animation Workflow in Industry

3D Scanning
Typical Facial Animation Workflow in Industry

3D Scanning → Modeling + Fitting
Typical Facial Animation Workflow in Industry

1. 3D Scanning
2. Modeling + Fitting
3. Light-weight Rigging
Typical Facial Animation Workflow in Industry

3D Scanning → Modeling + Fitting → Light-weight Rigging → Motion Capture
Typical Facial Animation Workflow in Industry

3D Scanning → Modeling + Fitting → Light-weight Rigging → Motion Capture → Cleanup & Key-Framing
Typical Facial Animation Workflow in Industry

- 3D Scanning
- Modeling + Fitting
- Light-weight Rigging
- Motion Capture
- Cleanup & Key-Framing
Typical Facial Animation Workflow in Industry
Typical Facial Animation Workflow in Industry

1. 3D Scanning
2. Modeling + Fitting
3. Light-weight Rigging
4. Motion Capture
5. Cleanup & Key-Framing

6. Modeling
7. Complex Rigging
8. Retargeting
Typical Facial Animation Workflow in Industry

1. 3D Scanning
2. Modeling + Fitting
3. Light-weight Rigging
4. Motion Capture
5. Cleanup & Key-Framing

- Modeling
- Complex Rigging
- Retargeting
Typical Facial Animation Workflow in Industry

- 3D Scanning
- Modeling + Fitting
- Light-weight Rigging
- Motion Capture
- Cleanup & Key-Framing

- Modeling
- Complex Rigging
- Retargeting
- Key-Framing + Proc. + Sim.
Markerless Facial Capture
3D range sensor
3D range sensor
3D range sensor

Motion can be captured at the same resolution as the Geometry.
USC ICT Light Stage 5
USC ICT Light Stage 5
Goal
Goal
Template-Based Tracking
Template-Based Tracking
Template-Based Tracking

analyze deformation
Template-Based Tracking

analyze deformation
Template-Based Tracking
Template-Based Tracking

transfer deformation
Template-Based Tracking
Template-Based Tracking
Correspondences Problem
Correspondences Problem
Correspondences Problem
Correspondences Problem
Non-Rigid Registration
Pair of 3D Scans
Pair of 3D Scans

source
Pair of 3D Scans

source

target
Correspondences are Lost
Correspondences are Lost
Correspondences are Lost
Overlapping Regions are Lost
Overlapping Regions are Lost
Overlapping Regions are Lost

missing data

overlapping regions
Overlapping Regions are Lost
Overlapping Regions are Lost
Non-Rigid Registration
Non-Rigid Registration
Three Ingredients
Three Ingredients

source
Three Ingredients

source

target
Three Ingredients

source

target
Three Ingredients

source

target

detect overlap
Three Ingredients

source

target

detect overlap
Three Ingredients

detect overlap

source

correspond

target
Three Ingredients

detect overlap

correspond
Three Ingredients

detect overlap → correspond → deform
Three Ingredients

detect overlap

correspond

deform
Challenges

detect overlap → correspond → deform
Challenges

detect overlap

correspond

deform
Challenges
Challenges

detect overlap

correspond

deform

deforation
Challenges
Challenges

detect overlap → correspond → deform
Challenges

- detect overlap
- correspond
- deform
Challenges

detect overlap

correspond

deform
Challenges

detect overlap  ➔  correspond  ➔  deform
Challenges

detect overlap  →  correspond  →  deform
Challenges

detect overlap

 correspond

deform
Challenges

detect overlap → correspond → deform
Challenges

detect overlap
correspond
deform
Challenges

correspond

detect
overlap

deform
Observation

correspond

detect overlap

deform
Observation

correspond

detect overlap

deform
Observation

correspond

detect overlap helps deform
Observation

correspond

detect overlap

deform

correspond helps detect overlap
correspond helps deform
Observation

correspond

detect overlap

deform
Observation
Observation

global optimization via local refinement
Iterative Global Optimization

correspond

detect overlap

deform
Iterative Global Optimization

correspond
detect overlap
deform
Iterative Global Optimization

correspond
detect overlap
deform
Iterative Global Optimization

correspond
detect overlap
deform
Iterative Global Optimization

correspond
detect overlap
deform
Iterative Global Optimization

correspond

detect overlap

deform
Iterative Global Optimization

closest point

detect overlap

deform
Iterative Global Optimization

- closest point
- detect overlap
- deform
Iterative Global Optimization

- Closest point
- Pruning
- Deform
Iterative Global Optimization

closest point

pruning

deform
Iterative Global Optimization

- closest point
- pruning
- deform
Iterative Global Optimization

- closest point
- pruning
- deform
Iterative Global Optimization

- closest point
- pruning
- deform
Iterative Global Optimization

closest point

pruning

global optimization
Iterative Global Optimization

closest point
pruning
global optimization
Iterative Global Optimization

closest point

pruning

global optimization

converges?
Iterative Global Optimization

- Closest point
- Pruning
- Global optimization

No converges?
Iterative Global Optimization

- Closest point
- Pruning
- Global optimization
- Converges?

No
Iterative Global Optimization

- closest point
- pruning
- global optimization
- converges?

No
Iterative Global Optimization

- closest point
- pruning
- global optimization
- converges?
  - yes
  - relax stiffness
  - no
Iterative Global Optimization

- closest point
- pruning
- global optimization
- converges?
  - yes: relax stiffness
  - no: continue

Eurographics 2012, Cagliari, Italy
Iterative Global Optimization

- closest point
- pruning
- global optimization

converges?

- yes
  - relax stiffness

- no
Iterative Global Optimization

Robust Non-Rigid ICP

- closest point
- pruning
- global optimization
- converges?
  - yes: relax stiffness
  - no: continues

Eurographics 2012, Cagliari, Italy
Iterative Global Optimization

Robust Non-Rigid ICP

- closest point
- pruning
- global optimization
- converges?
  - yes
  - relax stiffness
  - no
Embedded Deformation Model

detail preservation

global consistency
Embedded Deformation Model

detail preservation

global consistency
Embedded Deformation Model

detail preservation

global consistency
Embedded Deformation Model

detail preservation
global consistency
Embedded Deformation Model

detail preservation
global consistency
Embedded Deformation Model

de-coupled complexity
Embedded Deformation Model

de-coupled complexity
Embedded Deformation Model

$E_{\text{rigid}}$

decoupled complexity
Embedded Deformation Model

$E_{\text{rigid}}$  $E_{\text{smooth}}$

de-coupled complexity
Non-Linear Energy Minimization

$E_{\text{rigid}}$  $E_{\text{smooth}}$
Non-Linear Energy Minimization

\[ E_{\text{rigid}} \quad E_{\text{smooth}} \]
Non-Linear Energy Minimization

\[ E_{\text{rigid}} \quad E_{\text{smooth}} \]
Non-Linear Energy Minimization

\( E_{\text{rigid}} \)

\( E_{\text{smooth}} \)
Non-Linear Energy Minimization

\[ E_{\text{point}} \]
\[ E_{\text{rigid}} \]
\[ E_{\text{smooth}} \]
Non-Linear Energy Minimization

\[ E_{\text{plane}} \quad E_{\text{point}} \quad E_{\text{rigid}} \quad E_{\text{smooth}} \]

[Chen & Medioni '92]
Non-Linear Energy Minimization

\[ E_{\text{tot}} = E_{\text{plane}} + \alpha_{\text{point}} E_{\text{point}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} \]

[Chen & Medioni '92]
Non-Linear Energy Minimization

\[ E_{\text{tot}} = E_{\text{plane}} + \alpha_{\text{point}} E_{\text{point}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} \]

non-linear least squares minimization

[Chen & Medioni '92]
Non-Linear Energy Minimization

\[ E_{\text{tot}} = E_{\text{plane}} + \alpha_{\text{point}} E_{\text{point}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} \]

non-linear least squares minimization

Gauss-Newton method

[Chen & Medioni '92]
Non-Linear Energy Minimization

\[ E_{\text{tot}} = E_{\text{plane}} + \alpha_{\text{point}} E_{\text{point}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} \]

[Chen & Medioni '92]

- Non-linear least squares minimization
- Gauss-Newton method
- Jacobian is sparse

The figure illustrates the energy minimization process with contributions from different terms, each with its own parameterization.
Non-Linear Energy Minimization

\[ E_{\text{tot}} = E_{\text{plane}} + \alpha_{\text{point}} E_{\text{point}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} \]

[Chen & Medioni '92]

- non-linear least squares minimization
- Gauss-Newton method
- Jacobian is sparse
- sparse Cholesky factorization
Non-Linear Energy Minimization

\[ E_{\text{tot}} = E_{\text{plane}} + \alpha_{\text{point}} E_{\text{point}} + \alpha_{\text{rigid}} E_{\text{rigid}} + \alpha_{\text{smooth}} E_{\text{smooth}} \]

- non-linear least squares minimization
- Gauss-Newton method
- Jacobian is sparse
- sparse Cholesky factorization

that's it!

[Chen & Medioni '92]
Template-Based Tracking
Not only for Faces!
Not only for Faces!

template
Not only for Faces!

3D scan

template
Not only for Faces!
Requirements for a Practical System
Requirements for a Practical System
Requirements for a Practical System

1. Real-time performance
Requirements for a Practical System

1. Real-time performance
2. Robustness to noise
Requirements for a Practical System

1. Real-time performance

2. Robustness to noise

3. High-level semantics
Real-time Facial Capture
Objective
Building Expression Space

tracked template

input scan
Building Expression Space

tracked template

input scan
Expression PCA for Reduced Dimension
Expression PCA for Reduced Dimension
Expression PCA for Reduced Dimension

Principal Component Analysis
Expression PCA for Reduced Dimension

Principal Component Analysis
Expression PCA for Reduced Dimension

Principal Component Analysis
Expression PCA for Reduced Dimension

Principal Component Analysis

$+ w_1 + w_2 + w_3 + w_4$
Expression PCA for Reduced Dimension

Principal Component Analysis

\[ \text{Expression} = w_1 + w_2 + w_3 + w_4 + \ldots \]