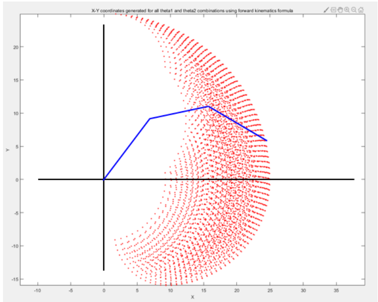
INDUSTRIAL AND MANAGEMENT ENGINEERING, POSTECH

Ergonomic Design Technology Lab

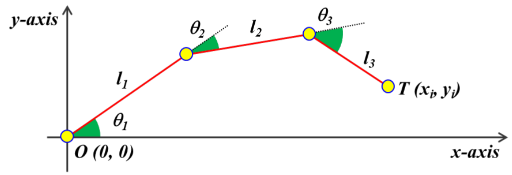
Pose Alignment of a Hand Template Model Using ANFIS based Kinematic Model

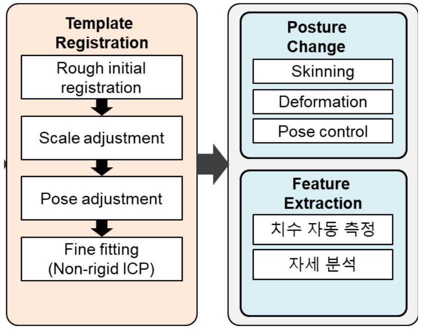


$$\text{If}: \quad \theta_1 \text{ is } A_i, \theta_2 \text{ is } B_i, \theta_3 \text{ is } C_i \ (i = 1, 2, \ldots, n)$$

$$\text{Then}: \quad f_x = l_1 \times \cos\theta_1 + l_2 \times \cos(\theta_1 - \theta_2) + l3 \times \cos(\theta_1 - \theta_2 - \theta_3)$$

$$f_y = l_1 \times \sin\theta_1 + l_2 \times \sin(\theta_1 - \theta_2) + l3 \times \sin(\theta_1 - \theta_2 - \theta_3)$$





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2019년 추계학술대회

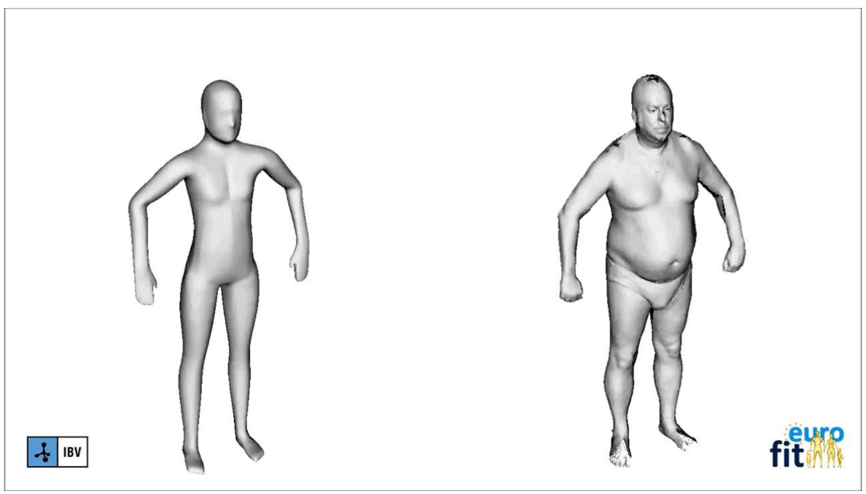
Global Contributor to Eco-Techno-Humanopia

Contents

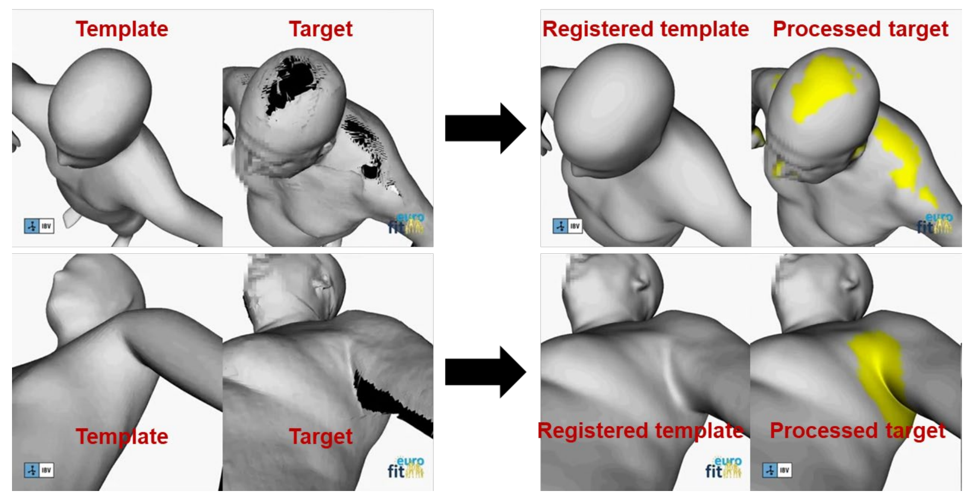
연구 배경

- Template registration은 structured human model을 raw scan data에 정렬하는 기술
- Template registration 수행 시 scan data 후처리, anthropometric measurement, homogenous mesh structure, posture analysis 등 scan data의 효율적 처리가 가능함

Human Body Template Registration 예



Human Body Template Model을 이용한 형상 보강 예



Posture Difference in Template Registration

- Human template model과 raw scan 간 자세 차이는 registration 성능을 저하시킴
  ⇒ Template registration 시 두 모델의 자세 정렬 선행 필요
- 기존 연구들은 template과 scan의 자세 정렬을 위해 경험적 kinematic model 기반 자세 추정 방법, 수리 모델 기반 최적화 방법을 활용함

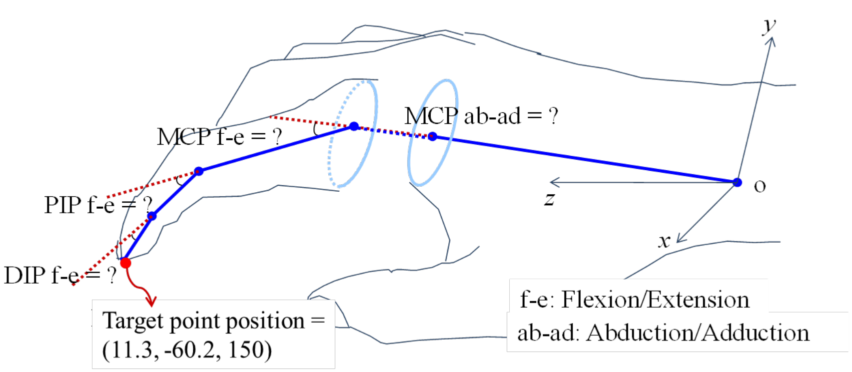
다른 자세의 Template 및 raw scan 정렬 결과 예

기존 연구의 자세 정렬 방법: Kinematic model, Optimization

기존 연구: 손 자세 추정 및 정렬 방법

- Kinematic model 기반 손 자세 추정 방법은 forward kinematics (자세 측정), inverse kinematics (자세 추정)의 2가지 단계로 수행됨 (Yang et al. 2010)
- 최적화 기반 자세 추정 및 정렬 방법은 자세 변수화를 위한 추가 정보가 필요함
  - 1) 다수의 landmark pair의 coordination을 이용한 자세 추정 (MPII)
  - 2) 관절 모델의 segmentation를 이용한 자세 정렬 (reference)
  - 3) 학습된 자세 및 형상 정보 database 활용 (SMPL, MANO 등)

Kinematic model 기반 손 자세 추정 (Yang et al., 2010)



최적화 기반 Template Model 자세 정렬 (Pischulin et al.)

기존 연구의 한계점 (1/2)

- Kinematic model 기반 자세 추정 방법은 정교한 hand model을 생성을 위해 실측 기반의 large data set 구축이 필요함
- 자세 및 형상 정렬을 위해 다수의 data 측정 기반한 data 학습이 선행되어야 함
  ⇒ 자세 학습을 용이하게 할 수 있는 모델 적용 필요

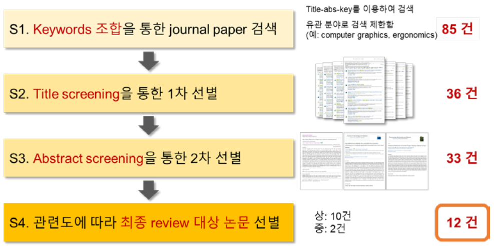
기존 연구의 한계점 (2/2)

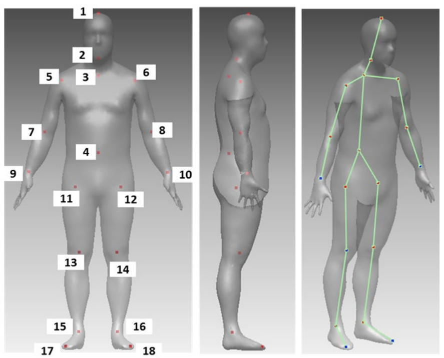
- 수리 모델을 이용한 hand kinematic model 생성 시 손 관절의 높은 자유도 및 비선형적 특성의 모델로 인해 연산이 복잡하고 computational cost가 증가함
  ⇒ 비선형성 및 높은 자유도를 고려한 간단한 연산을 수행하는 방법 적용 필요
- Landmark 정보가 체계적으로 포함된 hand scan DB가 부족함
  ⇒ 최소한의 landmark를 이용한 자세 추정 방법 개발 필요

연구 목표

ANFIS 기반 Kinematic Hand Model을 이용한 Template Model 자세 정렬 방법 개발

1. Hand posture control model 개발
2. Adaptive Neuro-Fuzzy Network 기반 Kinematic model 개발
3. Inverse kinematics 적용 및 Hand posture alignment
4. Hand posture 비교 평가





Big Picture: Template Model 기반 제품 설계 기술

Phase 1

Template Model 개발

Hand Template Model
- Point cloud
- Triangle mesh
- Joint CoRs
- Skeleton & link
- Landmarks
- Body segments
- Deformation characteristics

Phase 2

Digital Human Modeling 기술 개발 (Registration, Deformation, Posture Change)

Template Registration
- Rough initial registration
- Scale adjustment
- Pose adjustment
- Fine fitting (Non-rigid ICP)

Posture Change
- Skinning
- Deformation
- Pose control

Feature Extraction
- 치수 자동 측정
- 자세 분석

Phase 3

최적 설계 기술 개발

Pressure Estimation
- FEM 분석

Parametric Design
- 개인 맞춤형 제품 설계

포항공과대학교 산업경영공학과

Ergonomic Design Technology Lab

연구 절차

S1. Hand posture control model 개발

↓

S2. ANIFS 기반 hand kinematics model 개발

↓

S3. Inverse kinematics 기반 손 자세 추정 및 정렬

↓

S4. Hand model 자세 비교 평가

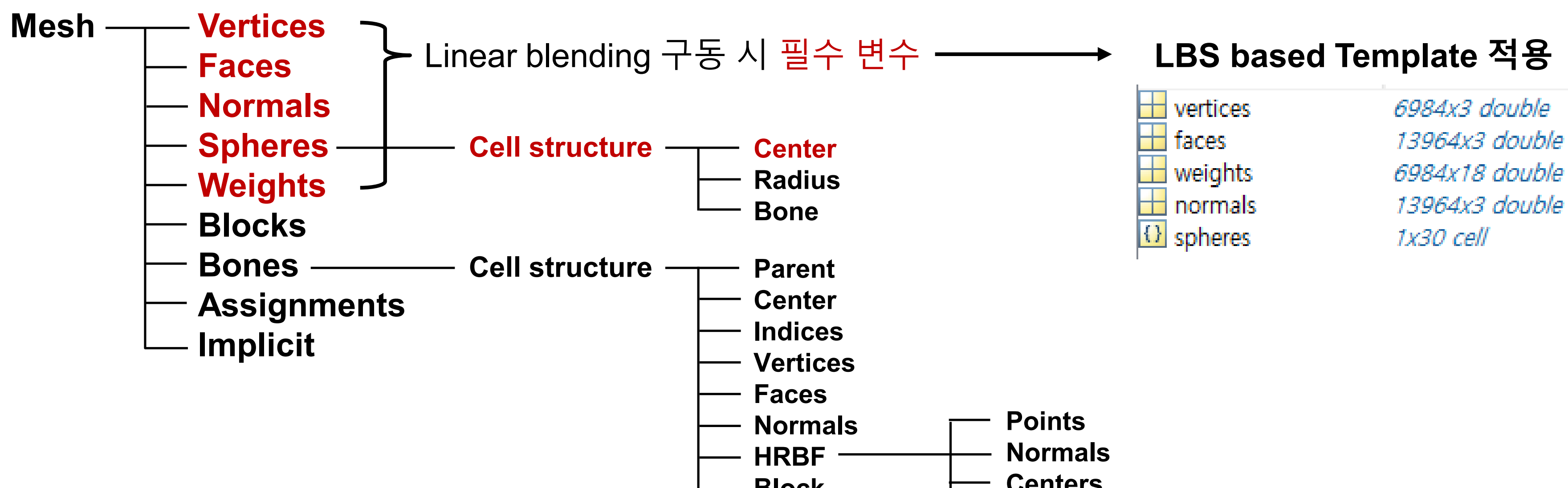
S1. Posable Hand Model 개발: 동작 범위

- 문헌 조사 및 기존 hand model을 조사하여 손가락 관절별 동작 범위 파악
- 자세 변경을 위해 손가락 관절의 19개 각도 입력 변수 생성 및 적용

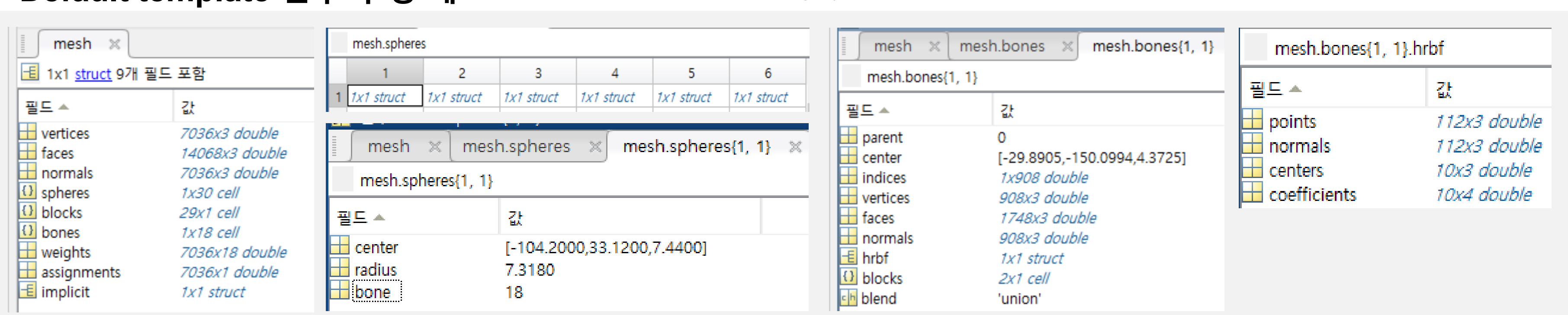
Angle	Digits	Joint	Motion	Range
1	Digit 1	IP	Flexion / Extension	0° ~ 80° (flexion)
2		MCP	Flexion / Extension	0° ~ 80° (flexion)
3		CMC	3D rotation	-
4	Digit 2	MCP	Flexion / Extension	-30° (hyper extension) ~ +80° (flexion)
5		PIP	Flexion / Extension	0° ~ 120° (flexion)
6		DIP	Flexion / Extension	0° ~ 80° (flexion)
7	Digit 3	MCP	Flexion / Extension	-30° (hyper extension) ~ +80° (flexion)
8		PIP	Flexion / Extension	0° ~ 120° (flexion)
9		DIP	Flexion / Extension	0° ~ 80° (flexion)
10	Digit 4	MCP	Flexion / Extension	-30° (hyper extension) ~ +80° (flexion)
11		PIP	Flexion / Extension	0° ~ 120° (flexion)
12		DIP	Flexion / Extension	0° ~ 80° (flexion)
13	Digit 5	MCP	Flexion / Extension	-30° (hyper extension) ~ +80° (flexion)
14		PIP	Flexion / Extension	0° ~ 120° (flexion)
15		DIP	Flexion / Extension	0° ~ 80° (flexion)
16	Digit 2	MCP	Abduction / Adduction	± 10 °
17	Digit 3	MCP	Abduction / Adduction	± 10 °
18	Digit 4	MCP	Abduction / Adduction	± 10 °
19	Digit 5	MCP	Abduction / Adduction	± 10 °

S1. Posable Hand Model 개발: 구성 요소

- Surface mesh를 이용한 posable hand model 개발을 위해 skinning 방법 적용
- LBS (Linear Blend Skinning) 적용을 위해 template model의 5가지 변수 (vertices, face, face normals, spheres (joint center), skinning weights) 구성



Default template 변수 구성 예



mesh — 1x1 struct 9개 필드 포함

필드	값
vertices	7036x3 double
faces	14068x3 double
normals	7036x3 double
spheres	1x30 cell
blocks	29x1 cell
bones	1x18 cell
weights	7036x18 double
assignments	7036x1 double
implicit	1x1 struct

mesh.spheres

	1	2	3	4	5	6
1	1x1 struct	1x1 struct	1x1 struct	1x1 struct	1x1 struct	1x1 struct

mesh.spheres{1, 1}

필드	값
center	[-104.2000,33.1200,7.4400]
radius	7.3180
bone	18

mesh.bones{1, 1}

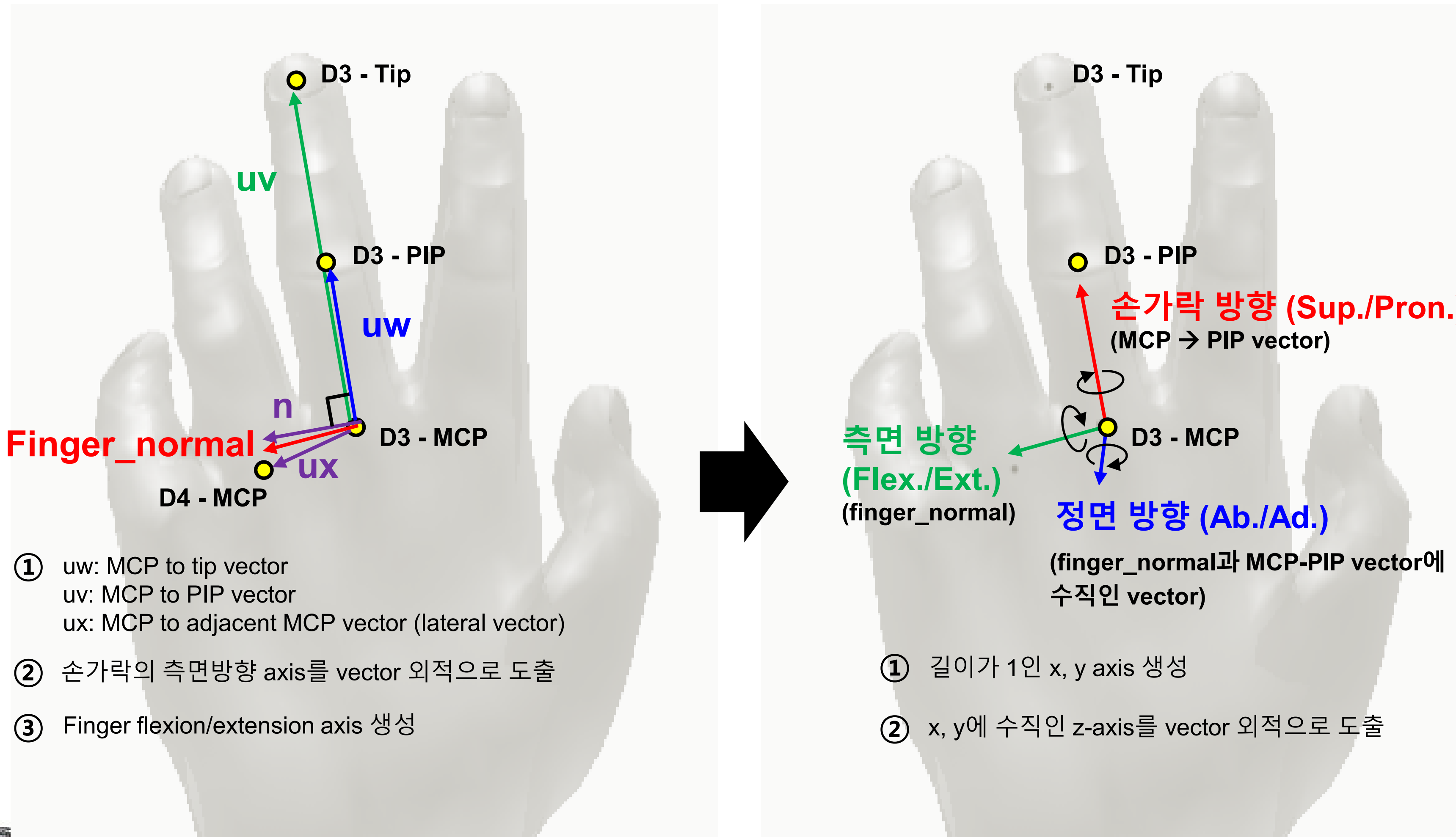
필드	값
parent	0
center	[-29.8905,-150.0994,4.3725]
indices	1x908 double
vertices	908x3 double
faces	1748x3 double
normals	908x3 double
hrbf	1x1 struct
blocks	2x1 cell
blend	'union'

mesh.bones{1, 1}.hrbf

필드	값
points	112x3 double
normals	112x3 double
centers	10x3 double
coefficients	10x4 double

S1. Posable Hand Model 개발: 회전축 생성

- 4개의 joint center points를 이용하여 lateral vector 생성 및 PIP, DIP의 flex./ext. axis 도출
- Axes center (MCP joint)와 2개의 vector를 이용하여 MCP joint의 회전축 구성



① uw: MCP to tip vector
uv: MCP to PIP vector
ux: MCP to adjacent MCP vector (lateral vector)

② 손가락의 측면방향 axis를 vector 외적으로 도출

③ Finger flexion/extension axis 생성

① 길이가 1인 x, y axis 생성

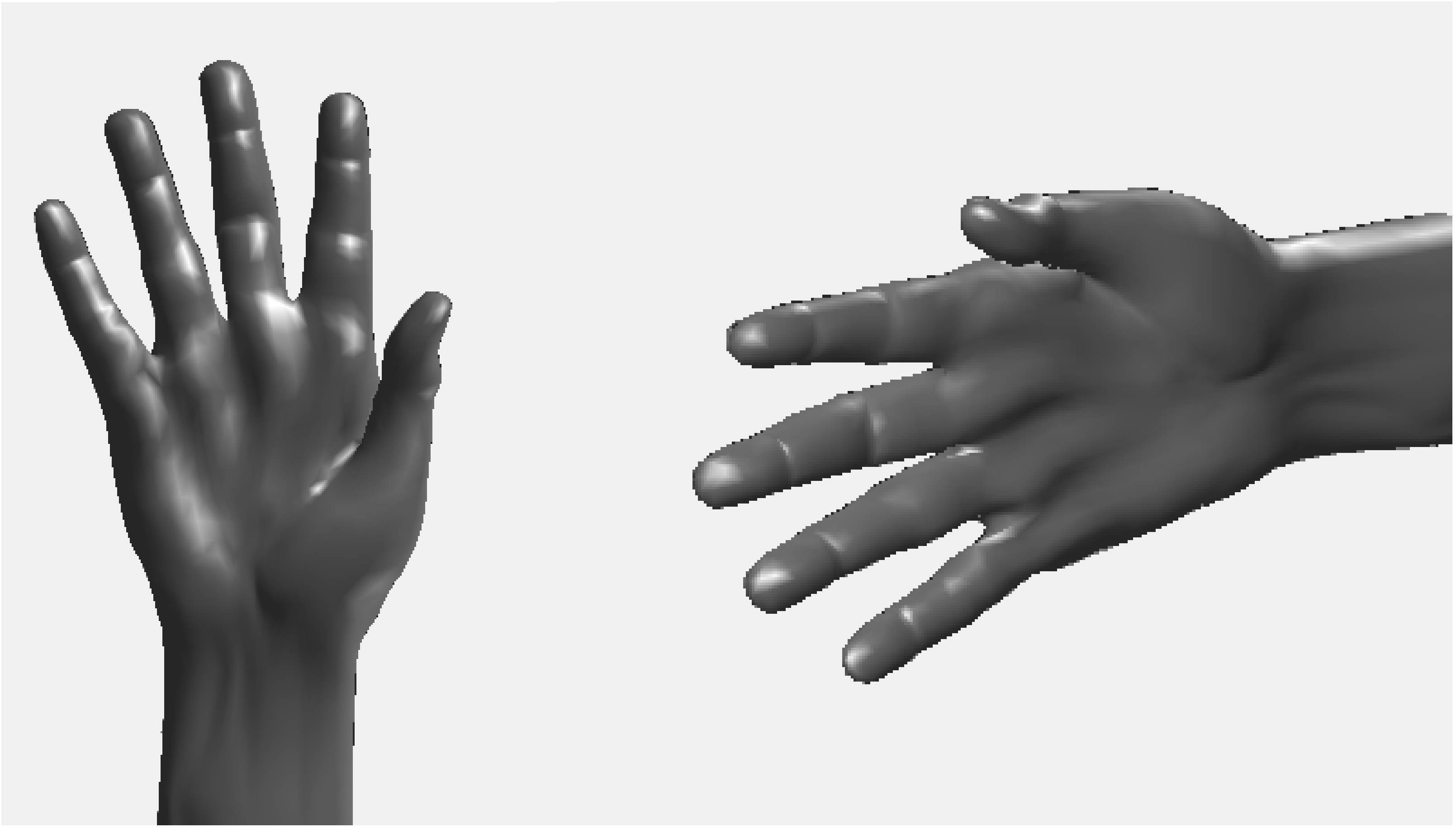
② x, y에 수직인 z-axis를 vector 외적으로 도출

S1. Posable Hand Model 개발: 회전 변환 및 Skinning Weight

- V' = V * rotation, scale, translation Matrix * skinning weight

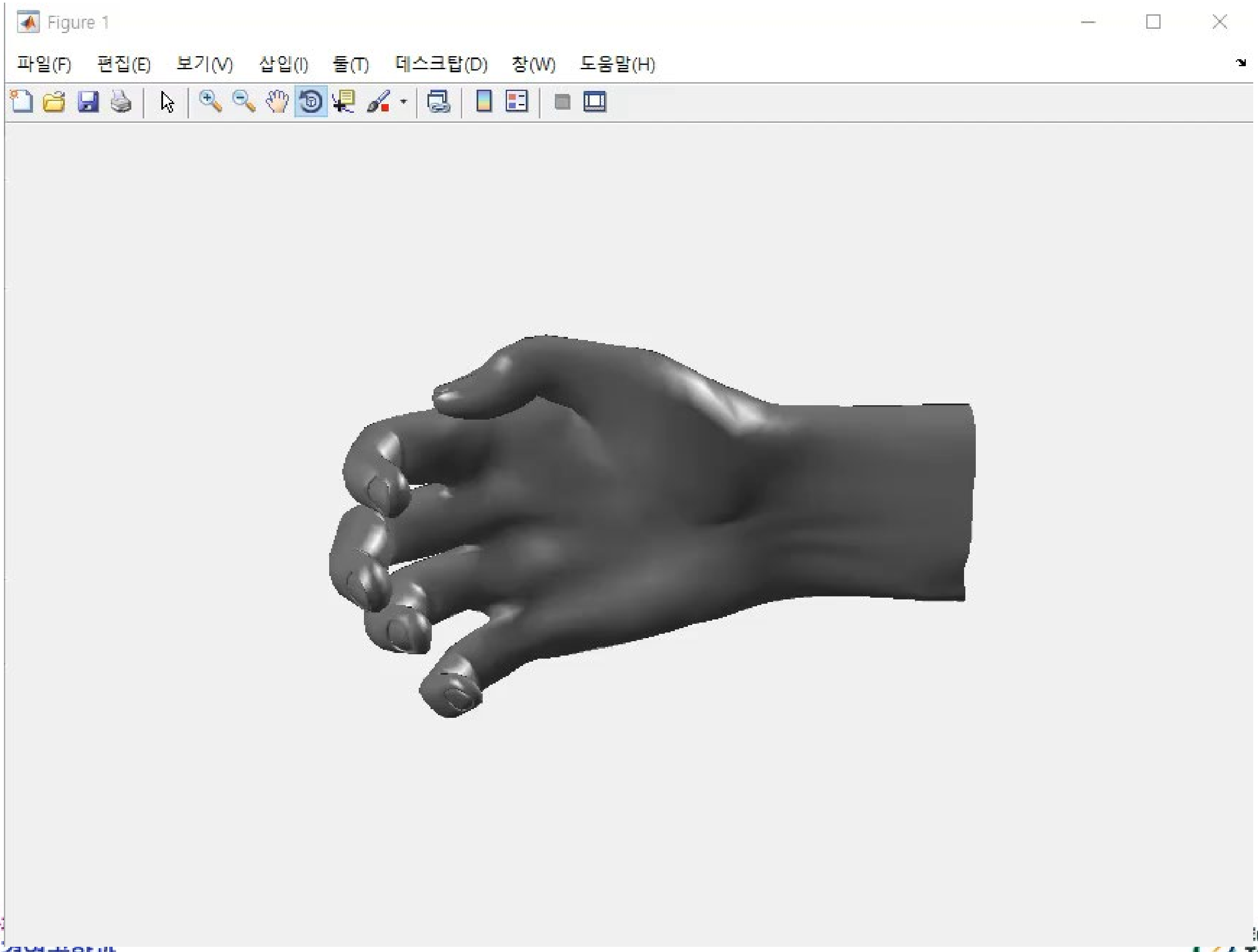
S1. Posable Hand Model 개발: Neutral Posture

- 편 기본 자세의 hand template model
- 손가락 관절별 각도(deg.)를 입력하여 자세 변경이 가능하도록 개발



S1. Posable Hand Model 개발: Half-Grasping Posture

- Grasping 자세 구현을 위해 digit 2-5 MCP: 30°, PIP: 45°, DIP: 45° 적용



S2. ANFIS (Adaptive Neuro-Fuzzy Inference System)

- Fuzzy Inference System (FIS)은 *If-then* 개념을 통해 인간의 언어 및 사고에 관련된 애매함 (fuzziness)을 수리적으로 표현할 수 있으나, 학습 능력의 부재로 의사 결정 모델인 fuzzy system 도출 시 전문가 지식에 의존하는 한계를 지님
- ANIFS는 FIS의 *If-then* 개념과 ANN의 학습능력을 결합한 모델로, 학습된 data set 안에서 최적화를 수행하고 비선형성을 고려할 수 있음

Fuzzy Inference System 개념 + **Artificial Neural Network 개념** → **Adaptive Neuro-Fuzzy Inference System**

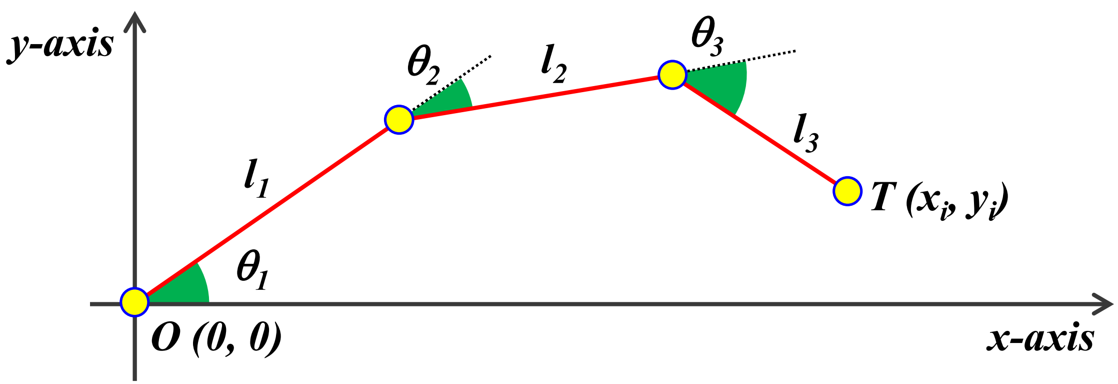
S2. ANFIS 기반 Kinematic Hand Model

- DIP, PIP, MCP는 flexion/extension 시 한 축의 영향을 받음 → 평면으로 가정
- (1) Finger tip 위치 $T(x_i, y_i)$, (2) MCP joint center $(0, 0)$, (3) finger segment length (l_1, l_2, l_3)를 이용하여 관절별 각도$(\theta_1, \theta_2, \theta_3)$를 연산하는 2차원 상의 수리 모델 생성
- ANFIS는 Finger tip 위치 $T(x_i, y_i)$ 에 대하여 관절별 각도 입력당 n개의 퍼지 집합 (fuzzy set)을 갖는 스게노형 FIS의 *If-then* 규칙을 정의함

If : θ_1 *is Ai*, θ_2 *is Bi*, θ_3 *is Ci* $(i = 1, 2, \ldots, n)$

Then : $f_x = l_1 \times \cos\theta_1 + l_2 \times \cos(\theta_1 - \theta_2) + l3 \times \cos(\theta_1 - \theta_2 - \theta_3)$

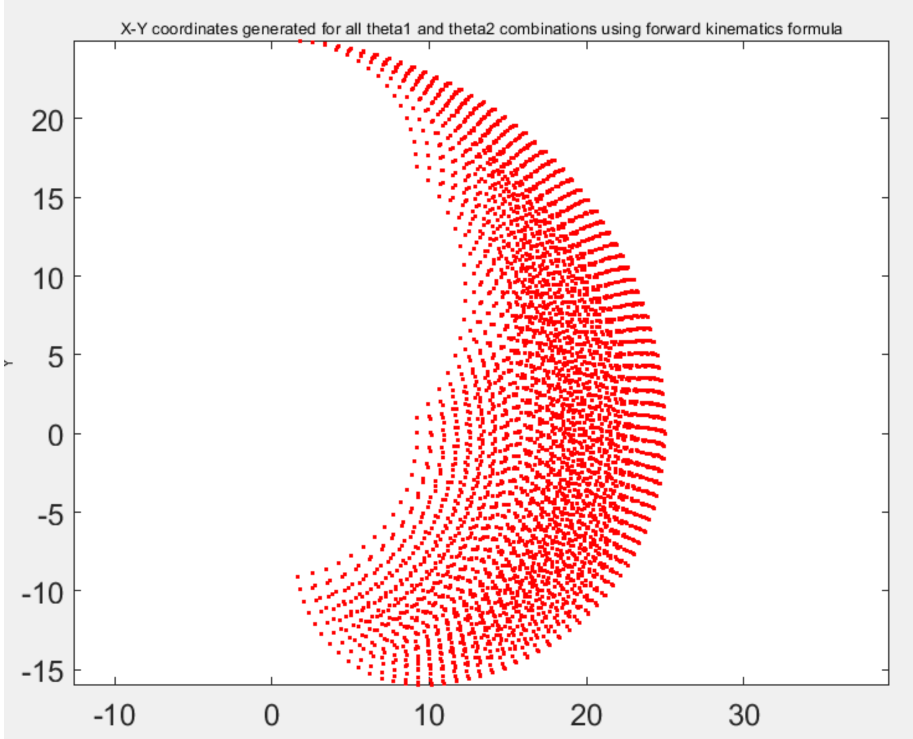
$f_y = l_1 \times \sin\theta_1 + l_2 \times \sin(\theta_1 - \theta_2) + l3 \times \sin(\theta_1 - \theta_2 - \theta_3)$



S2. ANFIS 기반 Kinematic Hand Model: Forward Kinematics

- Kinematic model 구성 시 손 자세 data 구축을 위한 forward kinematics 수행 필요
- 본 연구에서는 ANN을 이용한 dataset 구축을 수행하여 forward kinematic를 수행함

Forward Kinematics 결과: X, Y Data Plot



Forward Kinematics 결과: Data Matrix 생성 예

theta 1	theta 2	theta 3	coord-x	coord-y
0.0	0.0	0.0	25.0	0.0
0.0	0.1	0.0	24.9	-1.6
0.0	0.2	0.0	24.7	-3.2
0.0	0.3	0.0	24.3	-4.7
0.0	0.4	0.0	23.7	-6.2
0.0	0.5	0.0	23.0	-7.7
0.0	0.6	0.0	22.2	-9.0
0.0	0.7	0.0	21.2	-10.3
0.0	0.8	0.0	20.1	-11.5
0.0	0.9	0.0	18.9	-12.5
0.0	1.0	0.0	17.6	-13.5
0.0	1.1	0.0	16.3	-14.3
0.0	1.2	0.0	14.8	-14.9
0.0	1.3	0.0	13.3	-15.4
0.0	1.4	0.0	11.7	-15.8
0.0	1.5	0.0	10.1	-16.0
0.1	0.0	0.0	24.9	2.5
0.1	0.1	0.0	25.0	0.9
0.1	0.2	0.0	24.9	-0.7
...	...	...	...	...

S2. ANFIS 기반 Kinematic Hand Model: Inverse Kinematics

- 생성된 ANFIS 모델에 inverse kinematics 개념을 적용하여 입력값 (x_i, y_i)에 대한 관절별 각도($\theta_1, \theta_2, \theta_3$) 도출
- 입력값에 대한 관절별 각도 도출을 위해 후견부 매개 변수에 LSE (Least-Square Estimate)를 이용하여 결과 최적화 수행

coord-x	coord-y
25.0	0.0
24.9	-1.6
24.7	-3.2
24.3	-4.7
23.7	-6.2
23.0	-7.7
22.2	-9.0
21.2	-10.3
20.1	-11.5
18.9	-12.5
17.6	-13.5
16.3	-14.3
14.8	-14.9
13.3	-15.4
11.7	-15.8
10.1	-16.0
24.9	2.5
25.0	0.9
24.9	-0.7
...	...

➡

theta 1	theta 2	theta 3
0.0	0.0	0.0
0.0	0.1	0.0
0.0	0.2	0.0
0.0	0.3	0.0
0.0	0.4	0.0
0.0	0.5	0.0
0.0	0.6	0.0
0.0	0.7	0.0
0.0	0.8	0.0
0.0	0.9	0.0
0.0	1.0	0.0
0.0	1.1	0.0
0.0	1.2	0.0
0.0	1.3	0.0
0.0	1.4	0.0
0.0	1.5	0.0
0.1	0.0	0.0
0.1	0.1	0.0
0.1	0.2	0.0
...	...	...

➡

S3. Inverse Kinematics 적용

- Hand scan data 상에 10개의 landmark 정의, hand digit ratio 측정(편 자세)
- 개발된 ANFIS algorithm을 이용하여 hand joint별 자세 추정
- Posable hand model에 hand joint별 자세 적용

S4. Hand Pose 비교 평가

- Surface marker 기반 자세 측정 방법 vs. Inverse kinematics 기반 자세 측정 방법
- Surface marker based, Inverse kinematics based 관절별 각도 추정 결과 비교

Discussion

- Posable hand model 개발
- Adaptive neuro-fuzzy network를 이용한 Inverse kinematics 구현
- 소규모 landmark를 이용하여 자세 추정, surface marker 와 유사/우수한 성능

Appendix

연구 배경 (1/2)

- 손은 5개의 손가락 및 18개의 관절(27 자유도)로 구성된 정교한 인체 기관
- 손은 정교하고 복잡한 동작을 요구하는 다양한 manual work 수행 시 활용됨

손 전반 형상 및 관절 구성

다양한 handle design

Drill

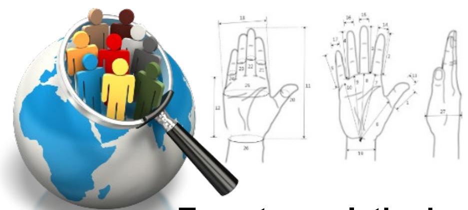
의료기기(초음파 probe)

청소기 handle

연구 배경 (2/2)

- 인간공학적 handle 및 hand tool 개발을 위해 손 파지 자세 및 형상 분석 필요
- 3D scanner를 이용한 3차원 손 측정 및 형상 분석이 수행됨

인간공학적 handle/hand tool 설계



Target population's hand anthropometry

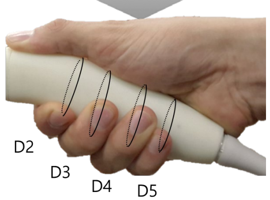
Various hand posture

Grip design process

Design analysis → … → Hand data analysis → … → Hand data base model

Optimal grip design for target population

Fitness ↑, satisfaction ↑



3D scanner를 이용한 3차원 손 scan

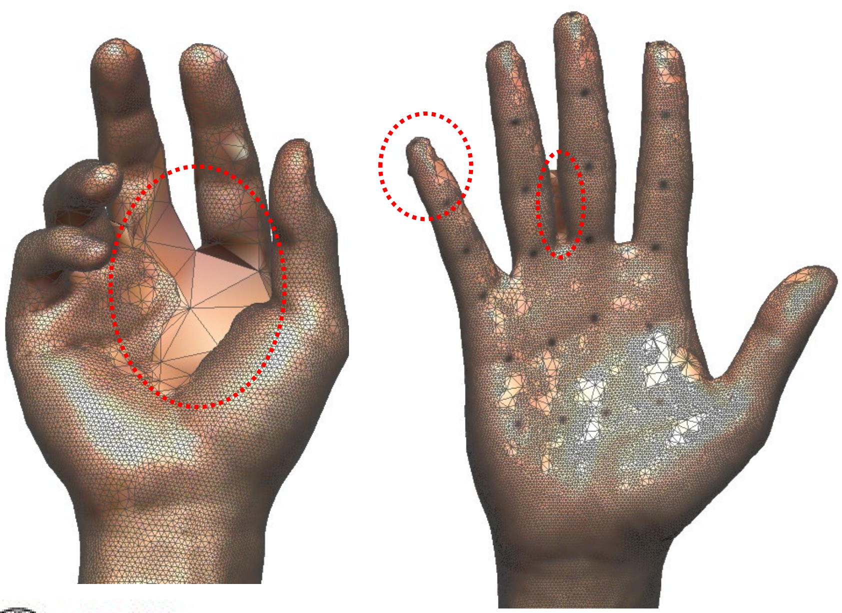
Hand 3D scanner

Scanned Hand

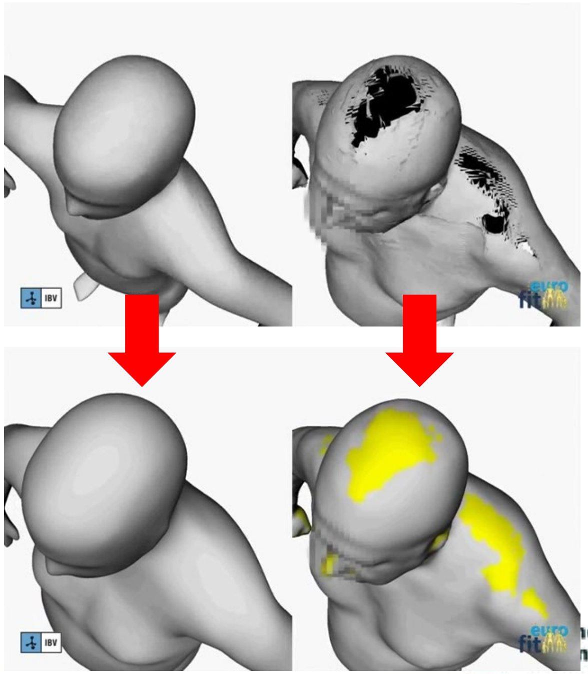
연구 필요성

- 3D scan을 통한 손 형상 재구성의 어려움
  - 손의 얇고 긴 형태적인 특성으로 3D scan으로 온전한 형상 획득이 어려움
  - 편 자세 외 파지 자세 등은 3D scan 시 가려져 측정이 불가능함
  - 3D scan 시 일부 접힘 부위 missing으로 형상 보강 및 후처리 필요
- 손 3D scan의 한계를 보완하기 위해 hand template model을 이용한 3차원 인체 형상 기술의 활용 필요

낮은 품질의 손 3D scan 예



Template model을 이용한 형상 보강 예



기존 연구의 한계점

- 기존 3차원 인체형상 기술 및 template model은 computer graphics 분야에서 자연스러운 3D animation 구현 등에 주로 활용됨
  ⇒ 3D 인체 형상 기술을 파지류 제품 설계에 적용 활성화 필요
  ⇒ 동작 변화에 따른 체표 길이, 둘레, 부피 변화 등 인체 치수 변형 특성 분석 기술 고도화 필요
- 기존 template model은 full body model로 손의 특성에 최적화된 모델은 부족함

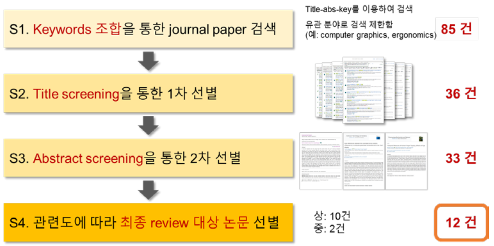
Computer graphics의 HBTM application 예

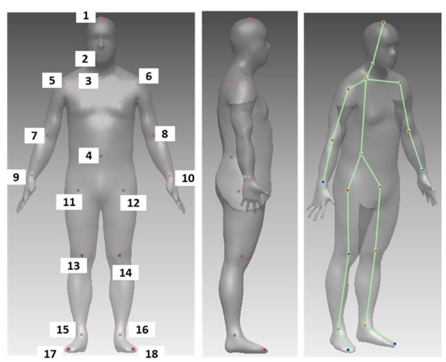
형상 변형 특성을 고려한 인간공학적 제품 설계 예

연구 목적

인간공학적 제품 설계를 위한
3차원 Deformable Hand Template Model 개발

1. Human Template Model 유관 문헌 조사
2. Human Template Model 구성요소 분석
3. 3D Hand Template Model 조사 및 개발
4. Deformable HTM Application 고찰





포항공과대학교 산업경영공학과

Ergonomic Design Technology Lab

Big Picture: Template Model 기반 제품 설계 기술

Phase 1

Template Model 개발

Hand Template Model
- Point cloud
- Triangle mesh
- Joint CoRs
- Skeleton & link
- Landmarks
- Body segments
- Deformation characteristics

Phase 2

Digital Human Modeling 기술 개발 (Registration, Deformation, Posture Change)

Template Registration
- Rough initial registration
- Scale adjustment
- Pose adjustment
- Fine fitting (Non-rigid ICP)

Posture Change
- Skinning
- Deformation
- Pose control

Feature Extraction
- 치수 자동 측정
- 자세 분석

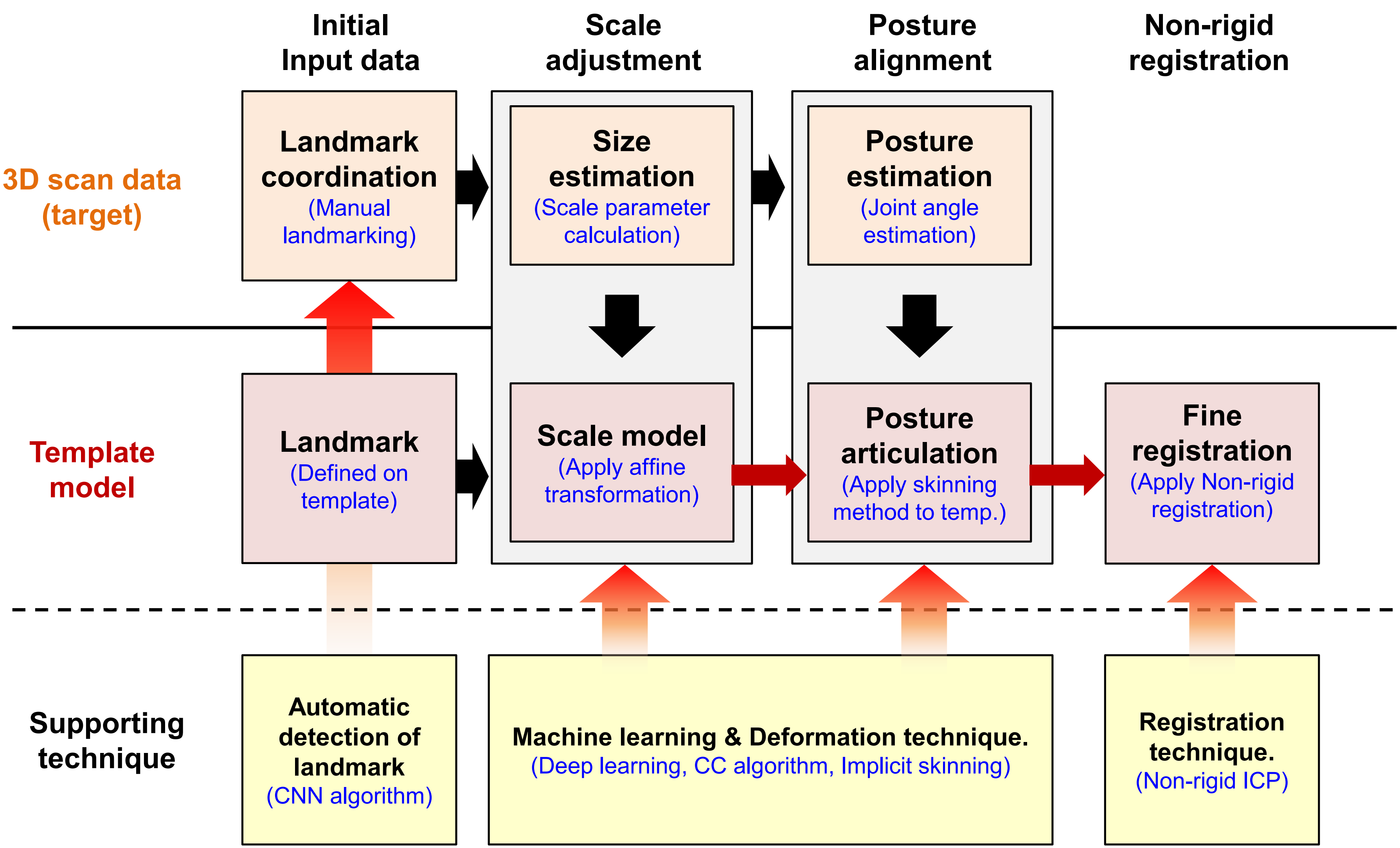
Phase 3

최적 설계 기술 개발

Pressure Estimation
- FEM 분석

Parametric Design
- 개인 맞춤형 제품 설계

Big Picture: Registration 기술 개발



Source: Allen et al., 2003; Anguelov et al., 2005; Pishchulin et al., 2017

Template Model 논문 조사: 방법

- 문헌 조사 site: www.scopus.com
- 검색 조건: title, abstract, keyword
- 검색 분야별 keyword
  - **공통 Keyword**: 3D scan, 3D Human, Body scanning, 3D human body, 3D hand
  - **Template model 관련**: Meshed human model, mesh animation, template model, body segment, skeleton estimation, linear blend skinning, skinning mesh
  - **검색 식 구성 방법**: Title-abs-key((공통 Keyword) AND (세부분야 Keyword))
  - **검색 식**: TITLE-ABS-KEY(("3D scan" or "3D Human" or "Body scanning" or "3D human body" or "3D body scan“ or “3D hand”) and ("meshed human model" or "mesh animation" or "template model" or template or "skeleton animation" or "linear blend skinning" or "skinning mesh" or skinning))

Template Model 논문 조사: 결과

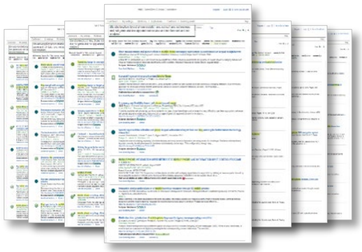
S1. Keywords 조합을 통한 journal paper 검색

Title-abs-key를 이용하여 검색

유관 분야로 검색 제한함
(예: computer graphics, ergonomics)

85 건

S2. Title screening을 통한 1차 선별



36 건

S3. Abstract screening을 통한 2차 선별

33 건

S4. 관련도에 따라 최종 review 대상 논문 선별

상: 11건
중: 2건

13 건

포항공과대학교 산업경영공학과

Ergonomic Design Technology Lab

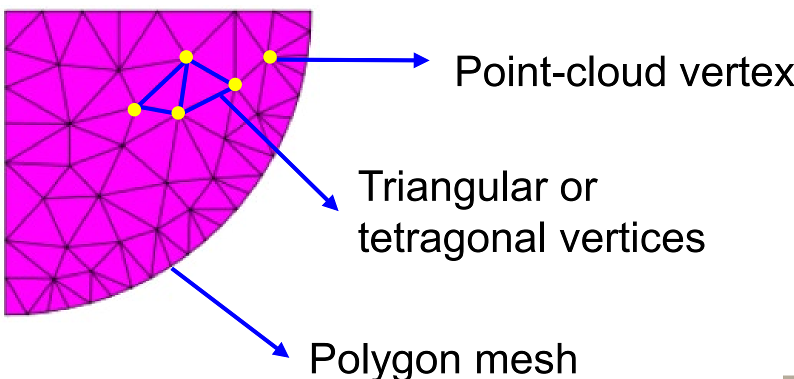
Template Model 논문 List

No.	Year	Author(s)	Title	Institute	중요도
1	2012	Ghosh et al.	From Deformations to Parts: Motion-based Segmentation of 3D Objects	Max Planck Institute (MPI)	상
2	2014	Loper et al.	MoSh: Motion and Shape Capture from Sparse Markers	Max Planck Institute (MPI)	상
3	2014	Tsoil	Modeling the Human Body in 3D: Data Registration and Human Shape Representation	Max Planck Institute (MPI)	상
4	2011	Tsoil and Black	Shape- and Pose-Invariant Correspondences using Probabilistic Geodesic Surface Embedding	Max Planck Institute (MPI)	상
5	2014	Tsoil et al.	Model-based Anthropometry: Predicting Measurements from 3D Human Scans in Multiple Poses	Max Planck Institute (MPI)	상
6	2014	Jacobson et al.	Bounded Biharmonic Weights for Real-Time Deformation	Interactive Geometry Lab, ETH IGL, Switzerland	상
7	2004	O. Sorkine et al.	Laplacian Surface Editing	Interactive Geometry Lab, ETH IGL, Switzerland	상
8	-	K. Takayama et al.	Sketch-Based Generation and Editing of Quad Meshes	Interactive Geometry Lab, ETH IGL, Switzerland	상
9	2014	Jacobson et al.	Bounded Biharmonic Weights for Real-Time Deformation	IBV, Spain	상
10	2015	Reed et al.	Statistical Prediction of Body Landmark Locations on Surface Scans	UMTRI, US	상
11	2017	Romero et al.	Embodied Hands: Modeling and Capturing Hands and Bodies Together	ACM Transactions on Graphic / MPI - PS	상
12	2004	Moccozet et al.	Animatable Human Body Model Reconstruction from 3D Scan Data using Templates	MIRA Lab, University of Geneva, Switzerland	중
13	2011	Yeh et al.	Template-Based 3D Model Fitting Using Dual-Domain Relaxation	National Cheng-Kung University	중

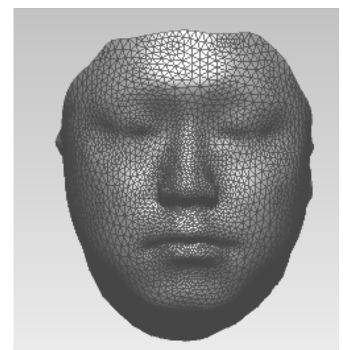
Human Body Template Model (HBTM)

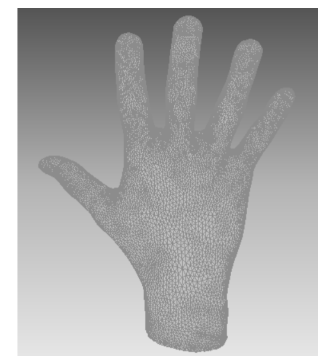
- Template model은 정교한 human surface mesh model의 복합체
- Bone(CoR 포함), skin, landmark 등으로 구성되며 각 요소별 특성 정보 포함
- Skin 및 bone은 triangle의 복합체로 구성된 polygon mesh (vertex, node 포함)

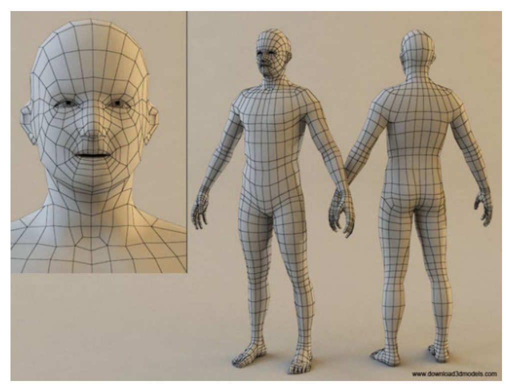
Polygon mesh 구성 요소

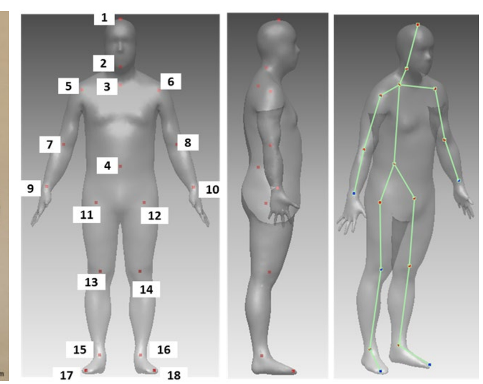


Human surface mesh model 예





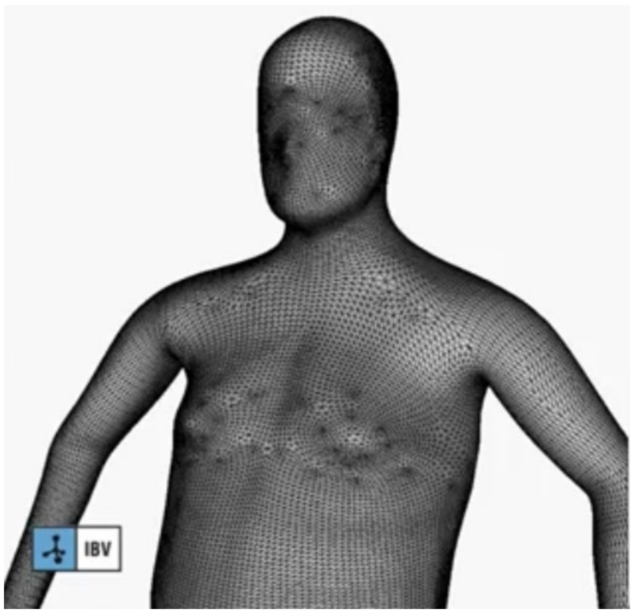




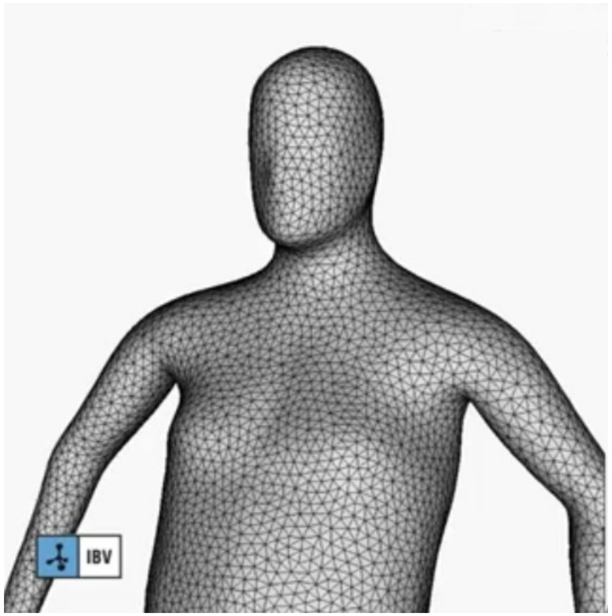
Template Model 구성 요소: Surface Mesh

- 적정 수의 vertex 및 node: 3D registration 효율을 고려한 적정 수 도출
- 인체 기준점(landmark): 효율적인 인체 치수 측정을 위한 기준점

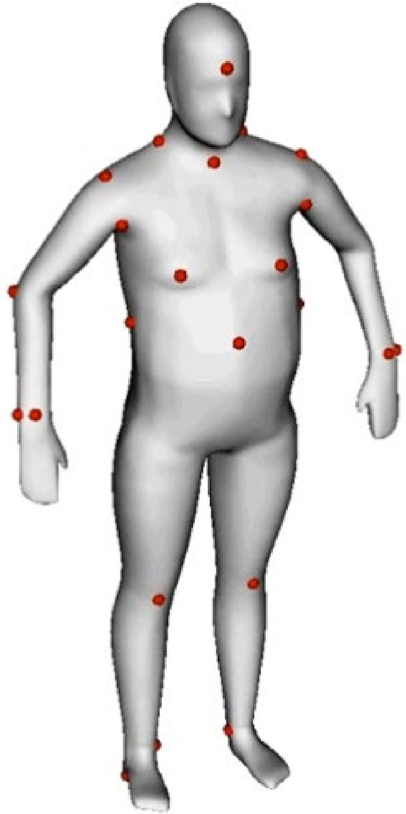
High-resolution HBTM



Low-resolution HBTM



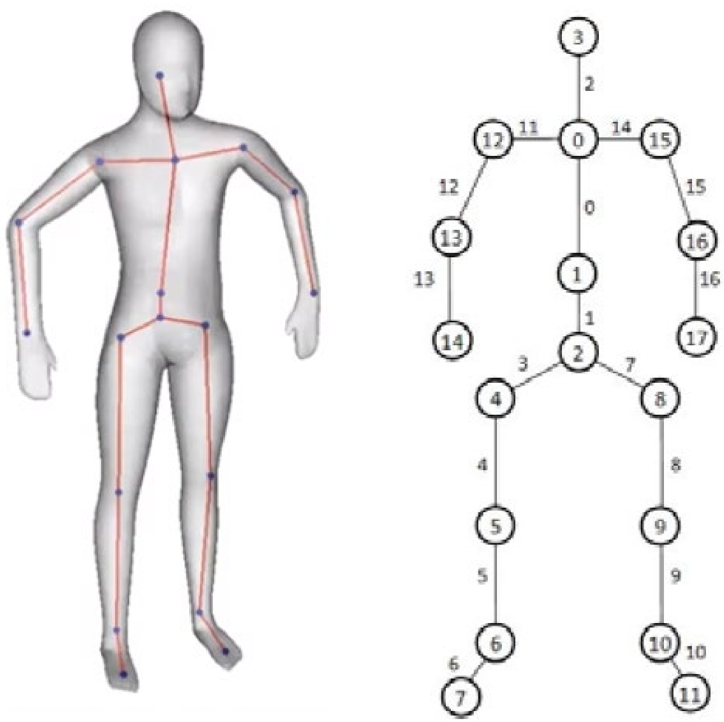
Landmark 예시



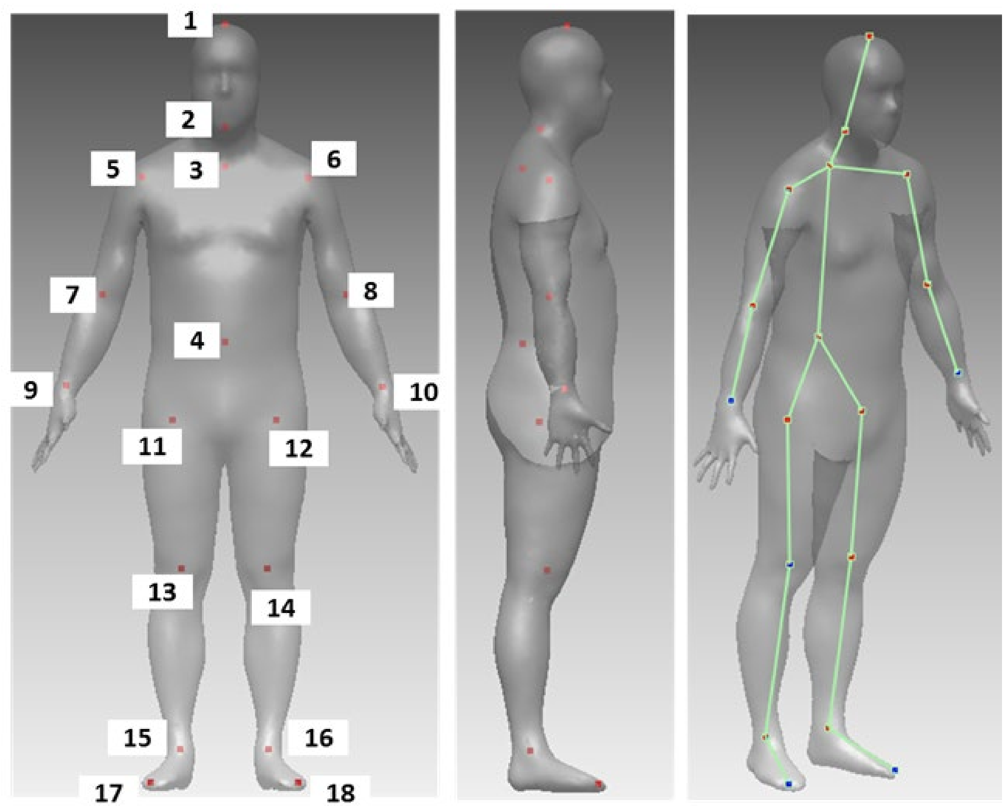
Template Model 구성 요소: Skeleton & Joint

❑ Skeleton 및 joint center: 인체 형상 및 자세를 고려한 skeleton link 생성

IBV, Spain



EDT Lab (POSTECH)



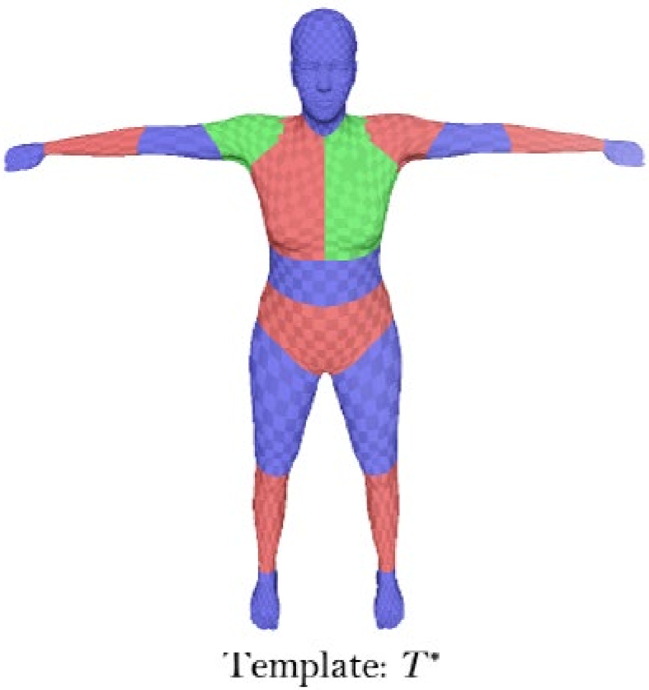
Template Model 구성 요소: Body Segment

❑ Body segmentation: 자세 변형 시 신체 부위별 변형 특성 고려

Segmentation of body parts
(# segment = 16)

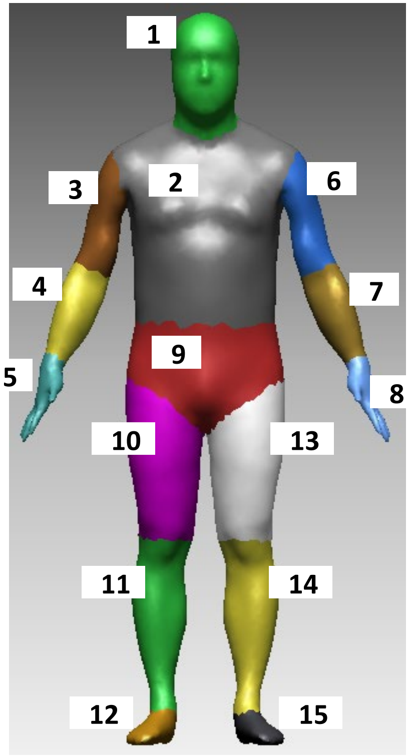
IBV, Spain

Segmentation of body parts
(# segment = 19)



Perceiving Systems Lab, Germany

Segmentation of body parts
(# segment = 15)



EDT Lab (POSTECH)

Hand Model 논문 List

No.	Year	Author(s)	Title	Source / Institute	중요도
1	2014	Endo et al.	Dhaiba: Development of Virtual Ergonomics Assessment System with Human Models	AIST (Japan)	상
2	2017	Romero et al.	Embodied Hands: Modeling and Capturing Hands and Bodies Together	ACM Transactions on Graphic / MPI – PS	상
3	2011	Buczekl et al.	Kinematic performance of a six degree-of-freedom hand model (6DHand) for use in occupational biomechanics	Journal of Biomechanics	상
4	2011	Oikonomidis et al.	Full DOF tracking of a hand interacting with an object by modeling occlusions and physical constraints	International conference on Computer Vision (ICCV)	중
5	2013	Sridhar et al.	Interactive Markerless Articulated Hand Motion Tracking using RGB and Depth Data	International conference on Computer Vision (ICCV)	중
6	2016	Tkach et al.	Sphere-meshes for real-time hand modeling and tracking.	ACM Transactions on Graphics	중
7	2014	Schmidt et al.	DART: Dense Articulated Real-Time Tracking	In Robotics: Science and Systems	중
8	2016	Tzionas et al.	Capturing Hands in Action using Discriminative Salient Points and Physics Simulation	International Journal of Computer Vision (IJCV)	중
9	2015	Khamis et al.	Learning an Efficient Model of Hand Shape Variation from Depth Images	In IEEE Conference on Computer Vision and Pattern Recognition (CVPR)	중
10	2015	Oberweger et al.	Training a Feedback Loop for Hand Pose Estimation	International conference on Computer Vision (ICCV)	중

Dhaiba Hand Model: AIST (Endo et al., 2014)

- 3D scan 및 motion marker data를 이용하여 deformable, reposable 모델 생성
- Grasp comfortability에 기반한 optimal grip 추정 방법 적용 및 접촉면 분석

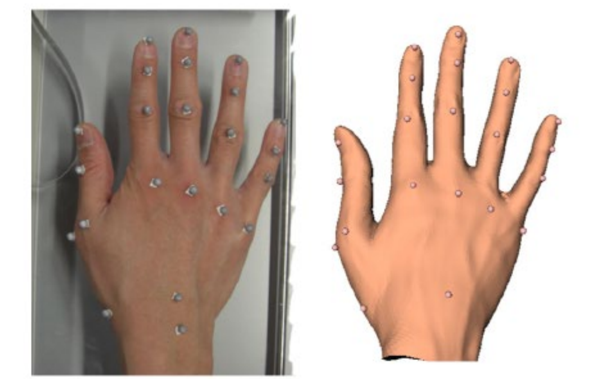
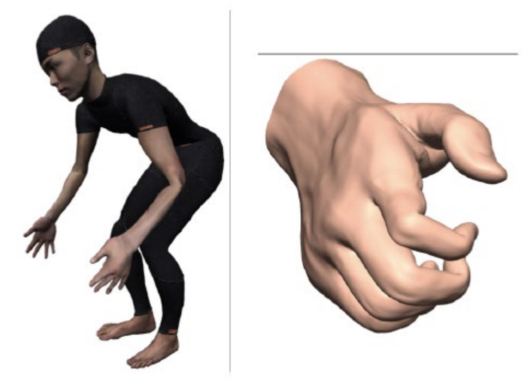


Fig. 4: Reconstruction of individual hand models from scanned hand images (reprinted from (Miyata 2011)).



(a) (b)

Fig. 2: Postures of the Dhaiba models. (a) DhaibaBody and (b) DhaibaHand.

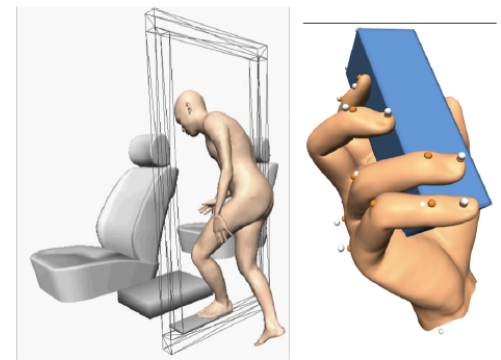


Fig. 7: Reconstructed postures of the Dhaiba models from marker trajectories obtained from the motion capture. White points show the measured markers and orange points show the feature points on the skin surface model.

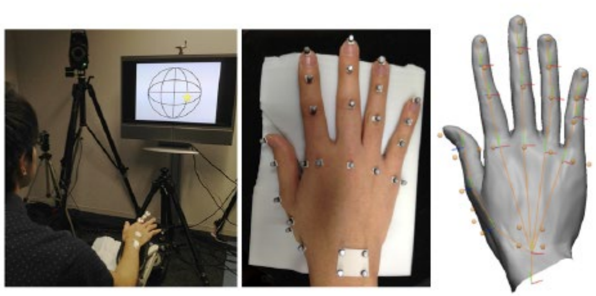


Fig. 5: Reconstruction of individual hand models from marker trajectories obtained from the motion capture (reprinted from (Endo 2014-1)).

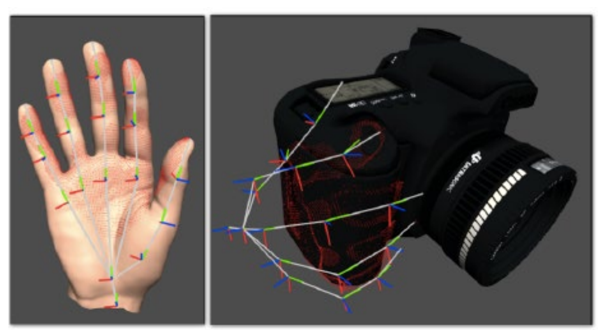


Fig. 11: Contact region for the grasp posture. Red points show the contact points.

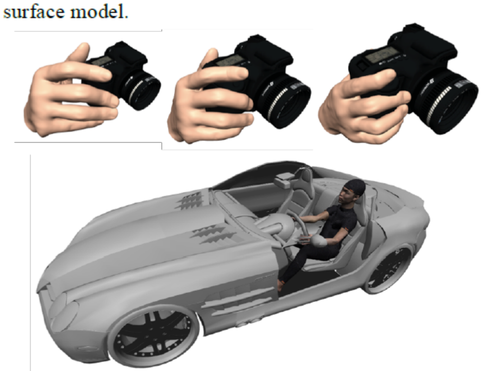
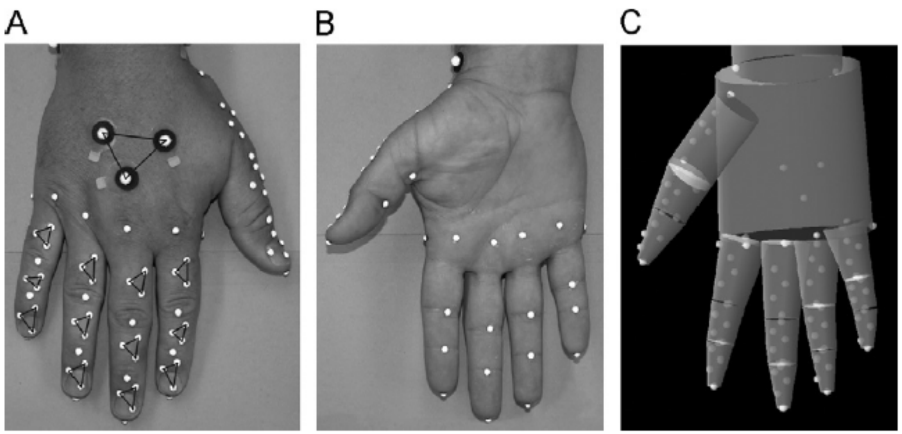
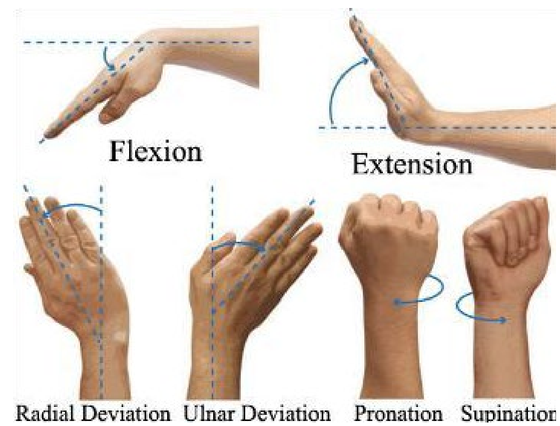


Fig. 8: Results of the posture reconstruction by the simulation using the spring and damper models. Upper left and upper middle figure show the posture reconstruction process. The product models are gradually magnified in the simulation so as to avoid the collision in the early stage of the simulation.

6 DoF Hand Model: Buczek et al., 2011

- Hand model 개발 시 손 segment를 기준으로 (1) flexion/extension, (2) ulnar/radial deviation, (3) pronation/supination, (4) radial, (5) palmar, (6) proximal translation 고려

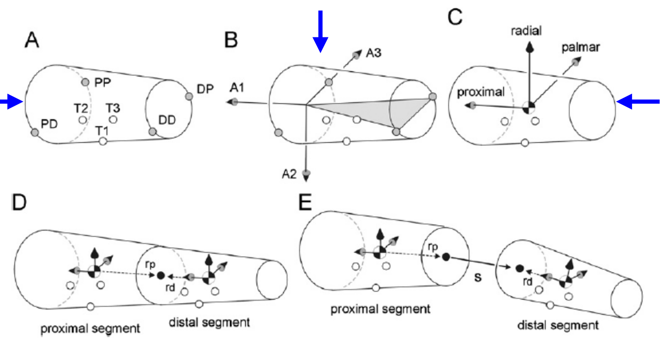




Defining axes

Anatomical landmarks

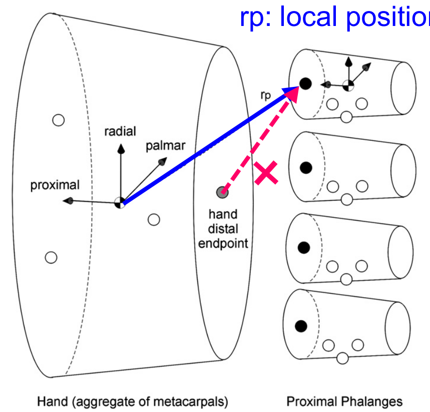
Defining LRF : center of mass



During the calibration

During dynamic activities

rp: local position vector



Result in spuriously large magnitudes

Metacarpals

Embodied Hand Model: MPI (Romero et al., 2017)

- 다양한 손 자세 및 손 형상을 학습하여 낮은 품질의 scan data에도 높은 정확도 및 성능으로 target scan data에 정렬되는 hand template model 및 인체형상 기술 개발
- 기존 전신 정렬 기술(Loper et al., 2015)에 손의 특성을 분석 및 적용하여 전신 및 손을 함께 처리할 수 있는 인체형상 기술 제안

Hand posture & shape learning

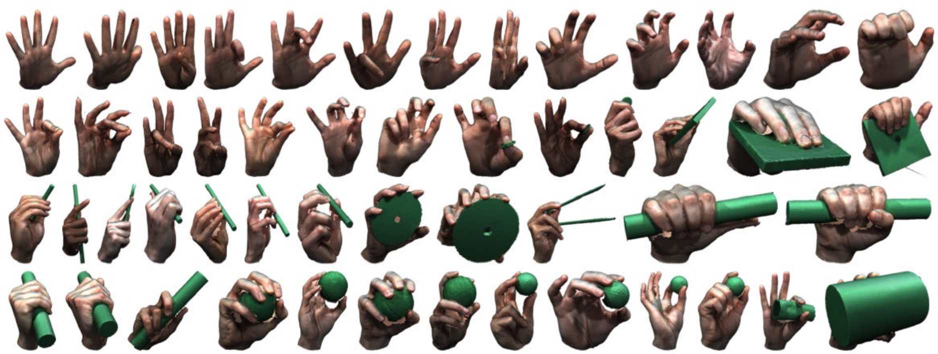
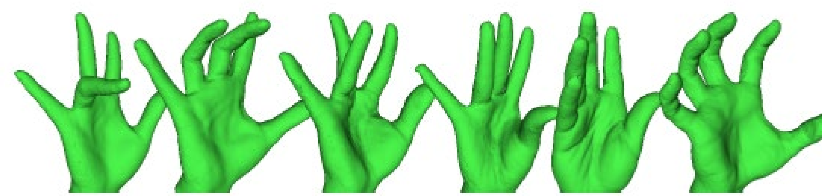
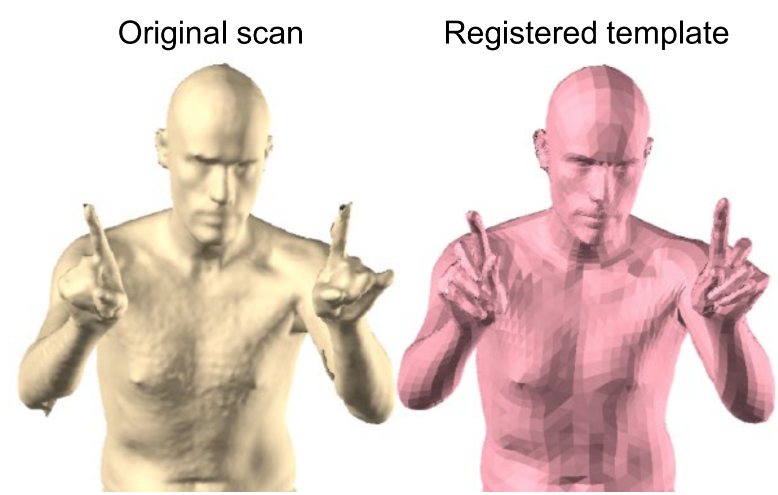


Fig. 5. Hand capture protocol. Each of the 31 subjects performed most of the 51 hand poses shown here. Images here are shown from multiple subjects.

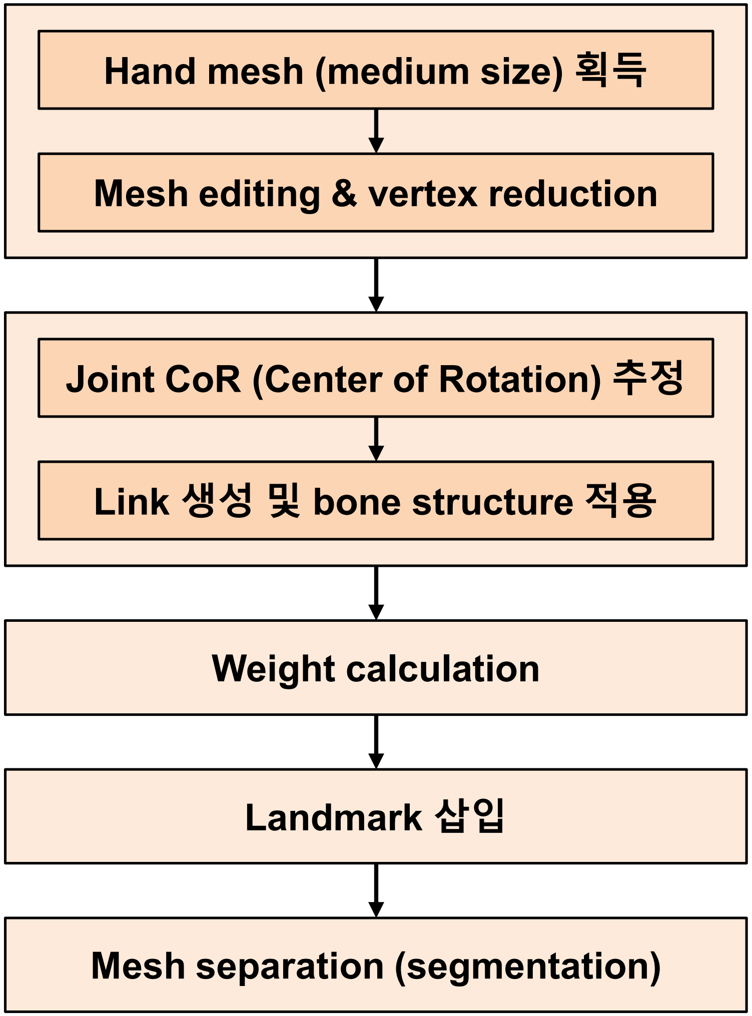
Fig. 7. Examples of the captured *"flat-hand"* pose for various subjects. The *top* row shows some of the captured *scans*, while the *bottom* row shows the corresponding mesh *alignments* with *pink* color.

High quality hand template registration 예





Hand Template Model (HTM) 개발 절차



- Size Korea 2010 손직선길이 기준 medium size male에 해당하는 손 scan 및 후처리
- Vertex reduction: target vertex 15,000 ~ 20,000 되도록 mesh reduction 수행

- 선행 연구(Lim, 2018) 결과를 이용하여 CoR 도출 (Delonge Kasa Method 활용, fixed CoR 도출)
- Link model 생성 및 hand bone 적용

- Weight: hand mesh 상의 vertex의 상대적인 중요도
- CoR로부터 거리를 기반으로 계산됨
- Blender S/W를 이용하여 연산

- 손등: 59개 landmark
- 손바닥: 16개 landmark

- 16개 hand region segmentation

HTM 개발: Surface Model

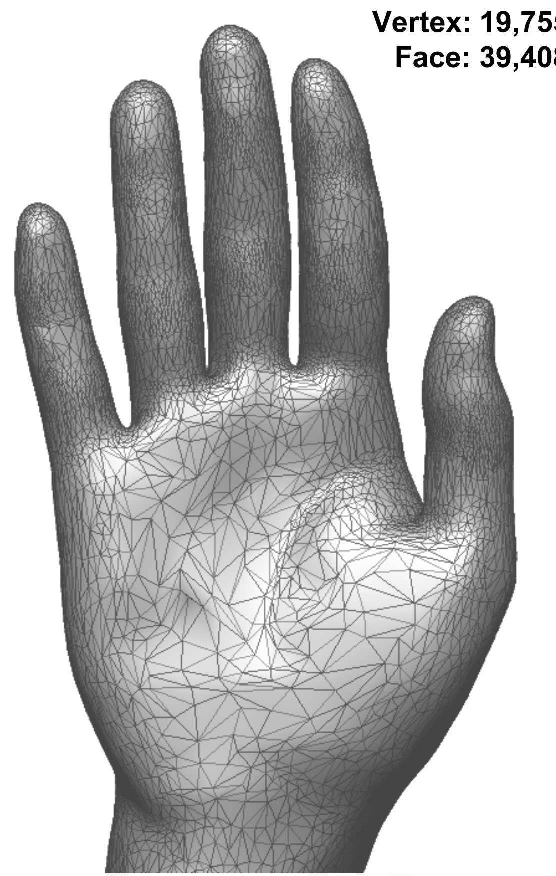
❑ 평균 크기(50th%ile)의 3D hand scan을 가공하여 hand template 개발

Original CT-Scan (Medium size)

edited

- Hole filling
- Smoothing
- Symmetrizing

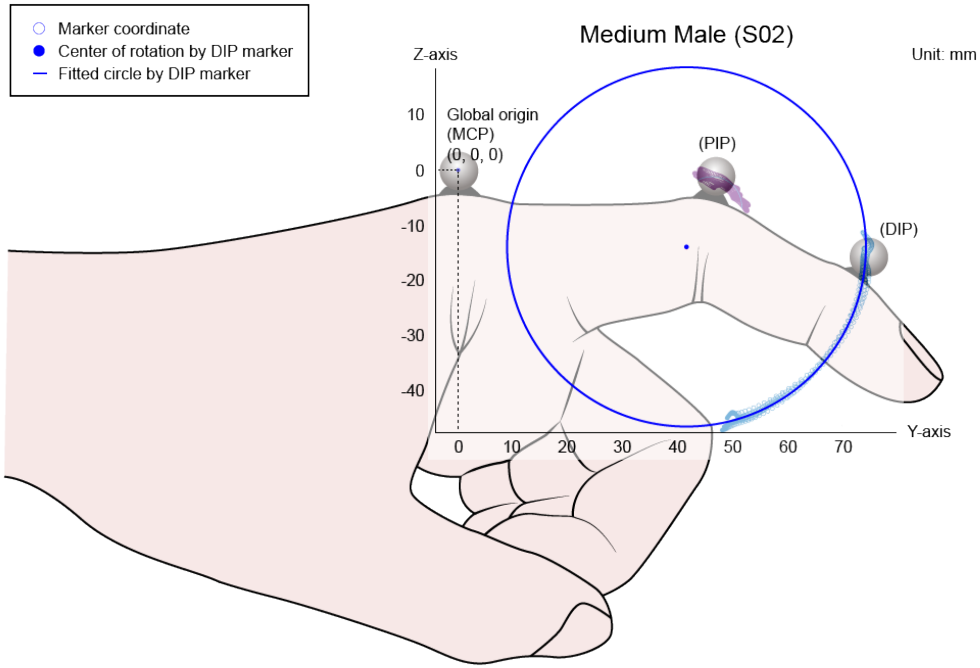
Hand Template



HTM 개발: Joint Center of Rotation

- 정교한 body & hand joint CoR 정의(fixed & instantaneous joint CoR)
- Simplified body & hand link model 정의 가능

Accurate hand joint CoR

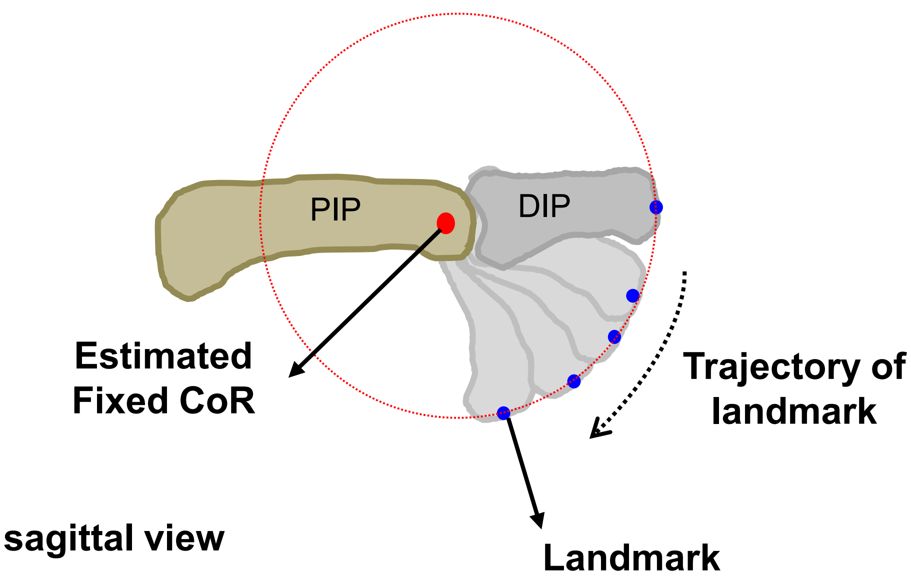


Hand joint CoR 적용 예

- Vertex: 54,589
- Face: 108,979

HTM 개발: Joint Center of Rotation 추정 방법(Lim et al. 2018)

- Delong-Kasa 방법 적용: landmark trajectory를 이용하여 fixed joint CoR 추정
- CoR estimation steps
  - S1. 10가지 natural grasping 자세의 bone surface data에서 동일 지점의 landmark 선정
  - S2. bone surface 상의 landmark trajectory에 least square error를 최소화하는 circle fitting 및 center of rotation 도출



Least square error criterion:

$$Min \sum_{i=1}^{N} (R_i - R)^2$$

$*$ Where $R_i = (x_i - A)^2 + (y_i - B)^2$

(x_i, y_i) = Marker locations

(A, B) = Calculated joint CoR

R = Radius of the fitted circle over the trajectory of marker motion

KASA. (1976). A Circle Fitting Procedure and Its Error Analysis. IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, 8-14.

HTM 개발: Joint CoR 도출 및 Link Model 생성

Hand Joint CoR 추정 결과

Digits	Joint	Coordinates		
		X	Y	Z
Digit 2	Tip	-4.15	-6.1	-98.16
	DIP	-1.85	-9.36	-76.81
	PIP	0.45	-13.83	-52.38
	MCP	0.67	-29.17	-10.23
Digit 3	Tip	-23.77	-4.15	-105.64
	DIP	-22.06	-9.28	-82.88
	PIP	-20.78	-16.39	-55.17
	MCP	-19.68	-25.48	-6.63
Digit 4	Tip	-43.83	-4.55	-93.14
	DIP	-42.38	-8.59	-70.29
	PIP	-40.14	-12.9	-43.96
	MCP	-35.41	-18.21	0.8
Digit 5	Tip	-68.04	-2.59	-65.44
	DIP	-65.42	-6.25	-44.81
	PIP	-60.51	-10.26	-26.71
	MCP	-52.06	-12.32	8.34
Digit 1	Tip	31.47	-6.79	-41.49
	IP	31.65	-11.61	-16.29
	MCP	29.43	-12.17	17.01
	CMC	12.24	-16.7	48.18
Wrist		-20.47	-17.32	70.64

CoR 기반 hand link 생성 (digits 1~5)

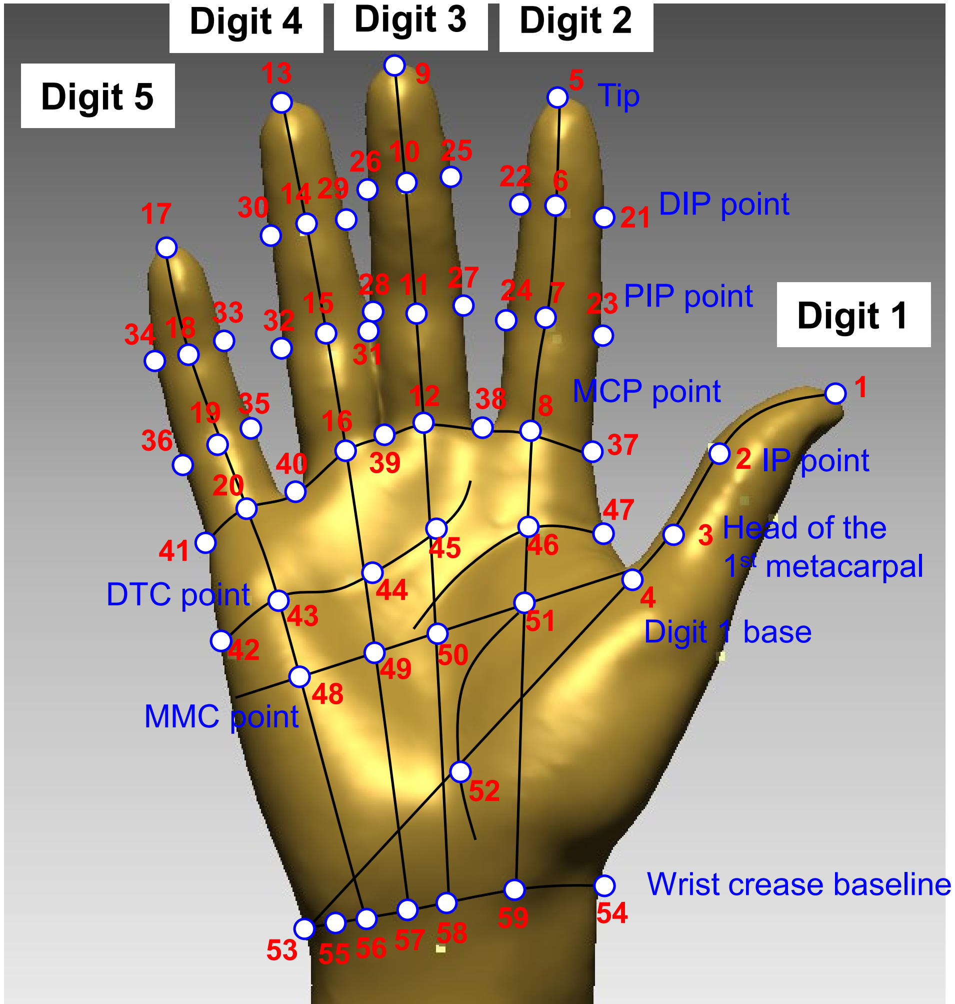
HTM 개발: Weight Calculation

- Hand joint center 위치에 따른 surface vertex의 weight (range: 0 ~ 1) 연산
- Blender를 이용하여 weight 연산 및 CSV format으로 출력 가능

HTM 개발: Hand Landmark (1/3)

❑ 손 치수 측정에 활용되는 손등/손바닥 부위의 주요 landmark 75개 선정

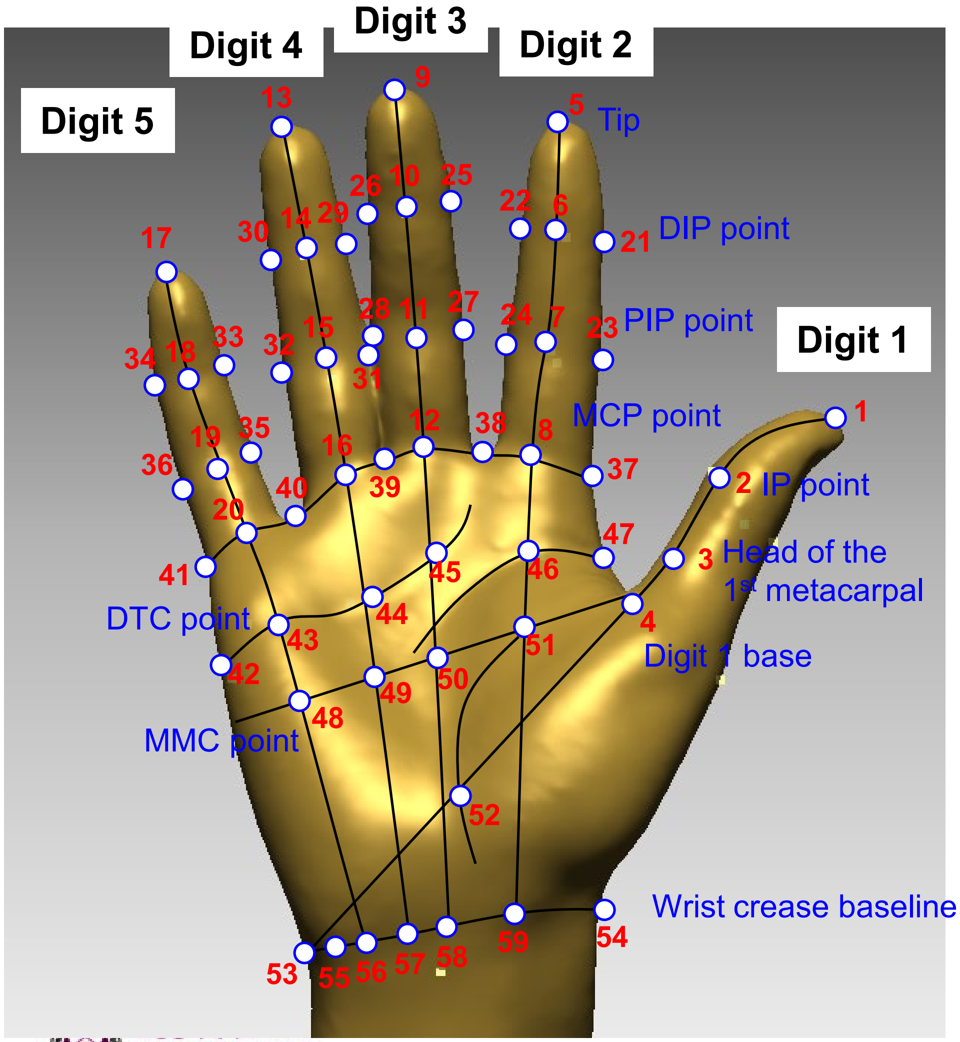
75개 hand landmark



No.	Name	No.	Name
1	The tip of digit 1	21	Digit 2 distal interphalangeal joint - radial
2	Digit 1 interphalangeal joint	22	Digit 2 distal interphalangeal joint - ulnar
3	Head of the first metacarpal	23	Digit 2 proximal interphalangeal joint – radial
4	The base of digit 1	24	Digit 2 proximal interphalangeal joint - ulnar
5	The tip of digit 2	25	Digit 3 distal interphalangeal joint – radial
6	Digit 2 mid-point of third crease	26	Digit 3 distal interphalangeal joint – ulnar
7	Digit 2 mid-point of second crease	27	Digit 3 proximal interphalangeal joint – radial
8	Digit 2 mid-point of first crease	28	Digit 3 proximal interphalangeal joint – ulnar
9	The tip of digit 3	29	Digit 4 distal interphalangeal joint – radial
10	Digit 3 mid-point of third crease	30	Digit 4 distal interphalangeal joint – ulnar
11	Digit 3 mid-point of second crease	31	Digit 4 proximal interphalangeal joint – radial
12	Digit 3 mid-point of first crease	32	Digit 4 proximal interphalangeal joint – ulnar
13	The tip of digit 4	33	Digit 5 distal interphalangeal joint – radial
14	Digit 4 mid-point of third crease	34	Digit 5 distal interphalangeal joint – ulnar
15	Digit 4 mid-point of second crease	35	Digit 5 proximal interphalangeal joint – radial
16	Digit 4 mid-point of first crease	36	Digit 5 proximal interphalangeal joint – ulnar
17	The tip of digit 5	37	Palm breadth – radial edge
18	Digit 5 mid-point of third crease	38	Crotch 2
19	Digit 5 mid-point of second crease	39	Crotch 3
20	Digit 5 mid-point of first crease	40	Crotch 4

HTM 개발: Hand Landmark (2/3)

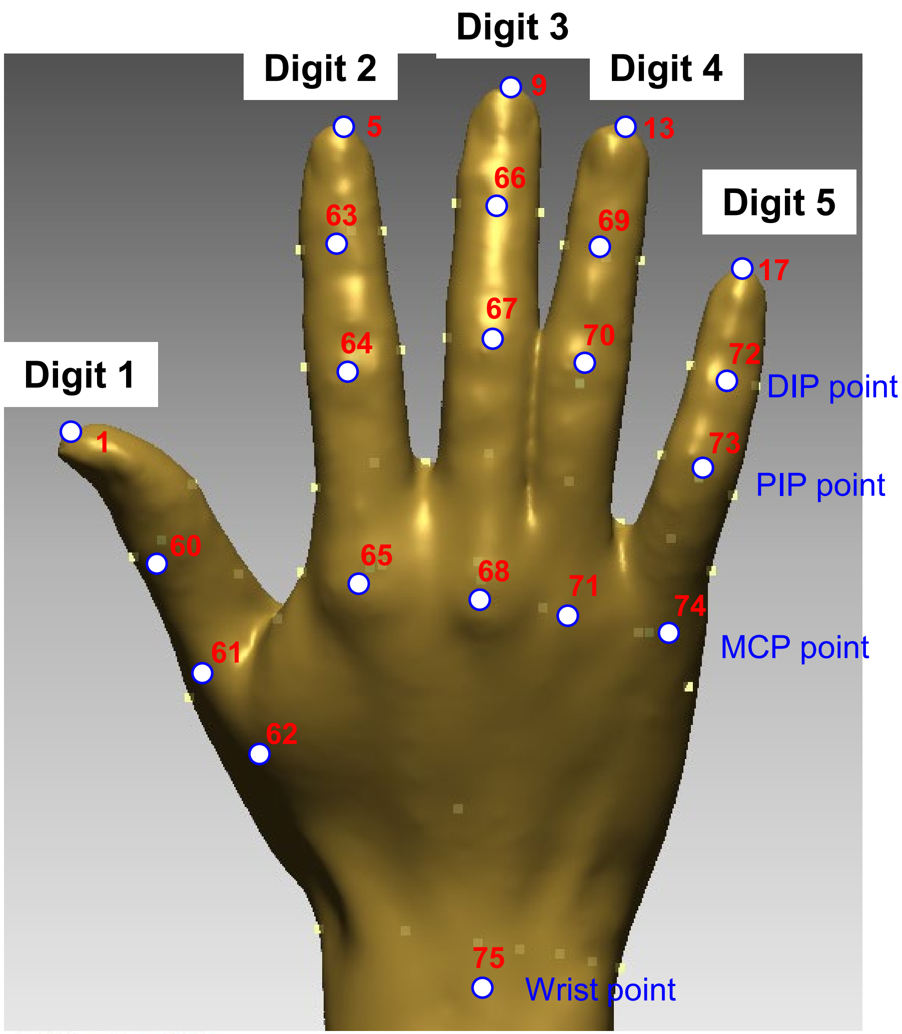
❑ 손바닥 부위의 주요 landmark 59개 선정



No.	Name
41	Palm breadth – ulnar edge
42	Proximal transverse palm crease - ulnar
43	Digit 2 distal transverse crease (DTC)
44	Digit 3 distal transverse crease (DTC)
45	Digit 4 distal transverse crease (DTC)
46	Digit 5 proximal transverse crease (PTC)
47	Proximal transverse palm crease - radial
48	Digit 2 mid-metacarpal (MMC)
49	Digit 3 mid-metacarpal (MMC)
50	Digit 4 mid-metacarpal (MMC)
51	Digit 5 mid-metacarpal (MMC)
52	Base of the first metacarpal
53	Ulnar edge of the distal wrist crease
54	Radial edge of the distal wrist crease
55	Digit 1 distal wrist crease
56	Digit 5 distal wrist crease
57	Digit 4 distal wrist crease
58	Digit 3 distal wrist crease
59	Digit 2 distal wrist crease

HTM 개발: Hand Landmark (3/3)

❑ 손등 부위의 주요 landmark 16개 선정

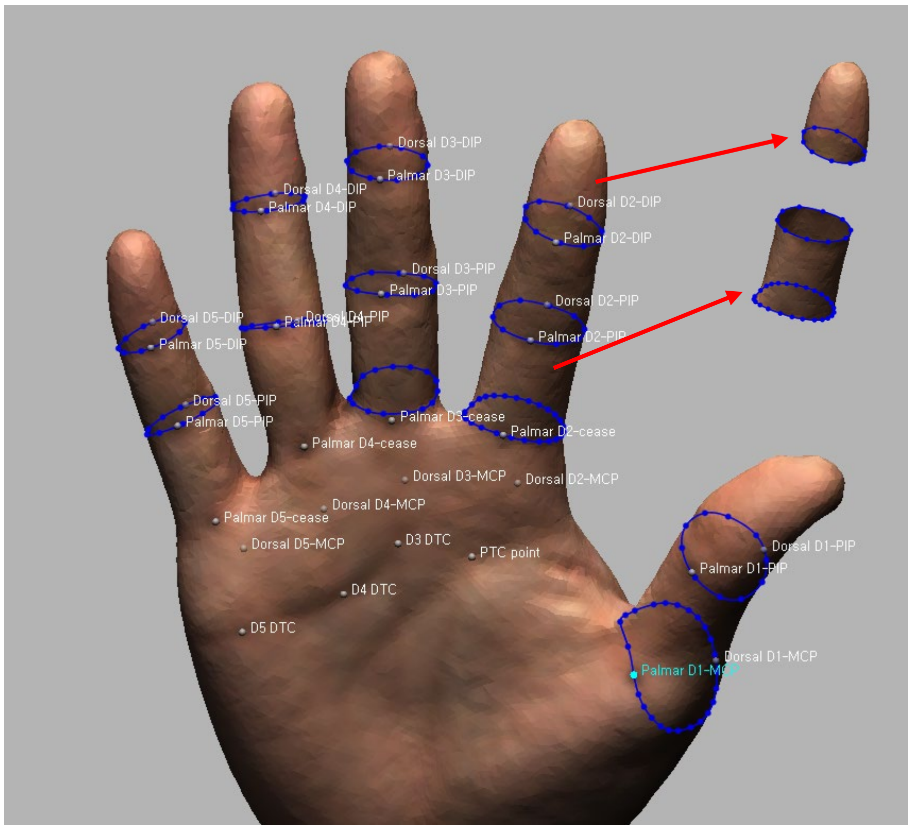


No.	Name
60	Digit 1 distal phalangeal joint - dorsal
61	Digit 1 proximal phalangeal joint – dorsal
62	Digit 1 metacarpal joint - dorsal
63	Digit 2 distal phalangeal joint – dorsal
64	Digit 2 proximal phalangeal joint – dorsal
65	Digit 2 metacarpal joint – dorsal
66	Digit 3 distal phalangeal joint – dorsal
67	Digit 3 proximal phalangeal joint – dorsal
68	Digit 3 metacarpal joint – dorsal
69	Digit 4 distal phalangeal joint – dorsal
70	Digit 4 proximal phalangeal joint – dorsal
71	Digit 4 metacarpal joint – dorsal
72	Digit 5 distal phalangeal joint – dorsal
73	Digit 5 proximal phalangeal joint – dorsal
74	Digit 5 metacarpal joint – dorsal
75	Wrist (origin)

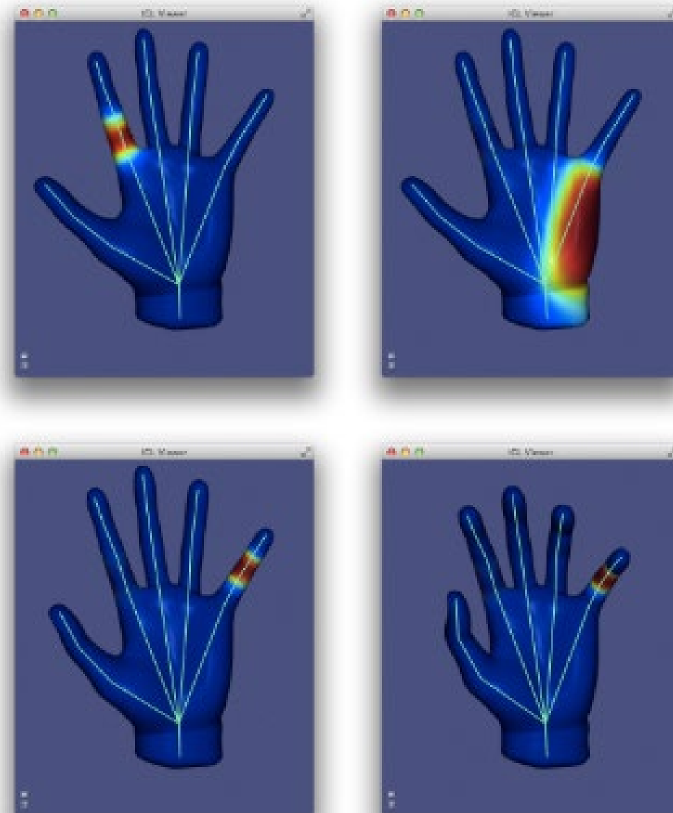
HTM 개발: Segmentation

- Hand landmark를 기준으로 손가락 및 손 부위를 16가지 영역으로 mesh 분리

Hand mesh separation 예



Hand mesh separation 및 weight 적용 예

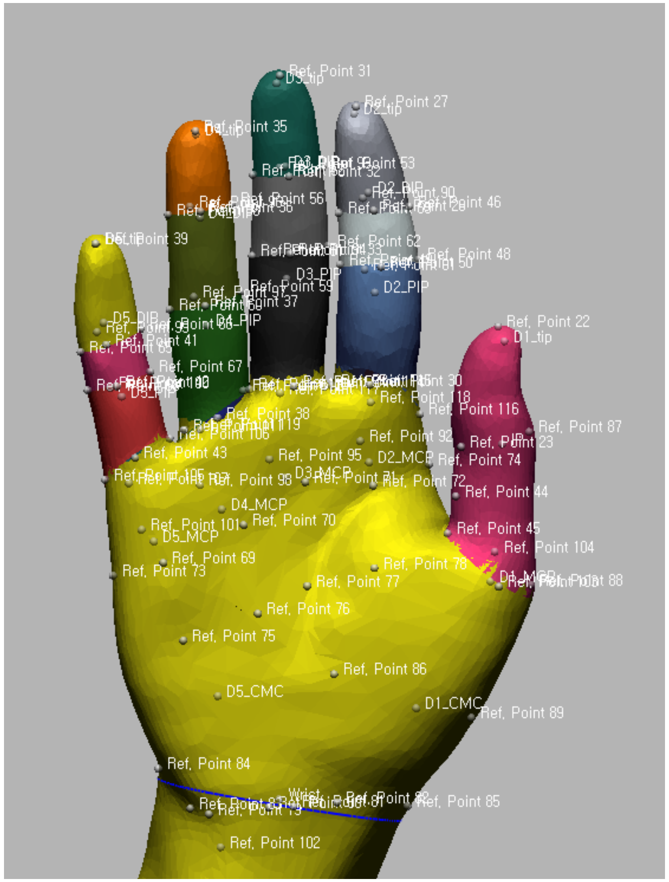


HTM 개발 결과

CoR estimation 결과

Digits	Joint	Coordinates		
		X	Y	Z
Digit 2	Tip	-4.15	-6.10	-98.16
	DIP	-1.85	-9.36	-76.81
	PIP	0.45	-13.83	-52.38
	MCP	0.67	-29.17	-10.23
Digit 3	Tip	-23.77	-4.15	-105.64
	DIP	-22.06	-9.28	-82.88
	PIP	-20.78	-16.39	-55.17
	MCP	-19.68	-25.48	-6.63
Digit 4	Tip	-43.83	-4.55	-93.14
	DIP	-42.38	-8.59	-70.29
	PIP	-40.14	-12.90	-43.96
	MCP	-35.41	-18.21	0.80
Digit 5	Tip	-68.04	-2.59	-65.44
	DIP	-65.42	-6.25	-44.81
	PIP	-60.51	-10.26	-26.71
	MCP	-52.06	-12.32	8.34
Digit 1	Tip	31.47	-6.79	-41.49
	IP	31.65	-11.61	-16.29
	MCP	29.43	-12.17	17.01
	CMC	12.24	-16.70	48.18
Wrist		-20.47	-17.32	70.64

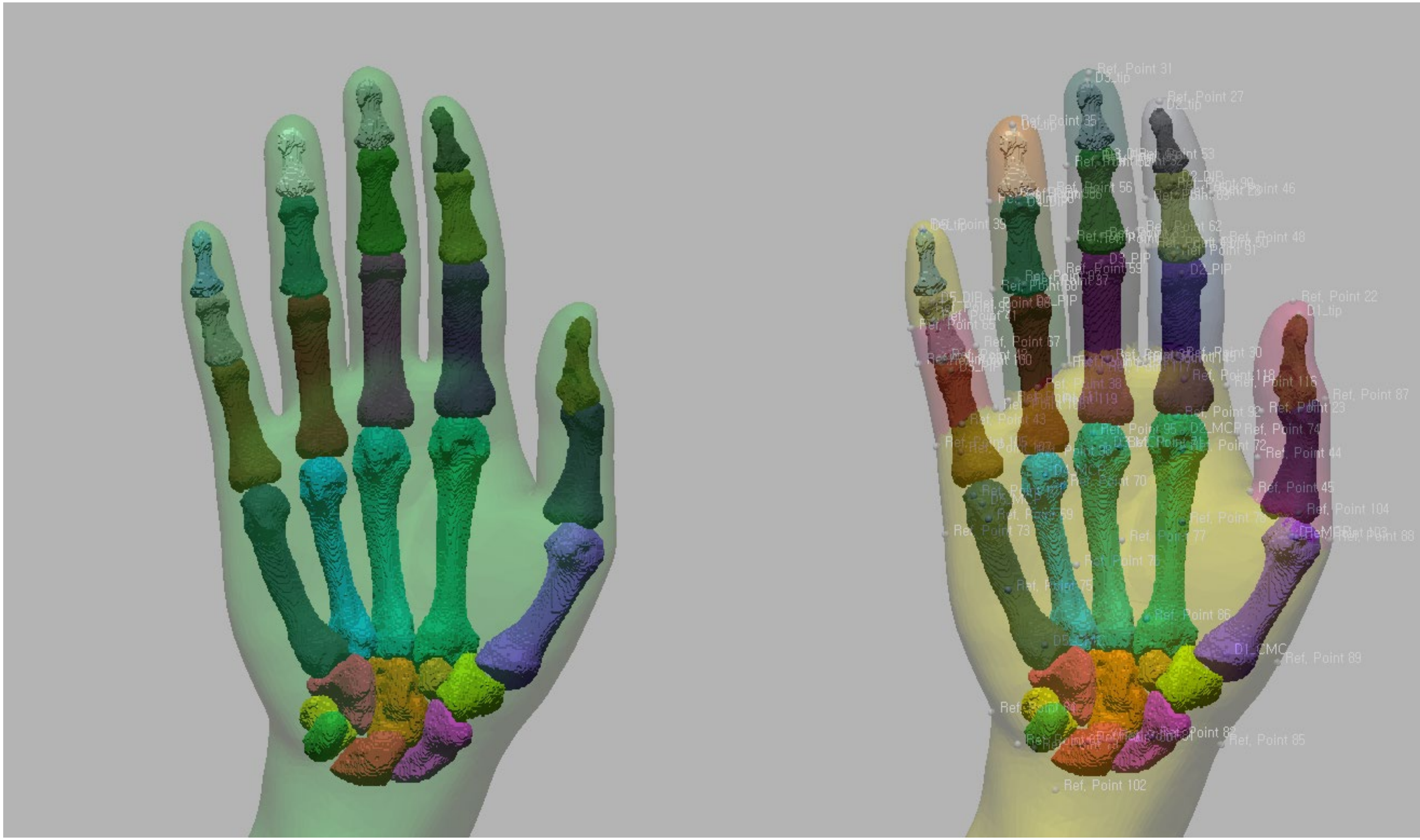
Hand region segmentation



Hand bond & joint CoR

- **Vertex: 19,755**
- **Face: 39,408**

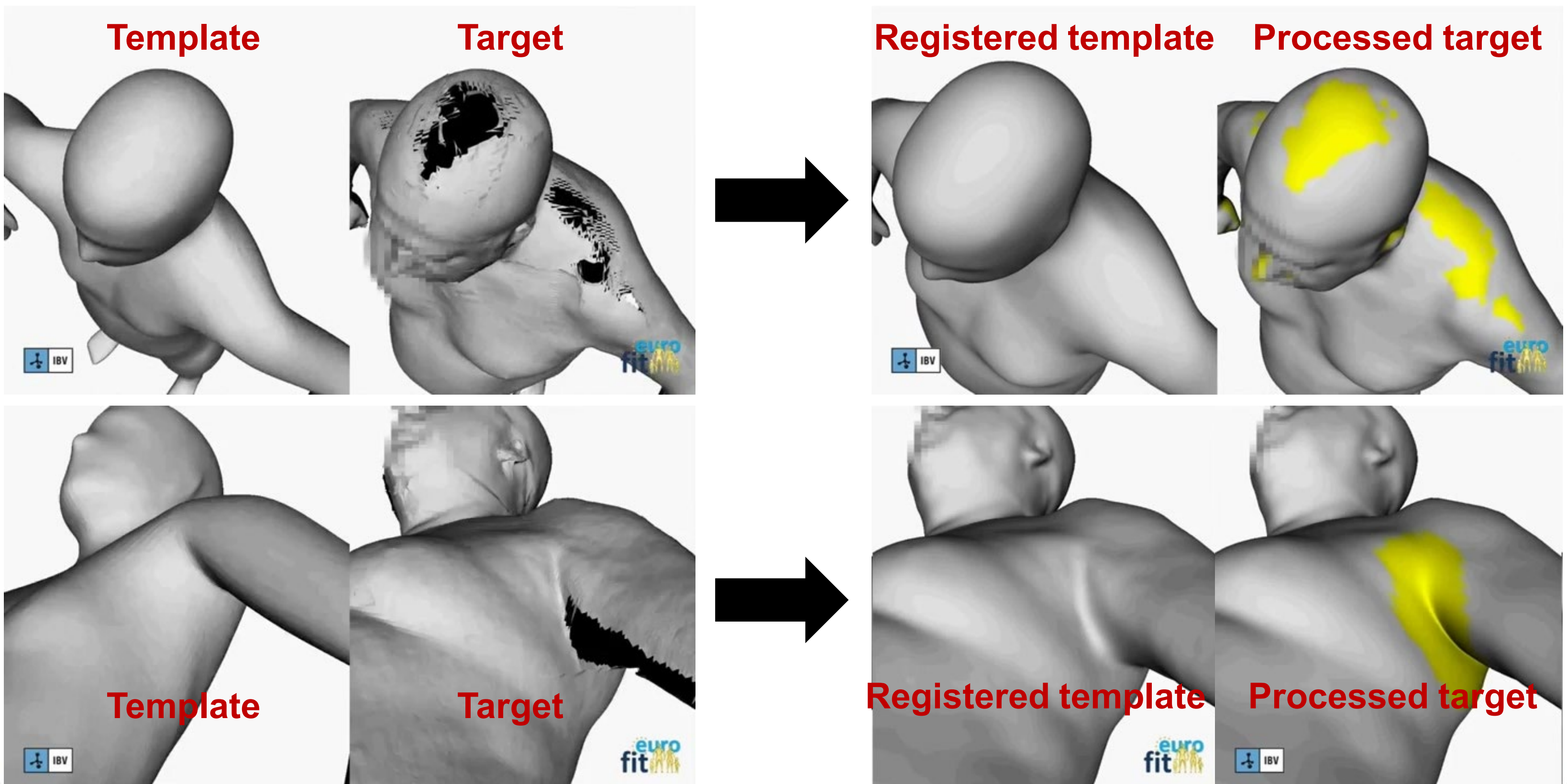
HTM 개발 결과


Ref. Point 31
D3_tip
Ref. Point 27
D2_tip
Ref. Point 22
D1_tip
D3_PIP
D2_PIP
Ref. Point 48
Ref. Point 87
D2_MCP
Ref. Point 44
Ref. Point 45
Ref. Point 104
Ref. Point 86
D1_CMC
Ref. Point 89
Ref. Point 85
Ref. Point 102

HTM Application: Template Registration (1/3)

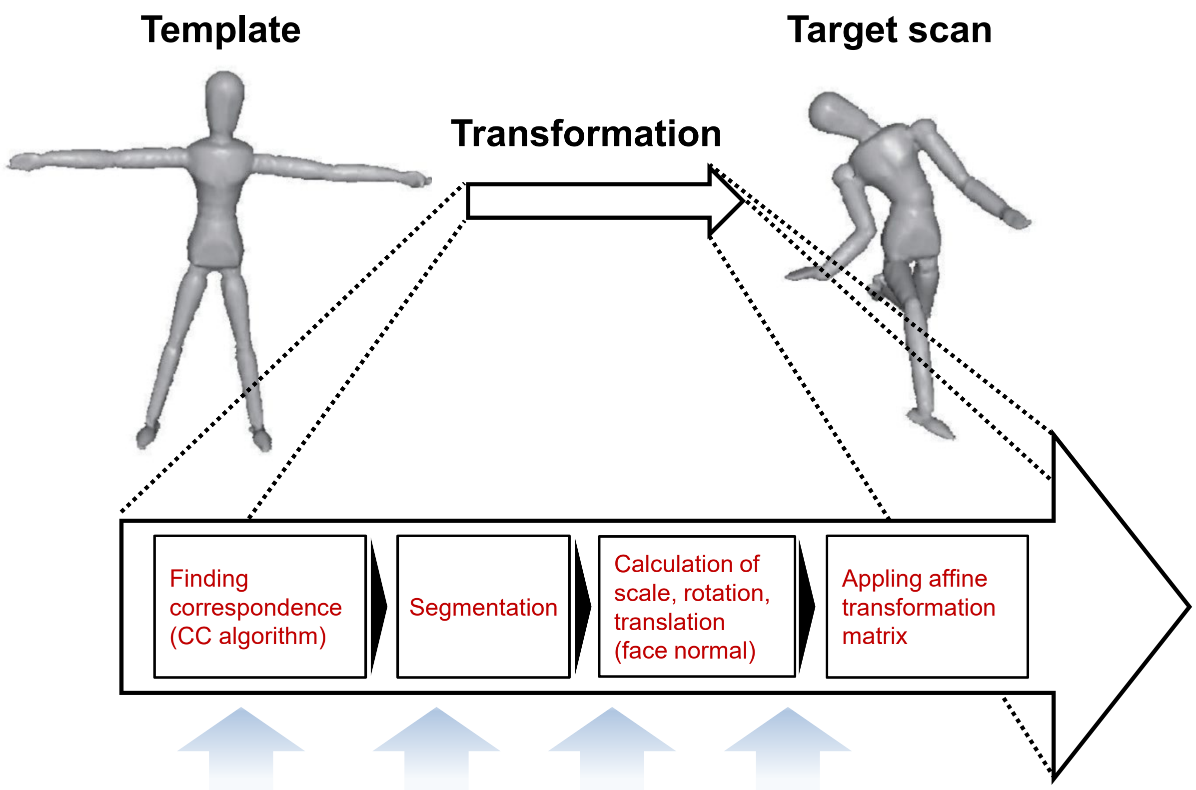
- 표준 자세(standing posture)로 측정된 3D body scan에 Template Model을 정렬
- Template registration 방법은 기존 3D scan 시 획득이 어려운 **접힘부 등의 missing part에 대하여 기존 인체 database를 이용한 보강 시 유용**함

Human Body Template Model을 이용한 형상 보강 예



HTM Application: Template Registration (2/3)

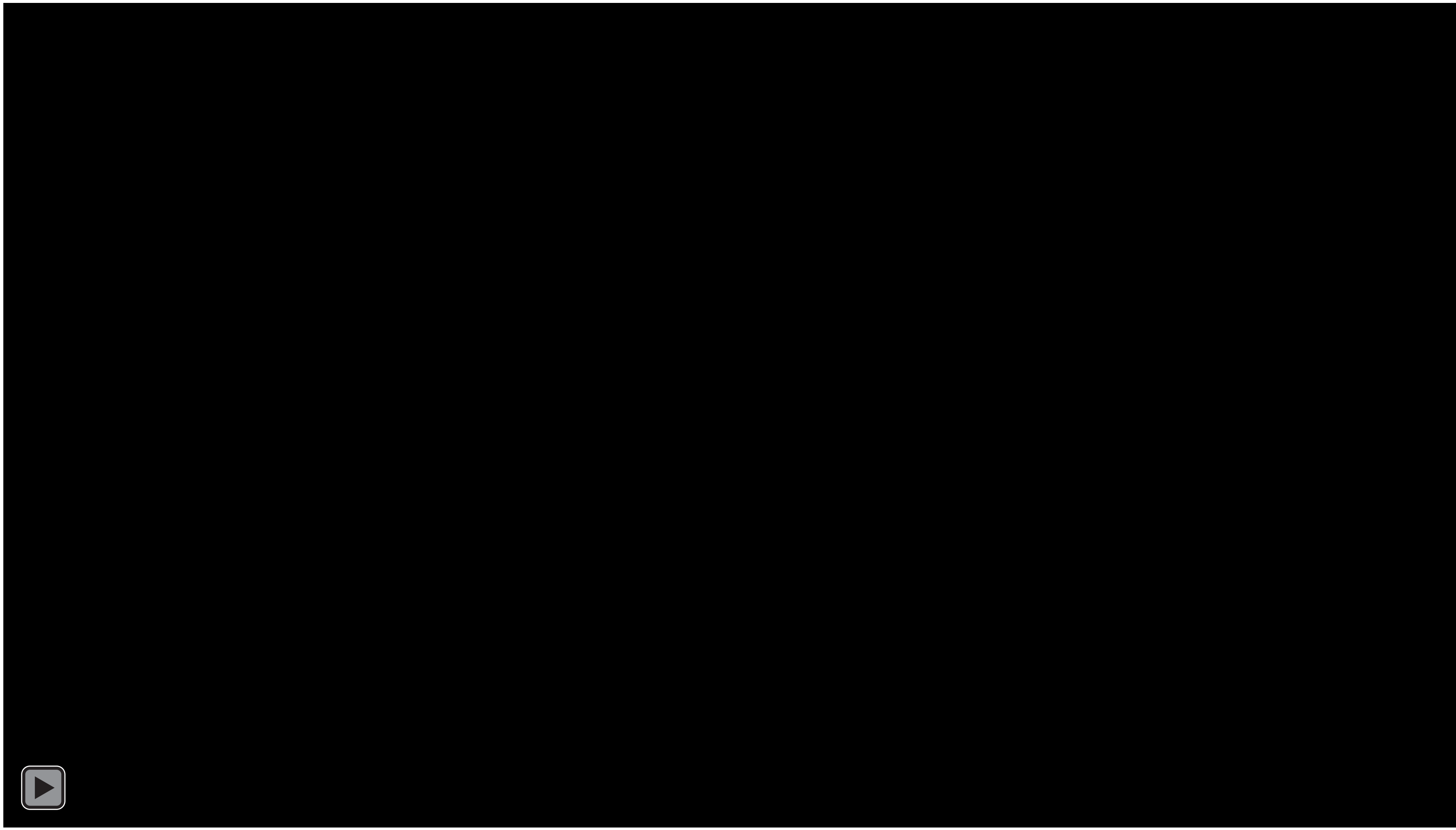
- Template의 **vertex *i***와 target scan의 **vertex *j***의 mapping 및 transform 문제
- Mapping 시 CC algorithm 적용, transform 시 affine transformation 적용



- Data term (vertex coordination)
- Smoothness term (similar affine transformation to vertex which belongs to the same face
- Landmark term (distance among the landmarks of Template & Target scan

Template Registration (IBV, Spain): Video

Posing of Template ⇒ **Pre-processing** of Body Scan ⇒ **Fitting** of Template to Body Scan



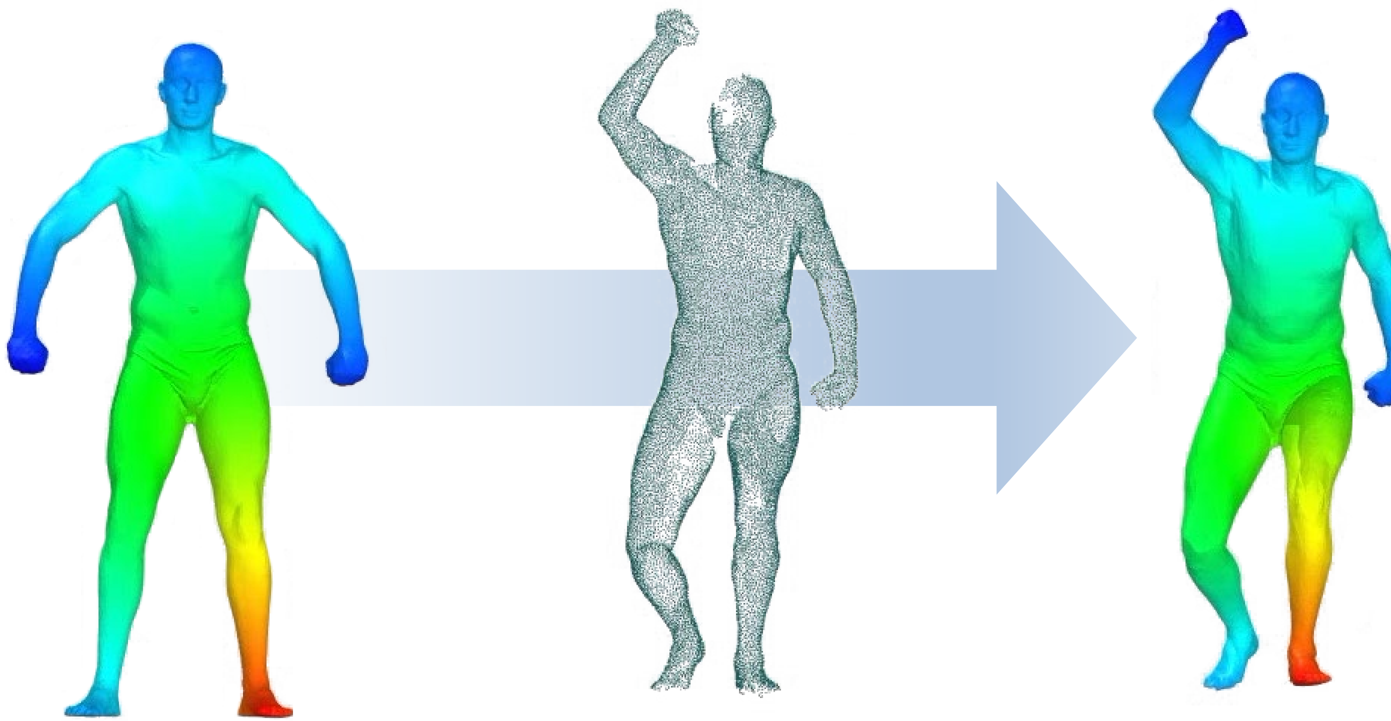
※ Source: Euro fit project, IBV, Spain

Template Registration (Hao Li): Video

- 최근에 개발되고 있는 기술은 다른 자세, incomplete scan data에도 높은 성능의 registration 성능을 보임

HTM Application: Posture Control

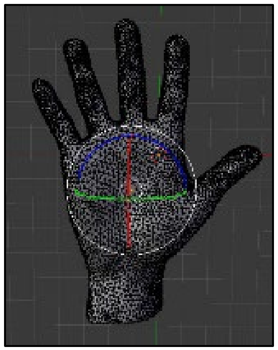
- 3D scan 기준 자세(standing, neutral)로 측정된 기존 3차원 인체형상 데이터를 **다양한 자세로 자세 변경 가능**
- **특정 자세**(e.g., 제품 사용 자세 등)**로의 변형 후 인체 계측** 등에 **활용 가능**

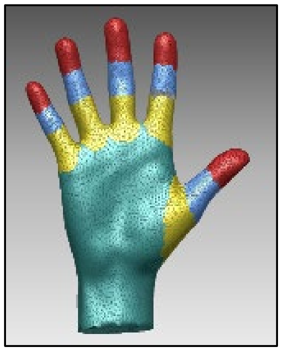


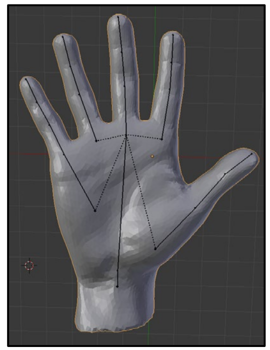
기준 자세 scan data (CAESAR data, Size Korea 3D data) | 특정 자세 측정 scan data | 특정 자세로 3d data 변환

HTM Application: Posture Control 적용 예 (Implicit Skinning)

- 중립 자세의 hand template에 **implicit skinning 방법을 적용**하여 **자연스러운 변형이 적용된 손 자세** 도출

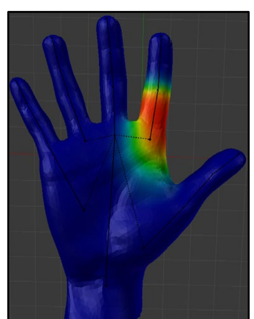






	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B11	B12	B13	B14	B15	B16	B17	B18
2	0	0	0	0.10843	0.890894	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0.084782	0.914681	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0.196993	0.801702	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.722384	0.269977	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0.057907	0.731907	0.176847	0	0.008072	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0.211347	0.787342	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0.823375	0.165023	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0.880217	0.070066	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0.826396	0	0	0	0.095995	0	0	0.016578	0	0	0	0	0	0	0	0	0
11	0	0.864012	0	0	0	0.032736	0	0	0.016931	0	0	0.019149	0	0	0	0	0	0
12	0	0.841049	0	0	0	0	0	0	0	0	0	0.033861	0	0	0.09145	0	0	0
13	0	0	0	0	0	0	0.40074	0.594672	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0.807075	0.179067	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0.887548	0.107986	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0.807793	0.186725	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0.618889	0.378106	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0.146477	0.852736	0	0	0	0	0	0	0
19	0	0.500819	0	0	0	0.339226	0	0	0.142091	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0.105464	0.878444	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0.95064	0.041161	0	0	0	0	0
22	0	0.009079	0	0	0	0	0	0	0	0	0	0.894658	0	0	0.039807	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0.321645	0.673262	0	0	0	0	0

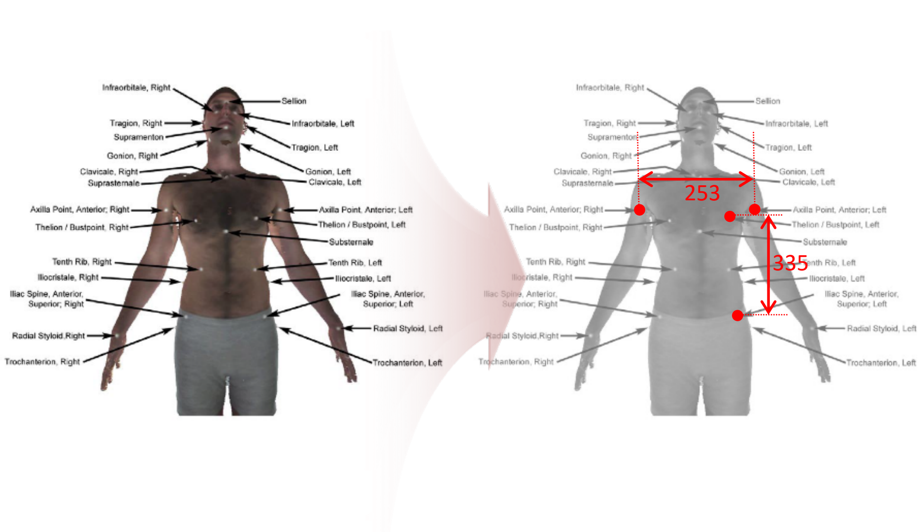
```
# Blender script to export the skinning weights in csv
import bpy

vertices = bpy.data.objects["hand"].data.vertices
group_names = [g.name for g in bpy.data.objects["hand"].vertex_groups]
bones_count = len(group_names)

file = open("zc_weights_1.csv", "w")
str = ",".join([name for name in group_names])
file.write(str + "\n")

for v in vertices:
    weights = [0 for i in range(bones_count)]
    for g in v.groups:
        weights[g.group] = g.weight
    #str1 = ",".join([("%.6f" % co) for co in v.co])
    str2 = ",".join([("%.6f" % w) for w in weights])
    file.write(str2 + "\n")
file.close()
```



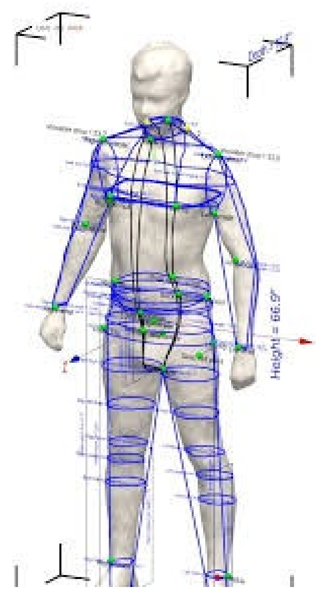
HTM Application: Automatic Anthropometry

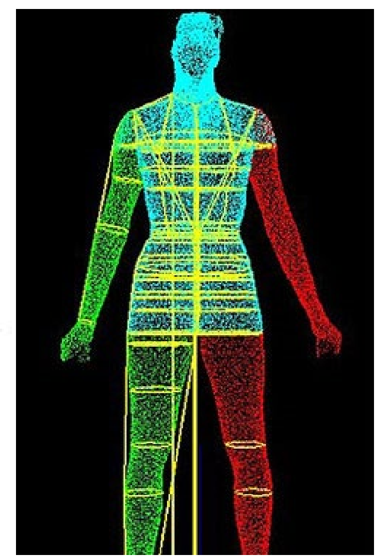
- **HTM 상에 기존에 정의된 landmark**에 의하여 **인체 부위의 형상**(e.g., 곡률, 면적 등) 및 **치수**(e.g., 길이, 각도, 둘레길이 등) **측정**
- **Template matching 시** template model 상의 **landmark, joint CoR, skeleton의 위치도 함께 정렬**되어 **변형된 HBTM 상의 landmark를 활용**하여 자동으로 **치수, 형상 및 자세 분석**

Template Model을 이용한 인체 치수 측정



3차원 scan data의 landmark 자동 추출 기술



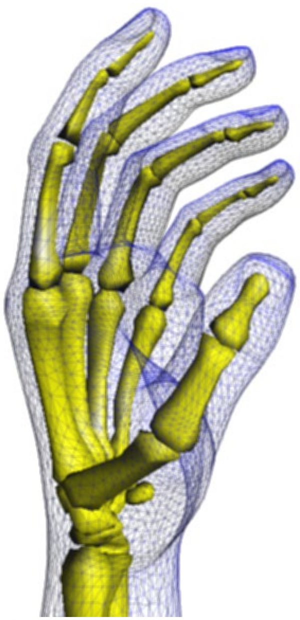


HTM Application: Pressure Estimation

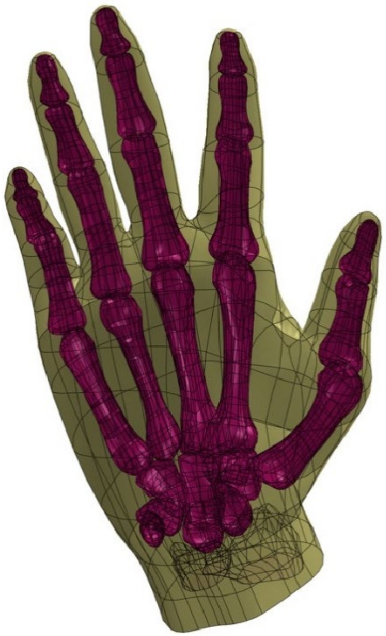
- 제품 사용 및 파지 자세로 변형된 HTM과 제품간의 접촉 부위의 물성을 고려한 **손-제품 간 변형 특성 분석** 필요
- **제품의 물성 data** 및 **손 부위 물성 data library 수집** 및 **유한 요소 손 모델(finite element human hand model) 개발** 예정

유한 요소 인체 모델(Hand Model) 개발 예시

James et al. (2012)

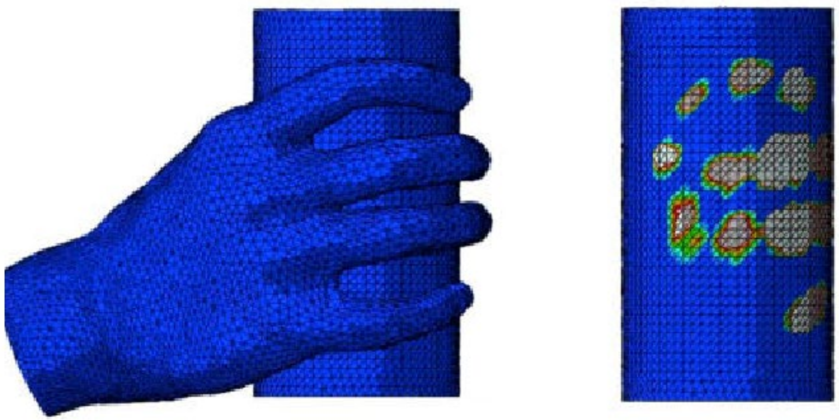


Harih and Tada (2016)



Pressure estimation 예시

Harih et al. (2017)



HTM Application: Product Design

- **Template model의 치수 및 형상 정보**를 **제품 설계 인자(design dimension) 와 연동**하면 사용자의 인체 크기 및 형상에 따른 **맞춤형 제품 형상 설계 시 효율적으로 활용 가능**함

인체 형상 기반 맞춤형 제품 설계 절차 및 적용 예

(1) 제품 설계 주요 변수(variable) 정의

↓

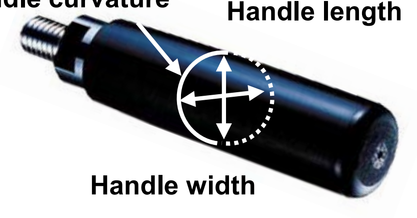
(2) Template model의 인체 변수(variable) 정의

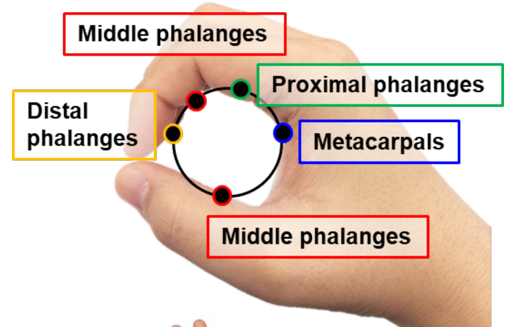
↓

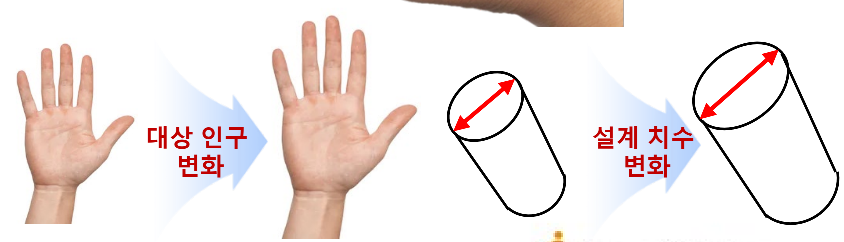
(3) 제품설계변수-인체변수간 연동

↓

(4) 맞춤형 자동 설계 치수 제공



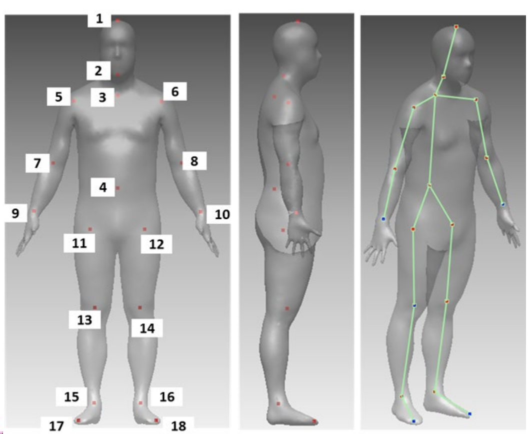




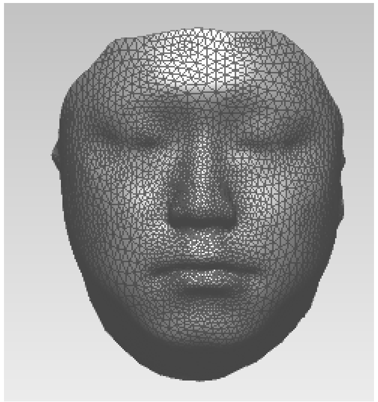
Discussion (1/3)

- 본 연구는 문헌 조사를 통하여 **Human Body & Hand Template Model을 조사**하고 **활용성을 파악**함
  - 인체 치수 및 형상의 자동 측정 가능함
  - 다양한 자세로 변형 가능
  - 인체-제품 간 상호작용 시 변형 특성 예측 가능
- **인체 부위별** 특성을 고려한 **Human Body & Hand Template Model을 개발**하면 제품 설계 시 효율적으로 활용 가능함
  - Whole body template 외 face template, hand template 개발

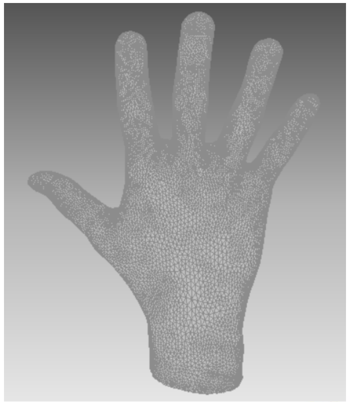
Whole body template



Face template



Hand template



Discussion (2/3)

- **Hand template model** 및 **인체형상 기술**은 개인 맞춤화를 필수적으로 요구하는 **dynamic scan data 기반 wearable handle 제품 설계** 시 적극적으로 활용 가능
  - 재활 치료 및 의수 제작
  - Exoskeleton 및 hand robot interface
  - 전투기 joystick과 같은 복잡한 형태의 customized handle 제품 설계

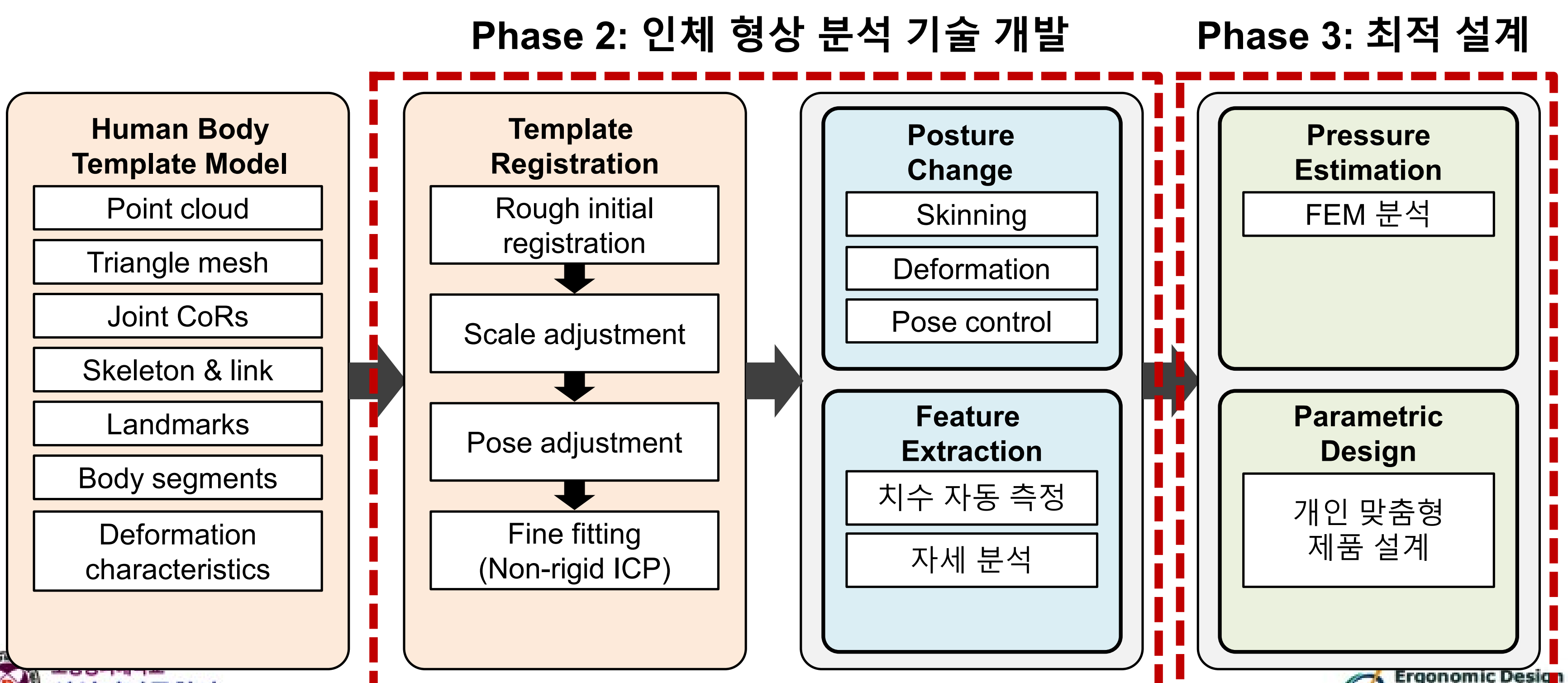
의수 제작 예

Exoskeleton 개발 예

Customized handle design 예

Discussion (3/3)

- 개발된 deformable human body template model을 기반으로 **3D registration 기술, 자세 변형 기술을 적용하여 다양한 제품 사용자세에서의 인체 형상 획득 및 분석** 예정
- Virtual fitting, FEM 분석 기술 및 parametric design 기술을 적용하여 개인 **인체 특성이 반영된 최적 제품 형상 설계 방법론 구축**



Q & A

경청해 주셔서 감사합니다. ☺

본 연구는 한국연구재단의 중견연구자 지원사업(NRF-2018R1A2A2A05023299)의
지원을 받아 수행되었습니다.

edt.postech.ac.kr
niceterran36@postech.ac.kr

Template Registration 논문 List

No.	Year	Author(s)	Title	Source / Institute	중요도
1	2017	Pishchulin et al.	Building statistical shape spaces for 3D human modeling	Pattern Recognition / MPII	상
2	2003	Allen et al.	The space of human body shapes - reconstruction and parameterization from range scans	ACM Transactions on Graphics / Washington University	상
3	2005	Angulove et al.	SCAPE: Shape Completion and Animation of People	ACM Transactions on Graphics / MPI - PS	상
4	2005	Allen	Learning body shape models from real-world data	Dissertation of Washington Univ. / MPI - PS	상
5	2014	Rodola et al.	Robust Region Detection via Consensus Segmentation of Deformable Shapes	Computer Graphics Forum / TU Munich	상
6	2011	Jacopson et al.	Bounded Biharmonic Weights for Real-Time Deformation	ACM Transactions on Graphics / ETH Zurich IGL	상
7	2008	Li et al.	Global Correspondence Optimization for Non-Rigid Registration of Depth Scans	Eurographics Symposium on Geometry Processing / Hao Li	상
8	2010	Myronenko and song	Point Set Registration: Coherent Point Drift	IEEE Transactions on Pattern Analysis and Machine Intelligence / OHSU	상
9	2017	Romero et al.	Embodied Hands: Modeling and Capturing Hands and Bodies Together	ACM Transactions on Graphic / MPI - PS	상
10	2005	Anguelov et al.	The Correlated Correspondence Algorithm for Unsupervised Registration of Nonrigid Surfaces	Advances in Neural Information Processing Systems	상
11	2004	Sumner and Popovic	Deformation Transfer for Triangle Meshes	ACM Transactions on Graphic	상
12	2014	Bonarrigo et al.	Deformable registration using patch-wise shape matching	Graphical Models / Hao Li	상

Hand Template Model (HTM) 개발

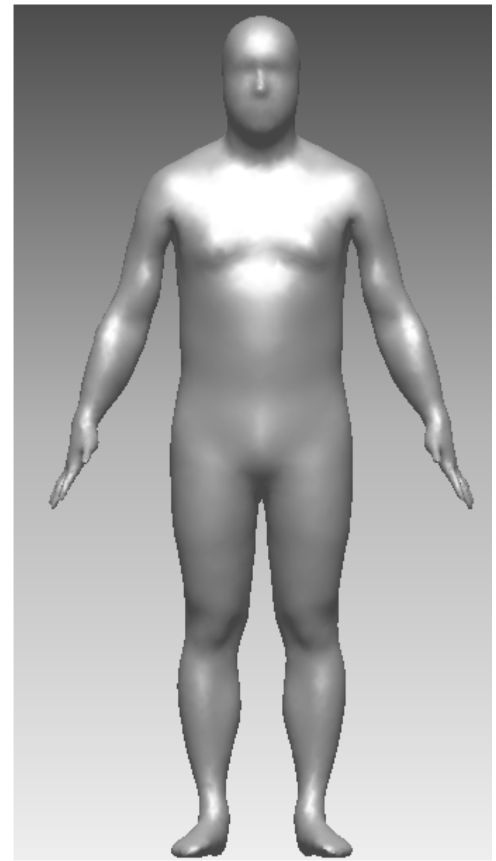
❑ 평균 크기(50th%ile)의 3D human model을 가공하여 test template model 개발

Original image (CAESAR data)

edited

- Hole filling
- Smoothing
- Symmetrizing

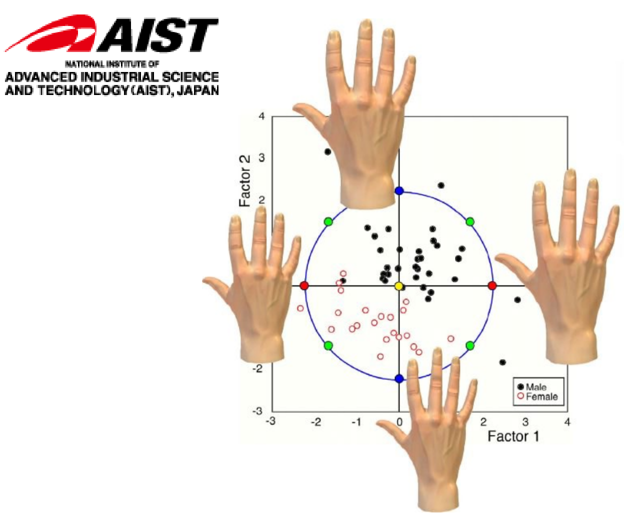
Template (test model)



State of the Art Hand Model: 검색 방법

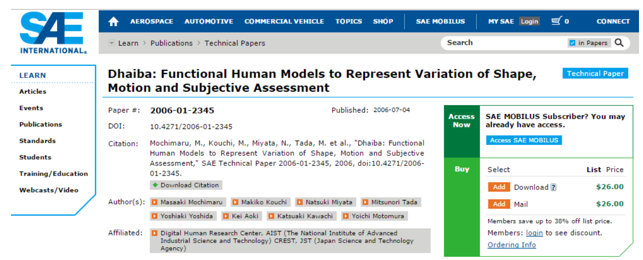
- 검색 site: www.google.co.kr
- 검색 keyword: (“3D” or “digital”) and (“hand model”) and (“ergonomic”)
- 검색 결과: Dhaiba (Digital Human Aided Basic Assessment system) model (Kouchi, 2005)

Digital hand to assist design of products



http://www.dh.aist.go.jp/research/centered/digitalhand/index.php.en

Dhaiba model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Dhaiba: Functional Human Models to Represent Variation of Shape, Motion and Subjective Assessment Technical Paper

Paper #: 2006-01-2345   Published: 2006-07-04
DOI: 10.4271/2006-01-2345
Citation: Mochimaru, M., Kouchi, M., Miyata, N., Tada, M. et al., "Dhaiba: Functional Human Models to Represent Variation of Shape, Motion and Subjective Assessment," SAE Technical Paper 2006-01-2345, 2006, doi:10.4271/2006-01-2345.
Download Citation
Author(s): Masaaki Mochimaru, Makiko Kouchi, Natsuki Miyata, Mitsunori Tada, Yoshiaki Yoshida, Kei Aoki, Katsuaki Kawachi, Yoichi Motomura
Affiliated: Digital Human Research Center, AIST (The National Institute of Advanced Industrial Science and Technology) CREST, JST (Japan Science and Technology Agency)

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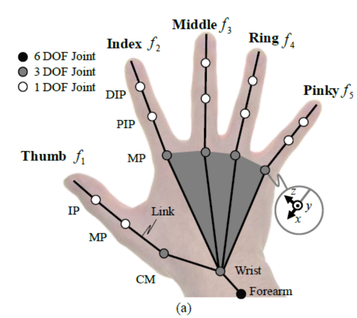
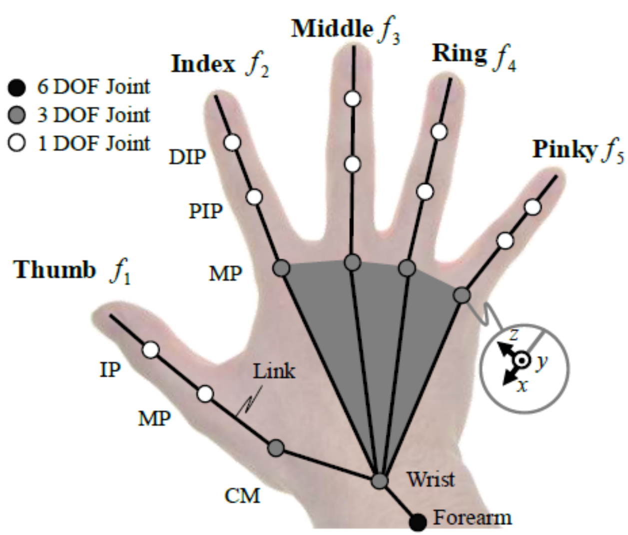


http://papers.sae.org/2006-01-2345/

State of the Art Hand Model: Dhaiba Model (2006)

- Dhaiba is a visualization software platform (VirTools®) supports the design of human-compatible products
- Dhaiba integrates
  - **Human motions** with strategy differences
  - **Subjective assessment** of usability
- Dhaiba model can be implemented to link structure model, surface skin model



(a)

Further Researches Based on Dhaiba Model (Endo et al., 2007)

- Virtual Grasping Assessment Using 3D Digital Hand Model (Endo et al., 2007)
- Dhaiba Model based **grip analysis** (posture, grip point, hand shape, etc.) **system**

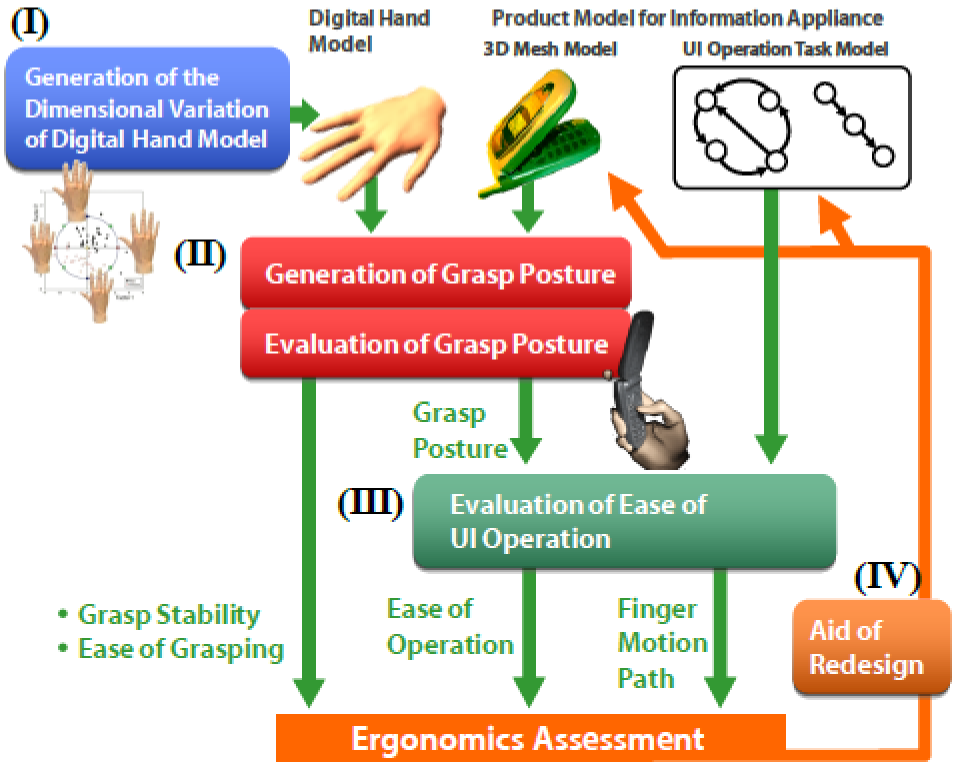
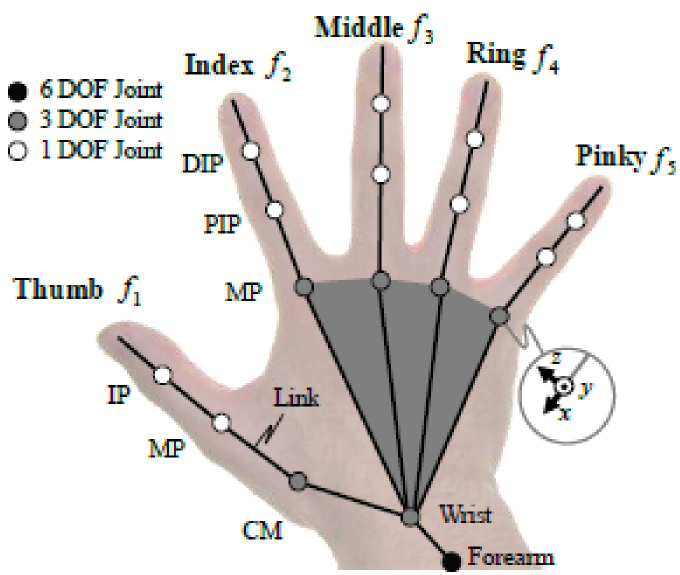


Figure 2. The overview of our proposed automatic ergonomic assessment system

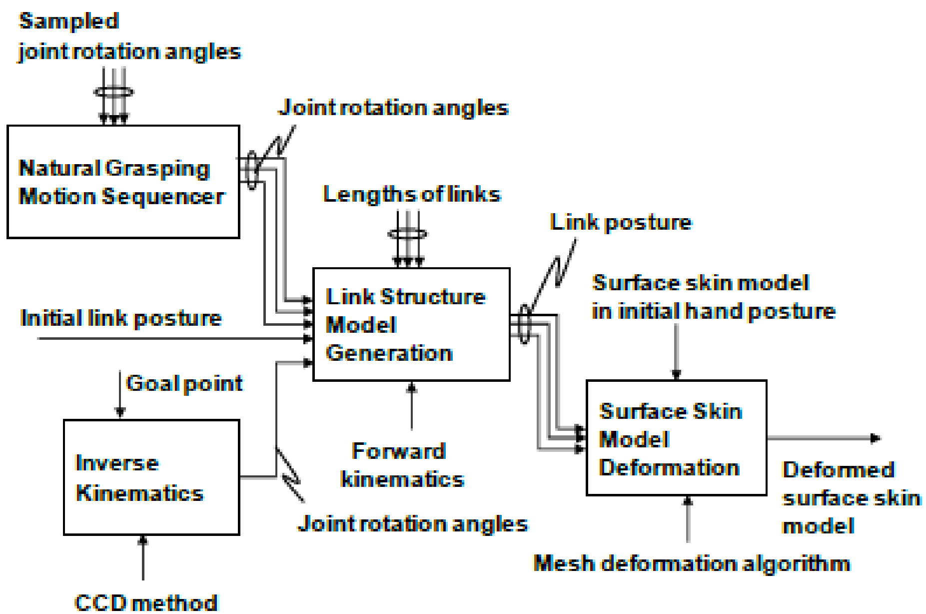
Further Researches Based on Dhaiba Model (Endo et al., 2007)

- Analyzing natural grasping motion using developed algorithm
- Surface skin deformation, natural grasping motion part was added to Dhaiba Model

Original Dhaiba Model



Developed Algorithm's Flow



Further Researches Based on Dhaiba Model (Endo et al., 2007)

- Natural grasping procedures
  - Input initial information and goal points to generate precise hand grip as parameters
  - Optimal hand grip posture was generated to maximize number of contact points

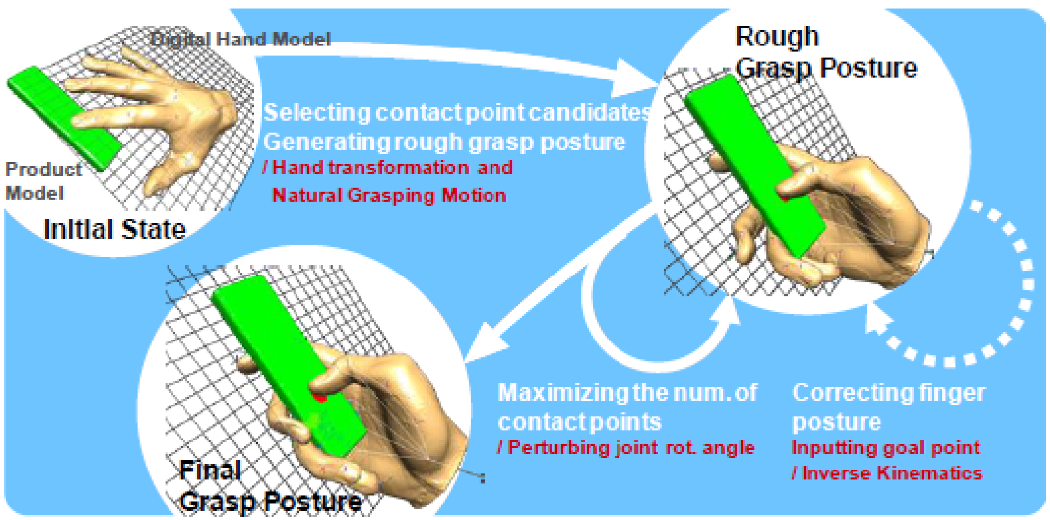


Figure 5. The algorithm to generate the grasp posture

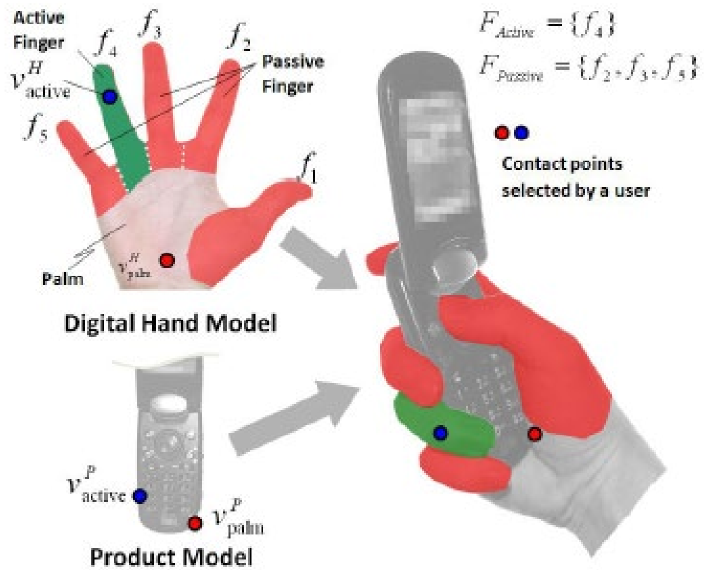
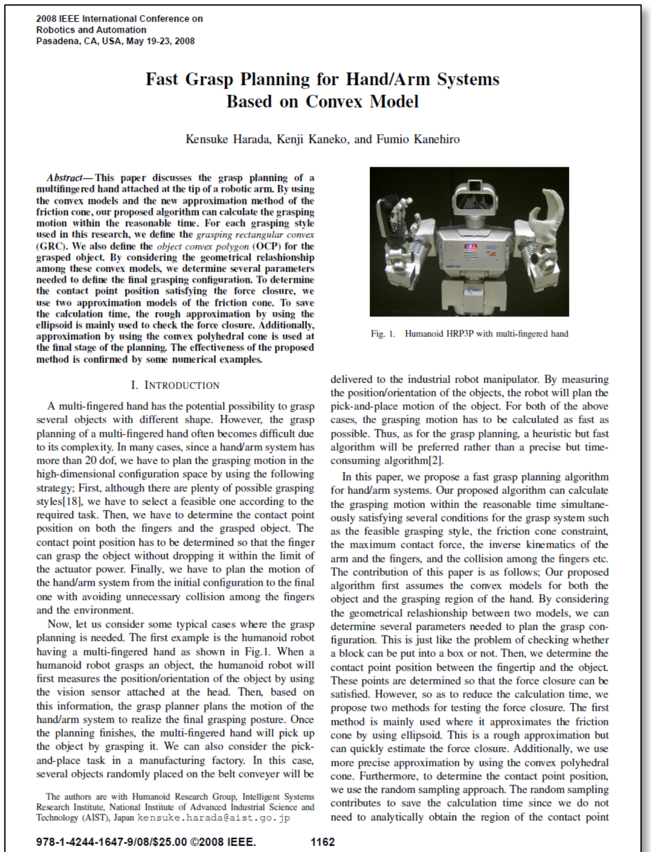


Figure 6. The selection of the contact point candidates

Recent Research: AIST

- Fast Grasp Planning for Hand/Arm Systems Based on Convex Model(Harada K. et al., 2008)
- Ananalysis of hand measurements for digital hand models (Kasai S. et al., 2003)
  XVth Triennial Congress, International Ergonomics Association (IEA2003), 2003



2008 IEEE International Conference on
Robotics and Automation
Pasadena, CA, USA, May 19-23, 2008

Fast Grasp Planning for Hand/Arm Systems Based on Convex Model

Kensuke Harada, Kenji Kaneko, and Fumio Kanehiro

***Abstract*— This paper discusses the grasp planning of a multifingered hand attached at the tip of a robotic arm. By using the convex models and the new approximation method of the friction cone, our proposed algorithm can calculate the grasping motion within the reasonable time. For each grasping style used in this research, we define the *grasping rectangular convex* (GRC). We also define the *object convex polygon* (OCP) for the grasped object. By considering the geometrical relashionship among these convex models, we determine several parameters needed to define the final grasping configuration. To determine the contact point position satisfying the force closure, we use two approximation models of the friction cone. To save the calculation time, the rough approximation by using the ellipsoid is mainly used to check the force closure. Additionally, approximation by using the convex polyhedral cone is used at the final stage of the planning. The effectiveness of the proposed method is confirmed by some numerical examples.**

Fig. 1. Humanoid HRP3P with multi-fingered hand

I. Introduction

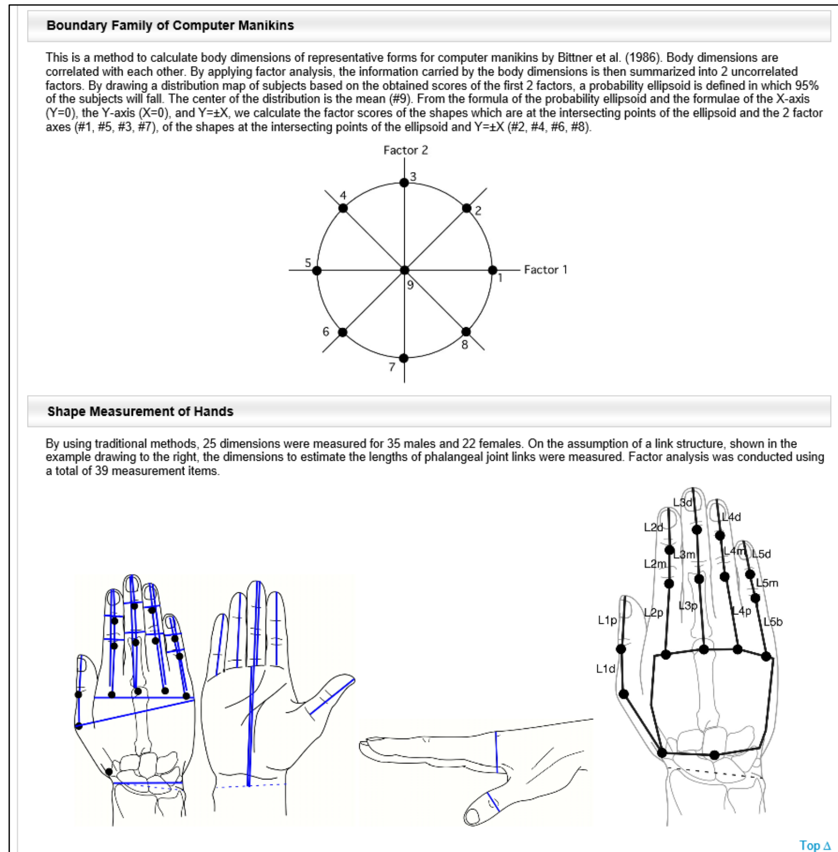
A multi-fingered hand has the potential possibility to grasp several objects with different shape. However, the grasp planning of a multi-fingered hand often becomes difficult due to its complexity. In many cases, since a hand/arm system has more than 20 dof, we have to plan the grasping motion in the high-dimensional configuration space by using the following strategy; First, although there are plenty of possible grasping styles[18], we have to select a feasible one according to the required task. Then, we have to determine the contact point position on both the fingers and the grasped object. The contact point position has to be determined so that the finger can grasp the object without dropping it within the limit of the actuator power. Finally, we have to plan the motion of the hand/arm system from the initial configuration to the final one with avoiding unnecessary collision among the fingers and the environment.

Now, let us consider some typical cases where the grasp planning is needed. The first example is the humanoid robot having a multi-fingered hand as shown in Fig.1. When a humanoid robot grasps an object, the humanoid robot will first measures the position/orientation of the object by using the vision sensor attached at the head. Then, based on this information, the grasp planner plans the motion of the hand/arm system to realize the final grasping posture. Once the planning finishes, the multi-fingered hand will pick up the object by grasping it. We can also consider the pick-and-place task in a manufacturing factory. In this case, several objects randomly placed on the belt conveyer will be delivered to the industrial robot manipulator. By measuring the position/orientation of the objects, the robot will plan the pick-and-place motion of the object. For both of the above cases, the grasping motion has to be calculated as fast as possible. Thus, as for the grasp planning, a heuristic but fast algorithm will be preferred rather than a precise but time-consuming algorithm[2].

In this paper, we propose a fast grasp planning algorithm for hand/arm systems. Our proposed algorithm can calculate the grasping motion within the reasonable time simultaneously satisfying several conditions for the grasp system such as the feasible grasping style, the friction cone constraint, the maximum contact force, the inverse kinematics of the arm and the fingers, and the collision among the fingers etc. The contribution of this paper is as follows; Our proposed algorithm first assumes the convex models for both the object and the grasping region of the hand. By considering the geometrical relashionship between two models, we can determine several parameters needed to plan the grasp configuration. This is just like the problem of checking whether a block can be put into a box or not. Then, we determine the contact point position between the fingertip and the object. These points are determined so that the force closure can be satisfied. However, so as to reduce the calculation time, we propose two methods for testing the force closure. The first method is mainly used where it approximates the friction cone by using ellipsoid. This is a rough approximation but can quickly estimate the force closure. Additionally, we use more precise approximation by using the convex polyhedral cone. Furthermore, to determine the contact point position, we use the random sampling approach. The random sampling contributes to save the calculation time since we do not need to analytically obtain the region of the contact point

The authors are with Humanoid Research Group, Intelligent Systems Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Japan kensuke.harada@aist.go.jp

978-1-4244-1647-9/08/$25.00 ©2008 IEEE. 1162



Boundary Family of Computer Manikins

This is a method to calculate body dimensions of representative forms for computer manikins by Bittner et al. (1986). Body dimensions are correlated with each other. By applying factor analysis, the information carried by the body dimensions is then summarized into 2 uncorrelated factors. By drawing a distribution map of subjects based on the obtained scores of the first 2 factors, a probability ellipsoid is defined in which 95% of the subjects will fall. The center of the distribution is the mean (#9). From the formula of the probability ellipsoid and the formulae of the X-axis (Y=0), the Y-axis (X=0), and Y=±X, we calculate the factor scores of the shapes which are at the intersecting points of the ellipsoid and the 2 factor axes (#1, #5, #3, #7), of the shapes at the intersecting points of the ellipsoid and Y=±X (#2, #4, #6, #8).

Shape Measurement of Hands

By using traditional methods, 25 dimensions were measured for 35 males and 22 females. On the assumption of a link structure, shown in the example drawing to the right, the dimensions to estimate the lengths of phalangeal joint links were measured. Factor analysis was conducted using a total of 39 measurement items.

Top ∆

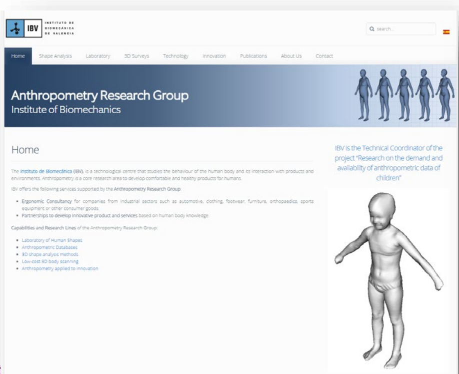
Recent Research: AIST

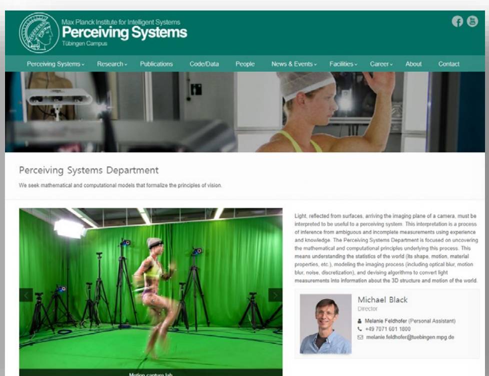
AIST Reference site

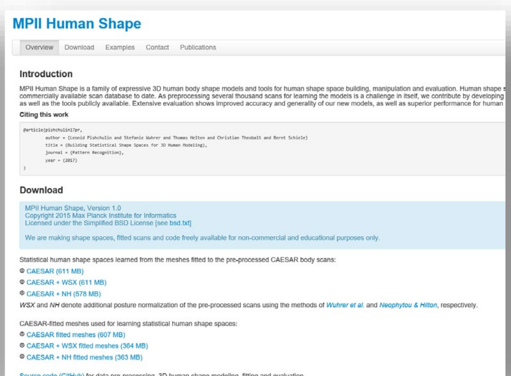
- http://www.aist.go.jp/aist_e/aist_google_search_e.html?cx=004983608496508821980:avdsyoeo0bu&cof=FORID%3A10&ie=UTF-8&q=hand
- http://www.dh.aist.go.jp/en/research/centered/dhand-link2/
- http://www.dh.aist.go.jp/en/research/centered/dhand-link1/
- https://unit.aist.go.jp/hiri/en/topics/06.html
- http://www.dh.aist.go.jp/en/research/centered/digitalhand/

Literature 검색 방법: Research Group 검색

- Human body model, 3D scan technique 분야의 주요 research group을 파악하고 연구 관련 문헌 조사, 유관 문헌 수집 예정
- 주요 연구 group list
  - Max Planck Institute for Perceiving Systems, Germany
  - Advanced Industrial Science and Technology, Japan
  - (위 2개) Hand template benchmarking 대상
  - Max Planck Institute for Informatics, Germany
  - Hao Li @ University of Southern California, USA
  - Instituto de Biomechania de Valencia, Spain
  - (위 3개) 3D registration benchmarking 대상
  - Interactive Geometry Lab, ETH, Switzerland
  - Computer Vision Group, TU muchen, Germany

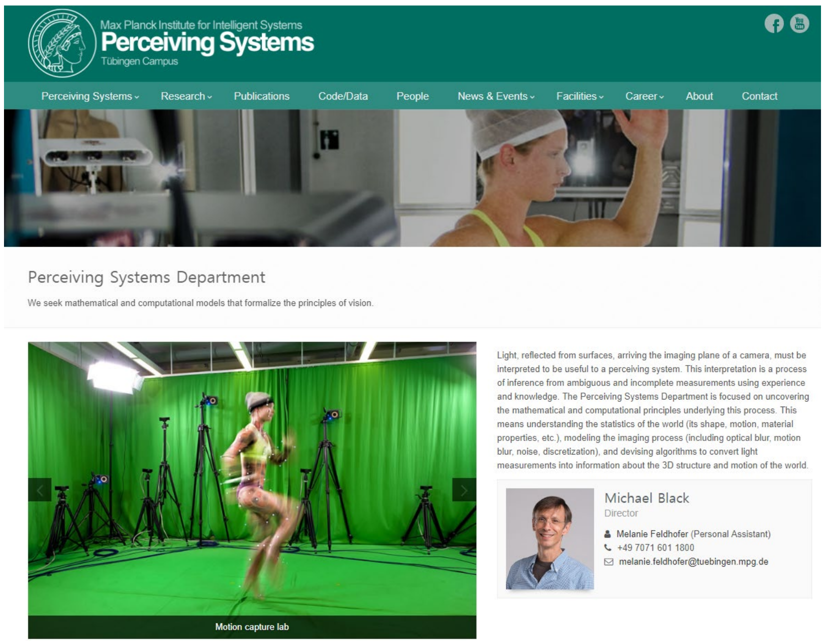




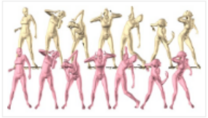


Perceiving Systems Lab (Max Planck Institute)

- Template model 기반 body shape, body deformation 형상 연구 선도 group
- Full body model 및 hand, foot 등 다양한 인체 부위 template 연구 수행 중
- Link: https://ps.is.tuebingen.mpg.de/



- Ballester et al. (2014)
- Feix et al. (2016)
- Romero et al. (2017)
- Tzionas (2016)_Dissertation
- Tzionas and Gall (2015)
- Tzionas et al. (2013)
- Tzionas et al. (2014)
- Tzionas et al. (2016)



Embodied Hands: Modeling and Capturing Hands and Bodies Together
Romero, J., Tzionas, D., Black, M. J.
ACM Transactions on Graphics, (Proc. SIGGRAPH Asia), 36(6):245:1-245:17, 245:1–245:17, ACM, November 2017 (article)
Abstract
website | youtube | paper | suppl | video | link (url) | DOI | Project Page | [BibTex] | Share

Capturing Hand-Object Interaction and Reconstruction of Manipulated Objects
Tzionas, D.
University of Bonn, 2017 (phdthesis)
Abstract
Thesis | link (url) | Project Page | [BibTex] | Share

Capturing Hands in Action using Discriminative Salient Points and Physics Simulation
Tzionas, D., Ballan, L., Srikantha, A., Aponte, P., Pollefeys, M., Gall, J.
International Journal of Computer Vision (IJCV), 118(2):172-193, June 2016 (article)
Abstract
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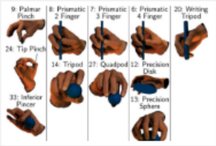
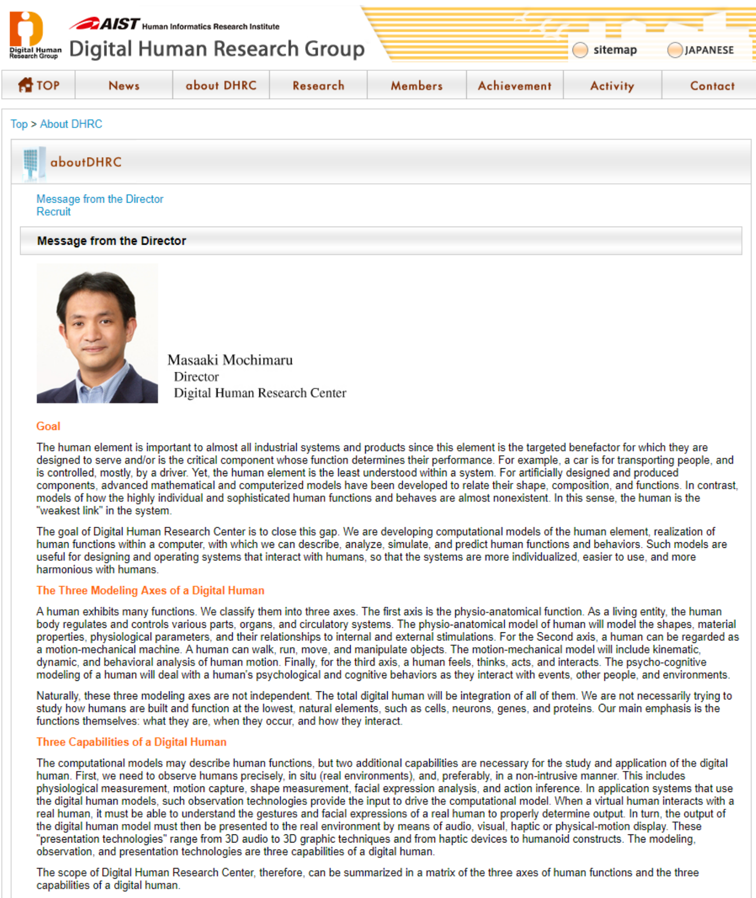


The GRASP Taxonomy of Human Grasp Types
Feix, T., Romero, J., Schmiedmayer, H., Dollar, A., Kragic, D.
Human-Machine Systems, IEEE Transactions on, 46(1):66-77, 2016 (article)
publisher website | pdf | DOI | [BibTex] | Share

AIST (Advanced Industrial Science and Technology)

- AIST Digital Human Research Group (DHRG)에서 hand template model 및 design 응용 연구 수행
- Link: http://www.dh.aist.go.jp/en/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aboutDHRC

Message from the Director
Recruit

Message from the Director

Masaaki Mochimaru
Director
Digital Human Research Center

Goal

The human element is important to almost all industrial systems and products since this element is the targeted benefactor for which they are designed to serve and/or is the critical component whose function determines their performance. For example, a car is for transporting people, and is controlled, mostly, by a driver. Yet, the human element is the least understood within a system. For artificially designed and produced components, advanced mathematical and computerized models have been developed to relate their shape, composition, and functions. In contrast, models of how the highly individual and sophisticated human functions and behaves are almost nonexistent. In this sense, the human is the "weakest link" in the system.

The goal of Digital Human Research Center is to close this gap. We are developing computational models of the human element, realization of human functions within a computer, with which we can describe, analyze, simulate, and predict human functions and behaviors. Such models are useful for designing and operating systems that interact with humans, so that the systems are more individualized, easier to use, and more harmonious with humans.

The Three Modeling Axes of a Digital Human

A human exhibits many functions. We classify them into three axes. The first axis is the physio-anatomical function. As a living entity, the human body regulates and controls various parts, organs, and circulatory systems. The physio-anatomical model of human will model the shapes, material properties, physiological parameters, and their relationships to internal and external stimulations. For the Second axis, a human can be regarded as a motion-mechanical machine. A human can walk, run, move, and manipulate objects. The motion-mechanical model will include kinematic, dynamic, and behavioral analysis of human motion. Finally, for the third axis, a human feels, thinks, acts, and interacts. The psycho-cognitive modeling of a human will deal with a human's psychological and cognitive behaviors as they interact with events, other people, and environments.

Naturally, these three modeling axes are not independent. The total digital human will be integration of all of them. We are not necessarily trying to study how humans are built and function at the lowest, natural elements, such as cells, neurons, genes, and proteins. Our main emphasis is the functions themselves: what they are, when they occur, and how they interact.

Three Capabilities of a Digital Human

The computational models may describe human functions, but two additional capabilities are necessary for the study and application of the digital human. First, we need to observe humans precisely, in situ (real environments), and, preferably, in a non-intrusive manner. This includes physiological measurement, motion capture, shape measurement, facial expression analysis, and action inference. In application systems that use the digital human models, such observation technologies provide the input to drive the computational model. When a virtual human interacts with a real human, it must be able to understand the gestures and facial expressions of a real human to properly determine output. In turn, the output of the digital human model must then be presented to the real environment by means of audio, visual, haptic or physical-motion display. These "presentation technologies" range from 3D audio to 3D graphic techniques and from haptic devices to humanoid constructs. The modeling, observation, and presentation technologies are three capabilities of a digital human.

The scope of Digital Human Research Center, therefore, can be summarized in a matrix of the three axes of human functions and the three capabilities of a digital human.

Physio- Motion- Physio-

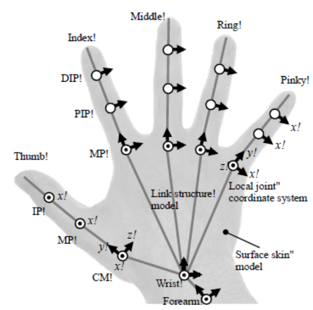


Figure 1. Link structure model and surface model of DhaibaHand.

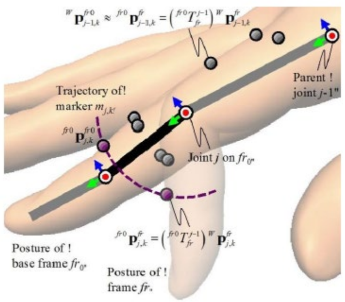
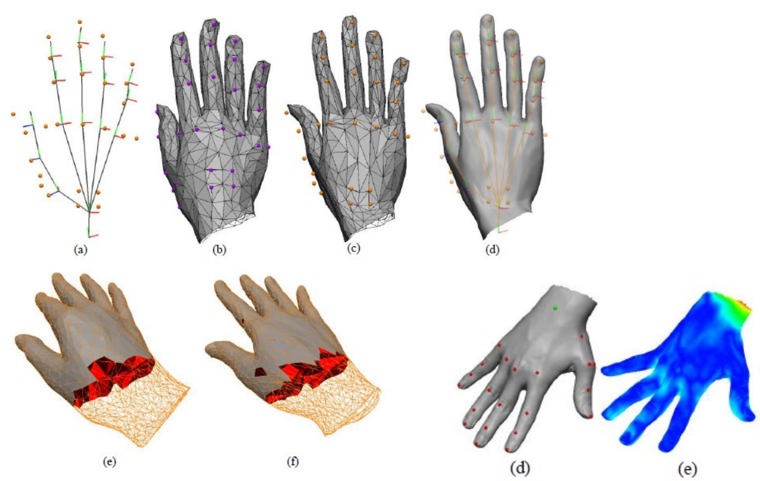


Figure 4. Estimation of joint coordinate system.



Informatics Lab (Max Planck Institute)

- MPI for intelligent system과는 별개의 연구 그룹으로 CAESAR data 기반 body template model 연구 성과 공유
- Link: http://humanshape.mpi-inf.mpg.de/

MPII Human Shape

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Introduction

MPII Human Shape is a family of expressive 3D human body shape models and tools for human shape space building, manipulation and evaluation. Human shape spaces are based on the widely used statistical body representation and learned from the CAESAR dataset, the largest commercially available scan database to date. As preprocessing several thousand scans for learning the models is a challenge in itself, we contribute by developing robust best practice solutions for scan alignment that quantitatively lead to the best learned models. We make the models as well as the tools publicly available. Extensive evaluation shows improved accuracy and generality of our new models, as well as superior performance for human body reconstruction from sparse input data.

Citing this work

```
@article{pishchulin17pr,
        author = {Leonid Pishchulin and Stefanie Wuhrer and Thomas Helten and Christian Theobalt and Bernt Schiele}
        title = {Building Statistical Shape Spaces for 3D Human Modeling},
        journal = {Pattern Recognition},
        year = {2017}
}
```

Download

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We are making shape spaces, fitted scans and code freely available for non-commercial and educational purposes only.

Statistical human shape spaces learned from the meshes fitted to the pre-processed CAESAR body scans:
- CAESAR (611 MB)
- CAESAR + WSX (611 MB)
- CAESAR + NH (578 MB)

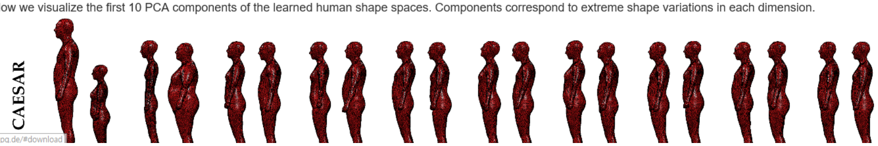
WSX and *NH* denote additional posture normalization of the pre-processed scans using the methods of *Wuhrer et al.* and *Neophytou & Hilton*, respectively.

CAESAR-fitted meshes used for learning statistical human shape spaces:
- CAESAR fitted meshes (607 MB)
- CAESAR + WSX fitted meshes (364 MB)
- CAESAR + NH fitted meshes (363 MB)

Source code (GitHub) for data pre-processing, 3D human shape modeling, fitting and evaluation.

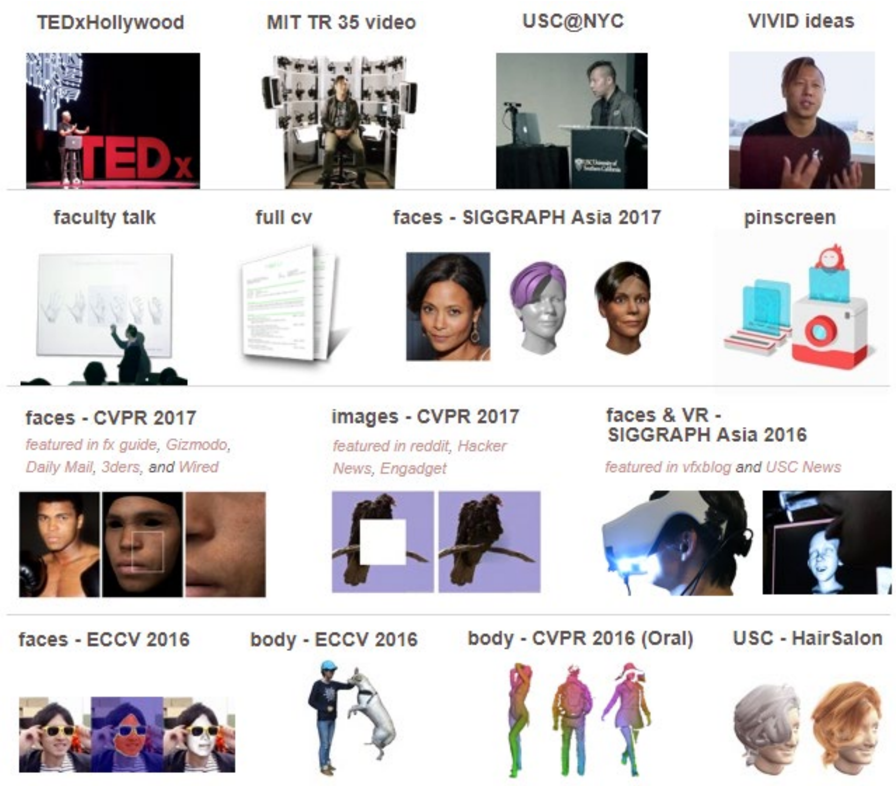
Examples

Below we visualize the first 10 PCA components of the learned human shape spaces. Components correspond to extreme shape variations in each dimension.



Hao Li (Univ. of Southern California)

- 3D scan data 처리 분야에 다양한 논문 및 연구 성과 공유
- Pinscreen, Inc,. CEO 및 co-founder



IBV (Instituto de Biomecanica)

- IBV anthropometry research group은 Eurofit project를 비롯하여 body template model 기반 anthropometry 분야에서 다양한 연구 활동을 수행 중
- 상용 application(e.g., Make Human) 개발 및 배포
- Link: https://anthropometry.ibv.org/en/publications.html