

# Optical Motion Capture

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<http://www.cs.umd.edu/~guerra/OpMcCap.html>




## Outline

I. Introduction	VI. Temporal Correspondence
II. Required Resources	VII. Post-Processing
III. Initialization	VIII. Rotational Data
IV. Marker Detection	IX. Data File Formats
V. Spatial Correspondence	X. Conclusions

## I. Introduction


## Realistic Movement

- Synthesis
  - simulate, control, or create new object/subject movement
- Analysis
  - evaluate some aspects of the musculo-skeletal system

## Motion Capture Systems

- Magnetic
  - Real-time with low processing costs
  - Restricts movement due to cabling
- Mechanic
  - Real-time with no processing
  - Special suit with sensors
- Optical
  - High accuracy and higher computational costs
  - Complete freedom of movement

## Optical Motion Capture

		Views	
		Monocular	Multi-View
Markers	Markerless		
	Marker-Based		

## Applications

- Computer Graphics
- Virtual Reality
- Video Games
- Robotics
- Kinesiology and Biomechanics
- Sports performance and Injuries
- Dance Annotation

## Computer Vision

- Camera Calibration
- Feature Detection
- Stereo Matching
- Tracking
- Volumetric Reconstruction


## II. Required Resources

### Required Resources

- Capture Room
- Body Suit
- Camera Equipment
- Acquisition System


### Capture Room

- Dimensions




### Capture Room

- Dimensions
- Background




### Capture Room

- Dimensions
- Background
- Lighting




### Capture Room

- Dimensions
- Background
- Lighting
  - Light sources




### Capture Room

- Dimensions
- Background
- Lighting
  - Light sources
  - Reflectors




### Capture Room

- Dimensions
- Background
- Lighting
  - Light sources
  - Reflectors
- Control Room




### Body Suit

- Parts



### Body Suit

- Parts
  - Socks



Body Suit

- Parts
  - Socks
  - Gloves

Body Suit

- Parts
  - Socks
  - Gloves
  - Mask

Body Suit

- Parts
  - Socks
  - Gloves
  - Mask
  - Leotard

Body Suit

- Markers

Body Suit

- Markers
  - Location

Body Suit

- Markers
  - Location
  - Color

Body Suit

- Markers
  - Location
  - Color
  - Shape

Camera Equipment

- Lenses
  - Focus

Camera Equipment

- Lenses
  - Focus
- Cameras
  - Progressive vs Interlaced
  - Frame Rate
  - Resolution
  - Exposure Time


### Camera Equipment

- Lenses
  - Focus
- Cameras
  - Progressive vs Interlaced
  - Frame Rate
  - Resolution
  - Exposure Time
- Support
  - Mounting Brackets




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### Camera Equipment

- Lenses
  - Focus
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  - Progressive vs Interlaced
  - Frame Rate
  - Resolution
  - Exposure Time
- Support
  - Mounting Brackets
  - Telescope Tripods
- Data Transfer
  - Synchronization



### Camera Equipment

- Lenses
  - Focus
- Cameras
  - Progressive vs Interlaced
  - Frame Rate
  - Resolution
  - Exposure Time
- Support
  - Mounting Brackets
  - Telescope Tripods
- Data Transfer
  - Synchronization
  - Bus Cables



### Acquisition System


- Synchronous in Real-Time
- Trigger Control
- I/O Bandwidth
- Storage

### MoCap Labs

	Keck Lab	Argus Eye	VideoRoom
Room Dimensions	7m x 7m x 3m	7m x 7m x 3m	11m x 5m x 3m
Camera	Kodak <sup>SM</sup> ES-310	Sony <sup>SM</sup> XCD-X7100	Sony <sup>SM</sup> DFW-V500
Number of Cameras	64	9	8
Resolution	648 x 484	1024 x 768	640 x 480
Frame Rate	85	15	30

### Anthropomorphic Features


- H-Anim
  - <http://www.h-anim.org/>
- CAESAR
  - <http://www.sae.org/technical/committees/caesar/home.htm>



### Markers Configuration

*(Note: The text in this slide is extremely small and mostly illegible, appearing as a list of technical specifications or marker names.)*

### Markers Configuration



### III. Initialization

- #### Initialization
- Camera Calibration
  - World Coordinate System
  - Background Subtraction
  - Skeleton Model

#### Camera Calibration

- Pinhole Camera Model

$$\lambda_i u_i^t = P^t U_i \Leftrightarrow \lambda \begin{bmatrix} u_x \\ u_y \\ 1 \end{bmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \end{bmatrix} \begin{bmatrix} U_x \\ U_y \\ U_z \\ 1 \end{bmatrix}$$

$$P^t = \begin{bmatrix} -f_x & 0 & x_c & 1 & 0 & 0 & 0 \\ 0 & -f_y & y_c & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{R}_{3 \times 3} & \mathbf{0}_{3 \times 3} \\ \mathbf{0}_{3 \times 3} & \mathbf{1}_{3 \times 3} \end{bmatrix} \begin{bmatrix} \mathbf{T}_{3 \times 3} \\ \mathbf{0}_{3 \times 3} \\ 1 \end{bmatrix}$$

Intrinsic  Extrinsic



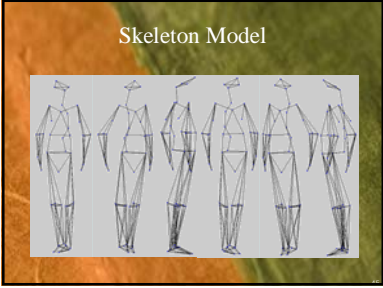
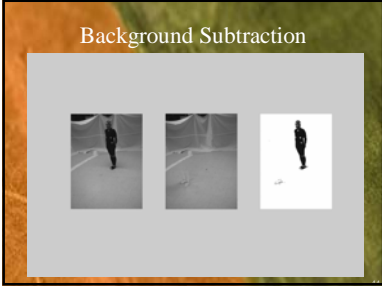
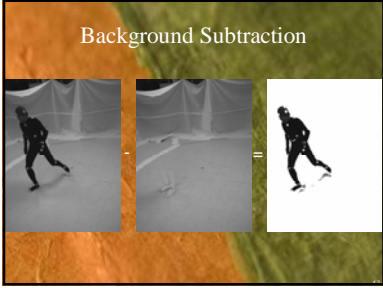
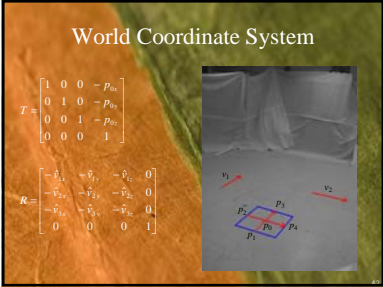
#### Calibration Procedure

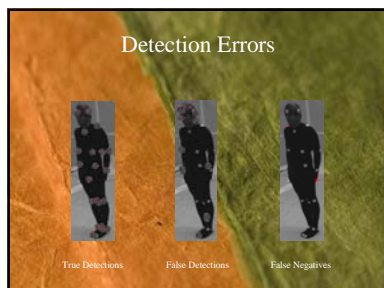
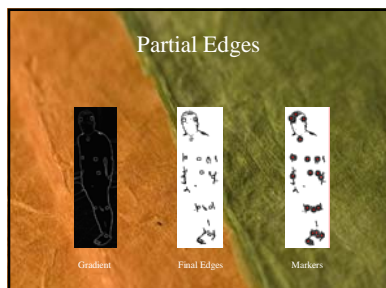
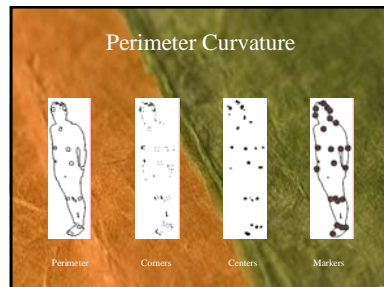
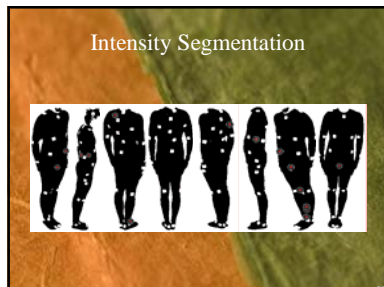
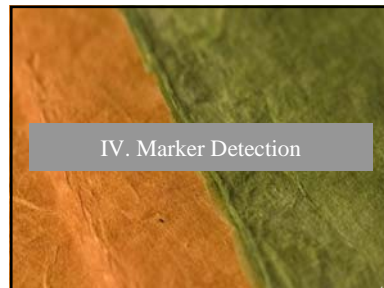
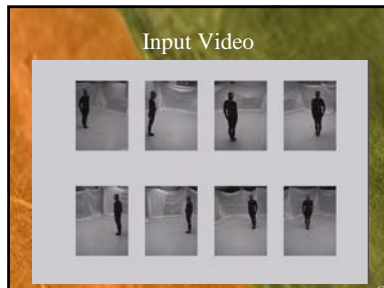
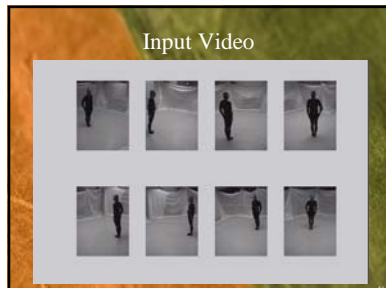
$$\begin{bmatrix} u_1^1 & u_2^1 & \dots & u_n^1 \\ u_1^2 & u_2^2 & \dots & u_n^2 \\ \vdots & \vdots & \ddots & \vdots \\ u_1^m & u_2^m & \dots & u_n^m \end{bmatrix} = \begin{bmatrix} P^1 \\ P^2 \\ \vdots \\ P^m \end{bmatrix} \begin{bmatrix} U_1 & U_2 & \dots & U_n \end{bmatrix}$$

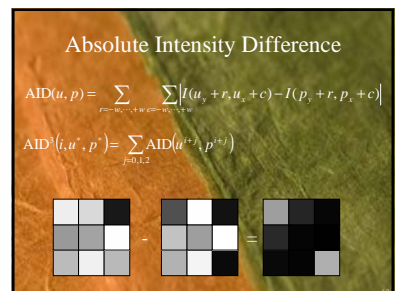
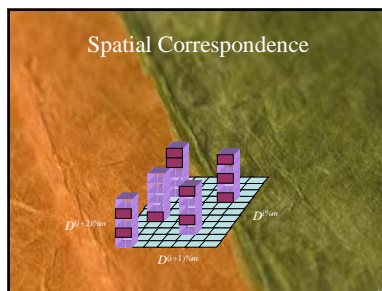
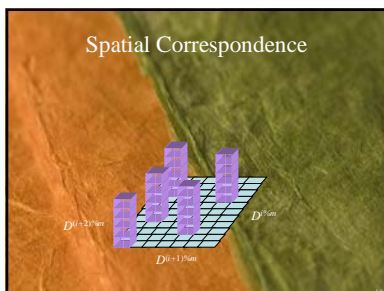
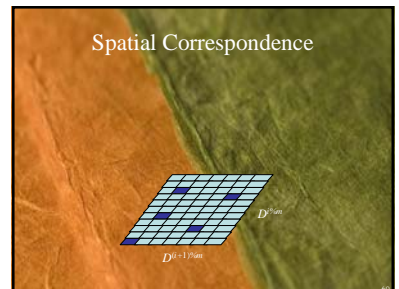
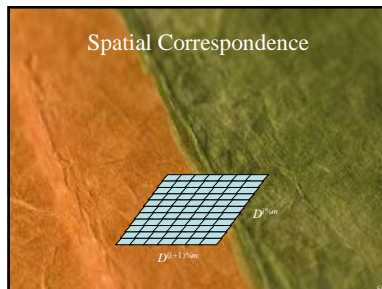
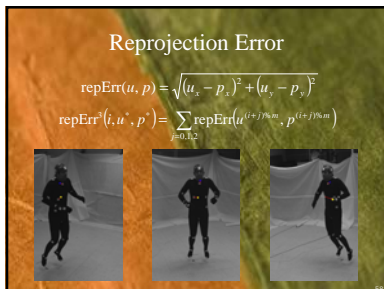
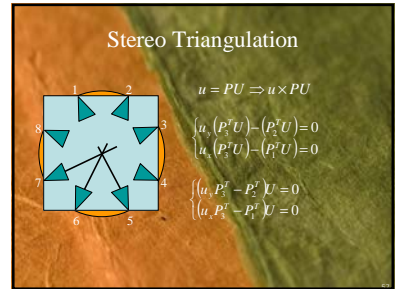
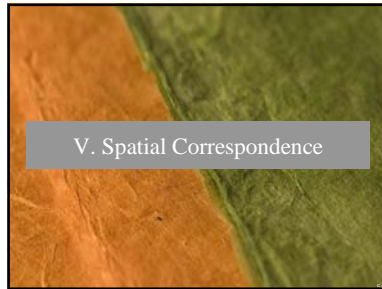
Scaled Measurement  Projective Motion  Projective Shape

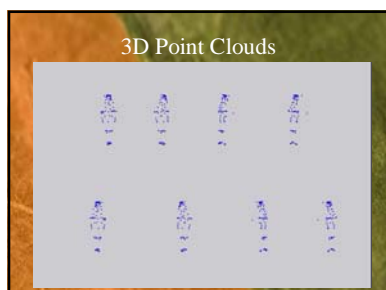
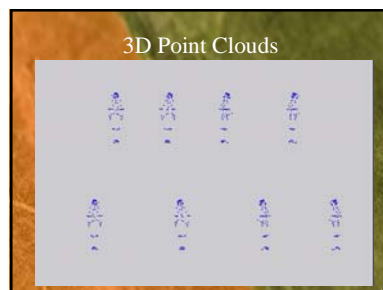
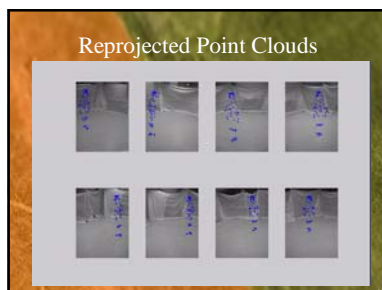
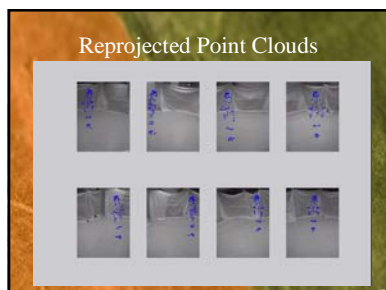
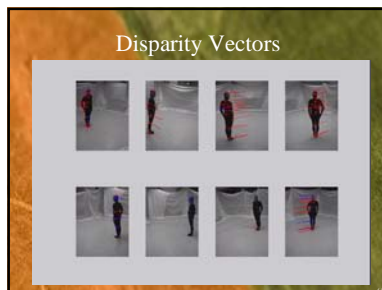
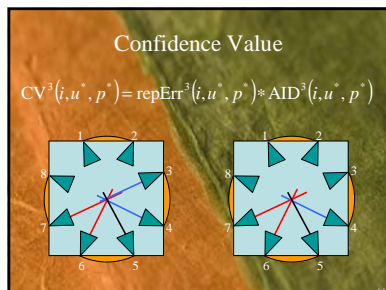
Factorization  $W = PU = P^t U^t$ , where

Euclidean Stratification  $P^t = PH$  and  $U^t = H^{-1}U$

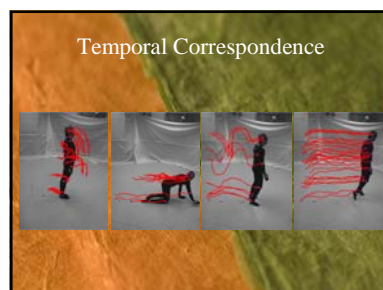


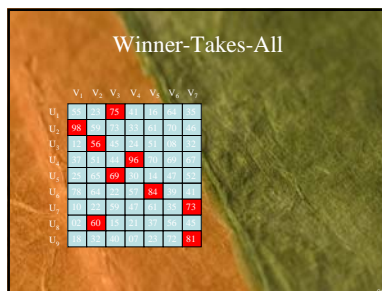
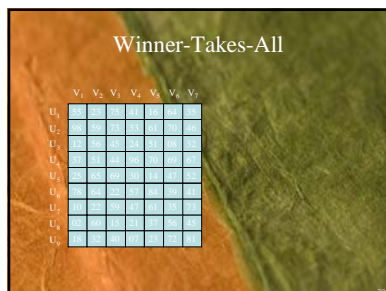
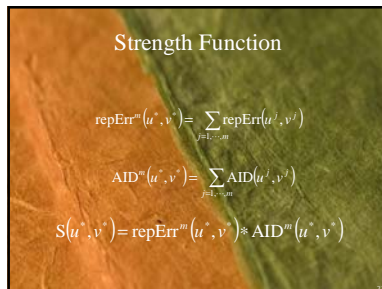
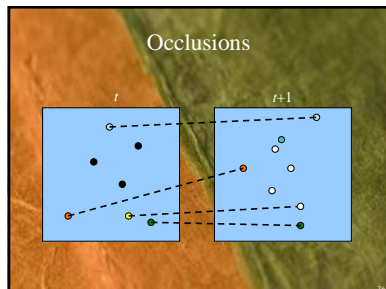
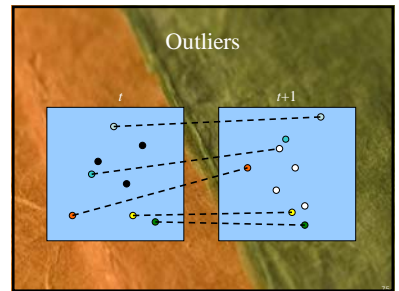
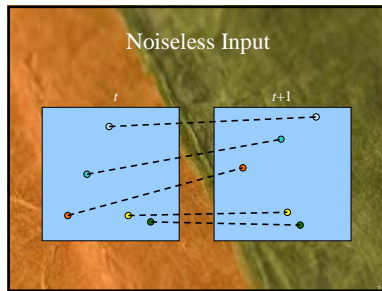
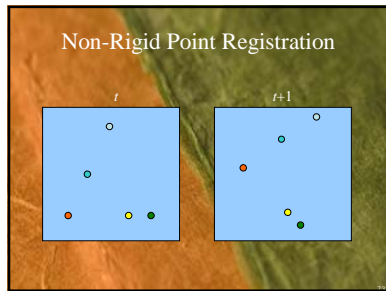


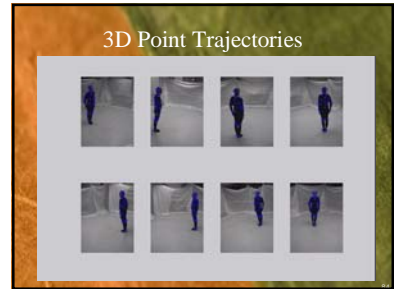
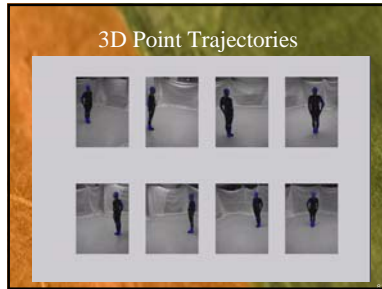
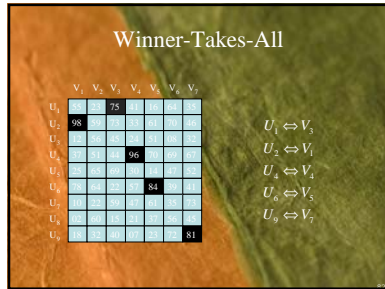




VI. Temporal Correspondence





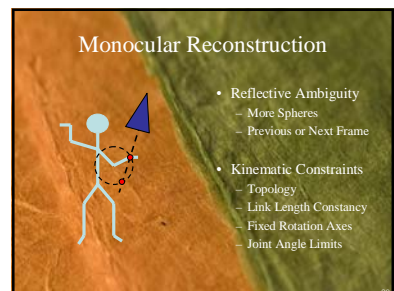


## VII. Post-Processing

- ### Post-Processing
- Labeling
  - Missing Markers
  - Correcting Errors




- ### Missing Markers
- Occlusions
    - Moving Subparts
    - Other Objects
    - Self-Occlusion
  - Camera Field of View
  - Sensory Error

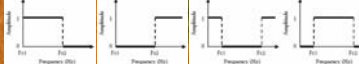


### Data Filtering

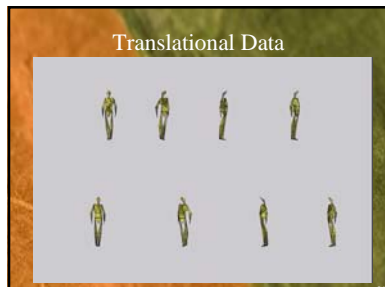
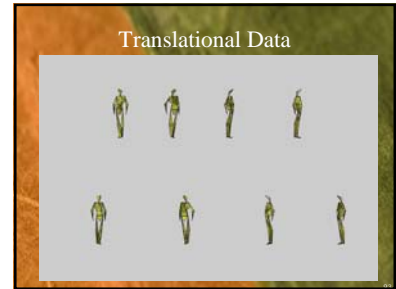
- Transfer Function bands
  - Pass  $[0, F_c]$
  - Transition  $[F_c, F_s]$
  - Stop  $[F_s, \infty]$



### Square Filters

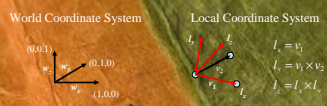


Low Pass    High Pass    Band Stop    Band Pass



### VIII. Rotational Data

### Rotational Data



World Coordinate System:  $(0,0,1)$ ,  $(0,1,0)$ ,  $(1,0,0)$

Local Coordinate System:  $l_1 = v_1$ ,  $l_2 = v_1 \times v_2$ ,  $l_3 = l_1 \times l_2$

### Rigid Subparts

Subpart	Marker I	Marker II	Marker III
PHN	R_HIP-L_HIP	SACRUM	L_HIP
Lumbar Spine	L1	SACRUM	R_HIP-L_HIP
Lower Thoracic	T7	L1	STERNUM
Upper Thoracic	T4	T7	STERNUM
Upper Thoracic	T1	T4	STERNUM
Cervical Spine	N7	N7	STERNUM
Head	FOREHEAD	L_EAR	
Right Upper Leg	R_HIP	RE_KNEE	RE_ANKLE
Right Lower Leg	RE_ANKLE-RE_KNEE	RE_ANKLE-RE_ANKLE	RE_ANKLE-RE_ANKLE
Right Foot	RE_ANKLE-RE_ANKLE	RE_ANKLE-RE_ANKLE	R_TOE
Left Upper Leg	L_HIP	LE_KNEE	LE_ANKLE
Left Lower Leg	LE_ANKLE	LE_ANKLE-LE_ANKLE	LE_ANKLE-LE_ANKLE
Left Foot	LE_ANKLE-LE_ANKLE	LE_ANKLE-LE_ANKLE	L_TOE
Right Clavicle	STERNUM	R_SHOULDER	R_ANKLE
Right Upper Arm	R_SHOULDER	RE_ELBOW	RE_ELBOW
Right Lower Arm	RE_ELBOW	RE_WRIST	RE_ELBOW-RE_ELBOW
Right Hand	RE_WRIST	R_HAND	RE_WRIST
Left Clavicle	STERNUM	L_SHOULDER	L_ANKLE
Left Upper Arm	L_SHOULDER	LE_ELBOW	LE_ELBOW
Left Lower Arm	LE_ELBOW	LE_WRIST	LE_ELBOW-LE_ELBOW
Left Hand	LE_WRIST	L_HAND	LE_WRIST



### Euler Angles

$$R(\phi, \theta, \psi) = R_z(\phi) \times R_y(\theta) \times R_x(\psi) =$$

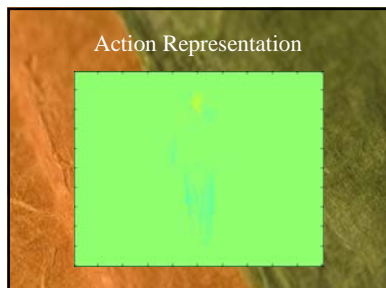
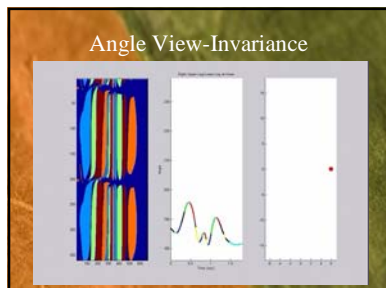
$$\begin{bmatrix} \cos\phi & -\sin\phi & 0 & \cos\theta & 0 & \sin\theta \cos\psi - \sin\psi & 0 \\ \sin\phi & \cos\phi & 0 & 0 & 1 & 0 & \sin\psi \cos\psi & 0 \\ 0 & 0 & 1 & -\sin\theta & 0 & \cos\theta & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} -\sin\phi \sin\psi + \cos\phi \cos\theta \cos\psi & -\sin\phi \cos\psi - \cos\phi \cos\theta \sin\psi & \cos\phi \sin\psi \\ \cos\phi \sin\psi + \sin\phi \cos\theta \cos\psi & \cos\phi \cos\psi - \sin\phi \cos\theta \sin\psi & \sin\phi \sin\psi \\ -\sin\theta \cos\psi & \sin\theta \sin\psi & \cos\theta \end{bmatrix}$$

$$\phi = \text{atan2}(R_{2,3}, R_{1,3})$$

$$\theta = \text{atan2}(\cos\theta R_{1,1} + \sin\theta R_{2,1}, R_{1,2})$$

$$\psi = \text{atan2}(-\sin\theta R_{1,1} + \cos\theta R_{2,1}, -\sin\theta R_{1,2} + \cos\theta R_{2,2})$$



## IX. Data File Formats

- ### Data File Formats
- Portability
    - Store
    - Import
    - Export
  - Biovision
    - BVA
    - BVH
  - Acclaim Motion
    - ASF
    - AMC

### BVA File

Segment	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
INCHES	INCHES	INCHES	DEGREES	DEGREES	DEGREES	DEGREES	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
0.00	12.35	36.80	-78.14	46.29	-2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
5.17	10.57	47.80	-68.82	74.97	-4.83	4.00	4.00	4.00	4.00	4.00	4.00	4.00

### BVH File

```

HIERARCHY
ROOT Joint
{
  OFFSET 0.00 0.00 0.00
  CHANNEL 4 Position Position Position Rotation Rotation Translation
  JOINT RightForeleg
  {
    OFFSET 0.00 5.21 0.00
    CHANNEL 3 Rotation Rotation Translation
    JOINT RightForewing
    {
      OFFSET 0.00 0.45 0.00
      CHANNEL 3 Rotation Rotation Translation
      End Site
    }
    OFFSET 0.00 3.87 0.00
  }
}
}
MOTION
Frames: 2
Frame Time: 0.083333
0.00 75.00 88.50 -5.41 14.76 -164.35 13.09 40.20 -54.00 7.49 43.00 0.00
7.83 75.00 88.47 -5.78 12.94 -165.97 12.44 42.57 -52.39 7.47 43.61 0.00
  
```

### ASF File

```

version 1.00
name Biovision
scale 1.0
name 1.0
length 1.0
major 0.0
minor 0.0
description
  Sample of an ASF File
axis XYZ
units 72 90 90 90 90
position D 0 0 0 0 0
orientation R 0 0 0 0 0
axes 0 0 0
name RightForewing
position 0.00000 1.00000 0.00000
length 1.00000
size 0.00000 0.00000 0.00000 XYZ
bit 14 14 14
label 128.0 128.0
{ 128.0 128.0
  128.0 128.0
}
end
hierarchy
name
root RightForewing
RightForewing RightForewing
end
  
```

### AMC File


```

Fully-OpenPose
Camera
Frame 12.0 35.0 45.0 0.0 0.0 45.0
RightForewing 0.0 0.0 0.0
Root 12.0 35.0 45.0 0.0 0.0 45.0
RightForewing 0.0 0.0 0.0
  
```

## X. Conclusions

### Visual Hull Reconstruction

- Volumetric
- Polyhedral



The image displays three stages of visual hull reconstruction for a person in a crouching pose. From left to right: 1) A solid black silhouette of the person. 2) A point cloud representation of the person's shape. 3) A polyhedral model (a mesh of flat surfaces) that approximates the person's form.

