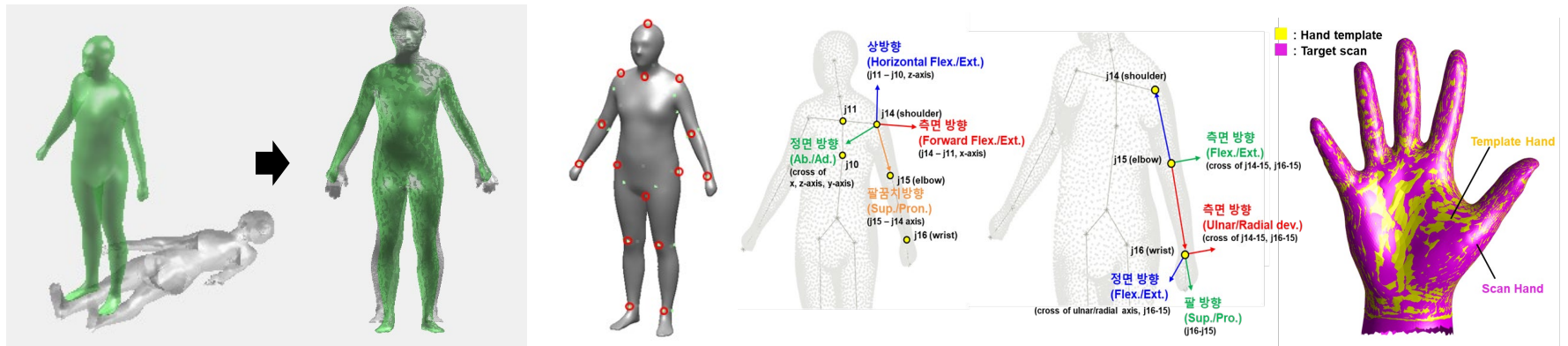


Registration Method of the Human Template Model for Learning of the Korean Anthropometric Size and Shape



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본 연구는 한국연구재단의 중견연구자 지원사업(NRF-2018R1A2A2A05023299)과 산업통상자원부의 미래첨단 사용자편의서비스 기반조성사업(R0004840, 2020)의 지원을 받아 수행되었습니다.

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- 연구 목적

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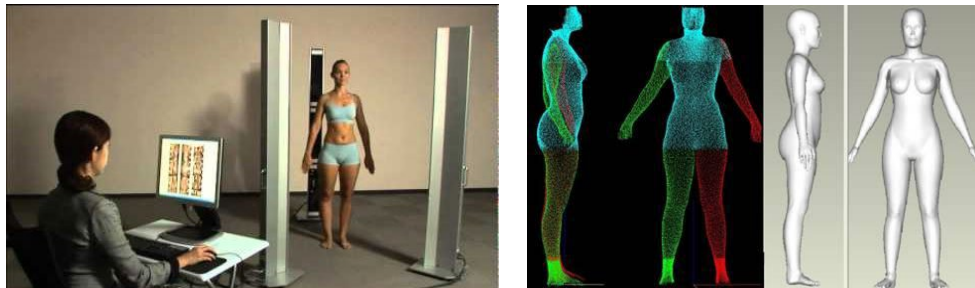
- Deformable Human Template 개발
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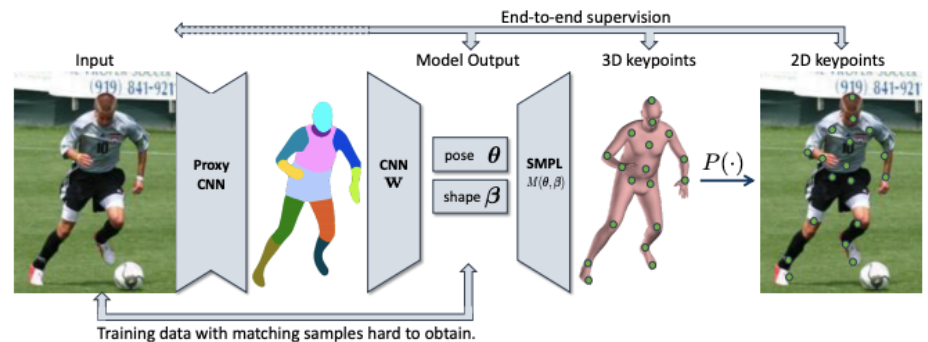
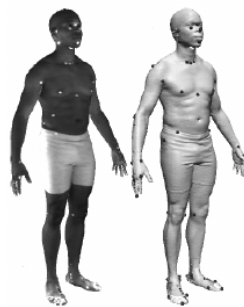
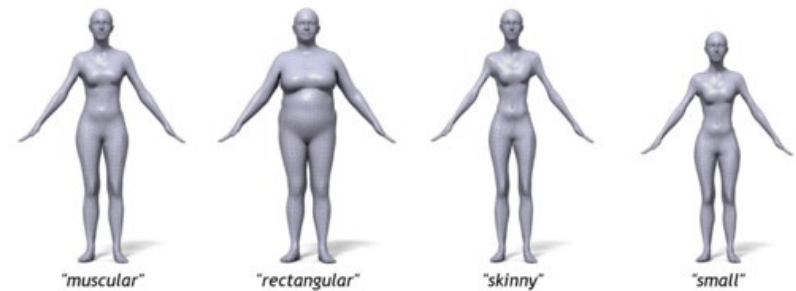
3D 인체형상 Scan 활용 증가

- 다양한 인체 형상 분석 및 활용을 위해 3D scanner를 이용한 **3차원 인체 측정 및 형상 분석**이 수행되고 있으며, 미국, 한국 등 다수 국가에 **3D 인체형상 DB 구축됨**
- AI 기술 개발과 함께 **인체 형상 학습이 요구됨**

3차원 인체 형상 scan data 예시



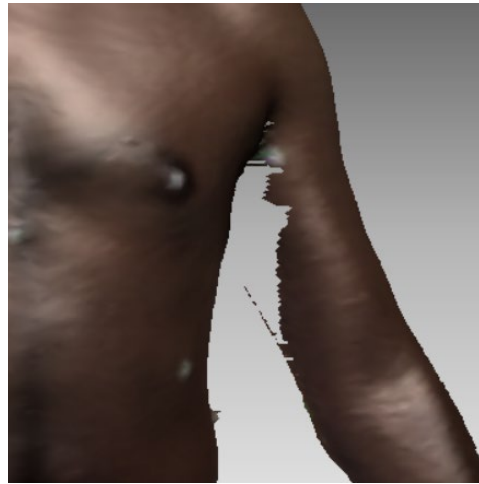
3차원 인체 형상 학습 및 적용 예



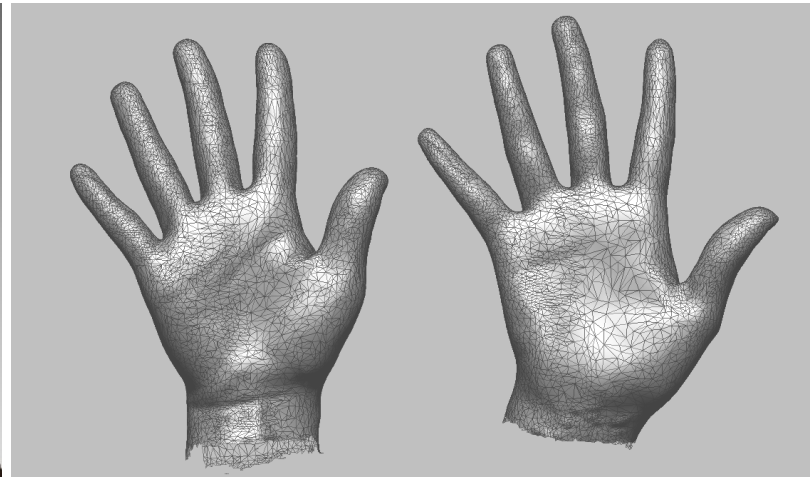
3D Scan Data 활용 한계점

- 3D 인체 형상 data는 scan 시 일부 부위의 missing이 발생하여 보완, 후처리 필요
 - 3D scan data는 정형 데이터지만 raw data는 비정형 데이터의 특성을 지님
 - Mesh 구조 임의 생성, 점군 수 임의 생성, 자세 차이에 의한 영향
 - 비정형 데이터는 학습이 어려움, 일관된 구조로 보정 필요
- ⇒ 3D scan data의 후처리, 데이터 구조화를 위해 template model이 활용됨

3D body scan data 및 scan missing 예: CAESAR data



3D scan의 비정형적 특성 예



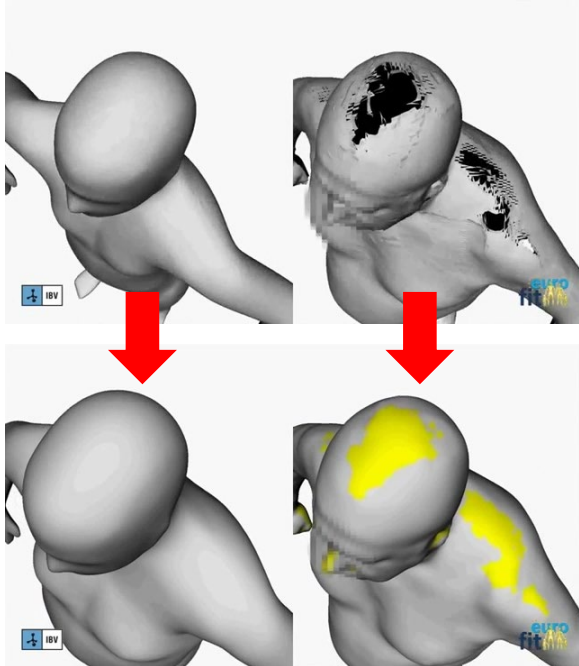
of vertices: 8195

of vertices: 9295

Deformable Human Template Model

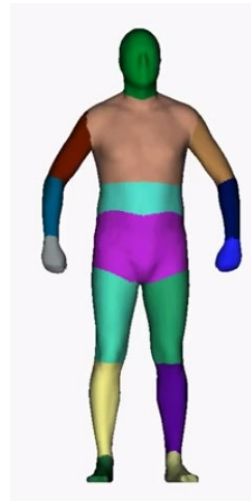
- 크기 조절, 자세 변화 및 표면 변형이 적용된 **deformable digital human template**은 다양한 **3D scan raw data**에 정렬되며 **인체 형상 측정 및 분석**에 유용하게 **활용**됨
- Human template model은 다양한 **연구기관별**로 **자체 개발**되어 **활용** 중이며, **template registration algorithm** 및 **활용 기술의 공개**는 **제한적**임

Template model을 이용한 형상 보강 예



연구기관별 Body Template Model 개발 예

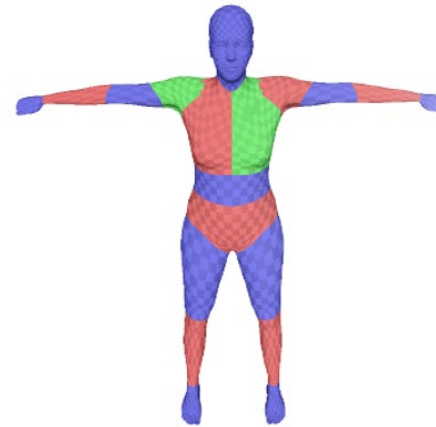
(# segment = 16)



IBV, Spain

Segmentation of body parts

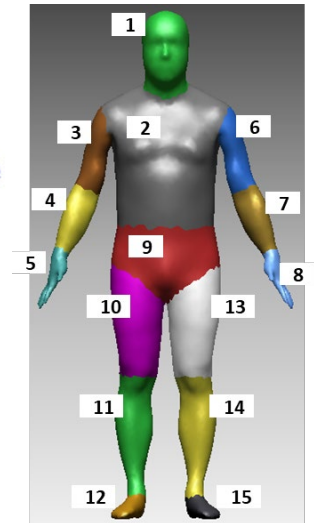
(# segment = 19)



Template: T^*

PSL, Germany

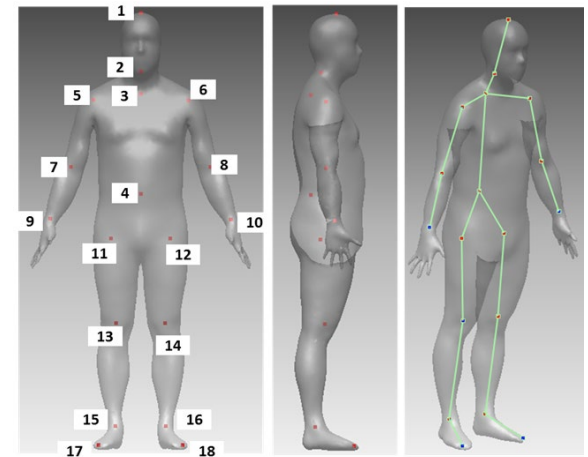
(# segment = 15)



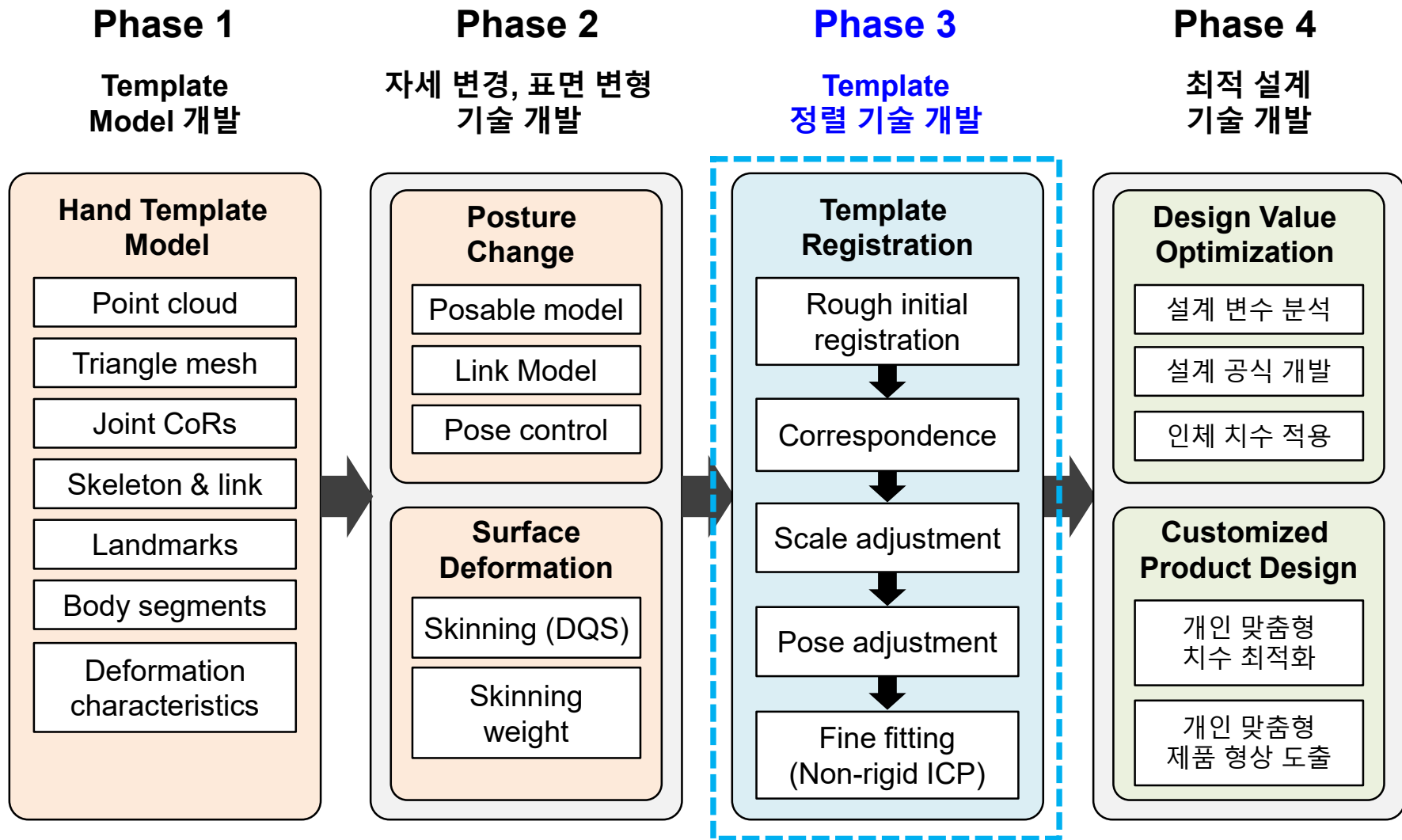
EDT, POSTECH

한국인 인체 치수 및 형상 학습을 위한 3차원 human template model 정렬 방법 개발

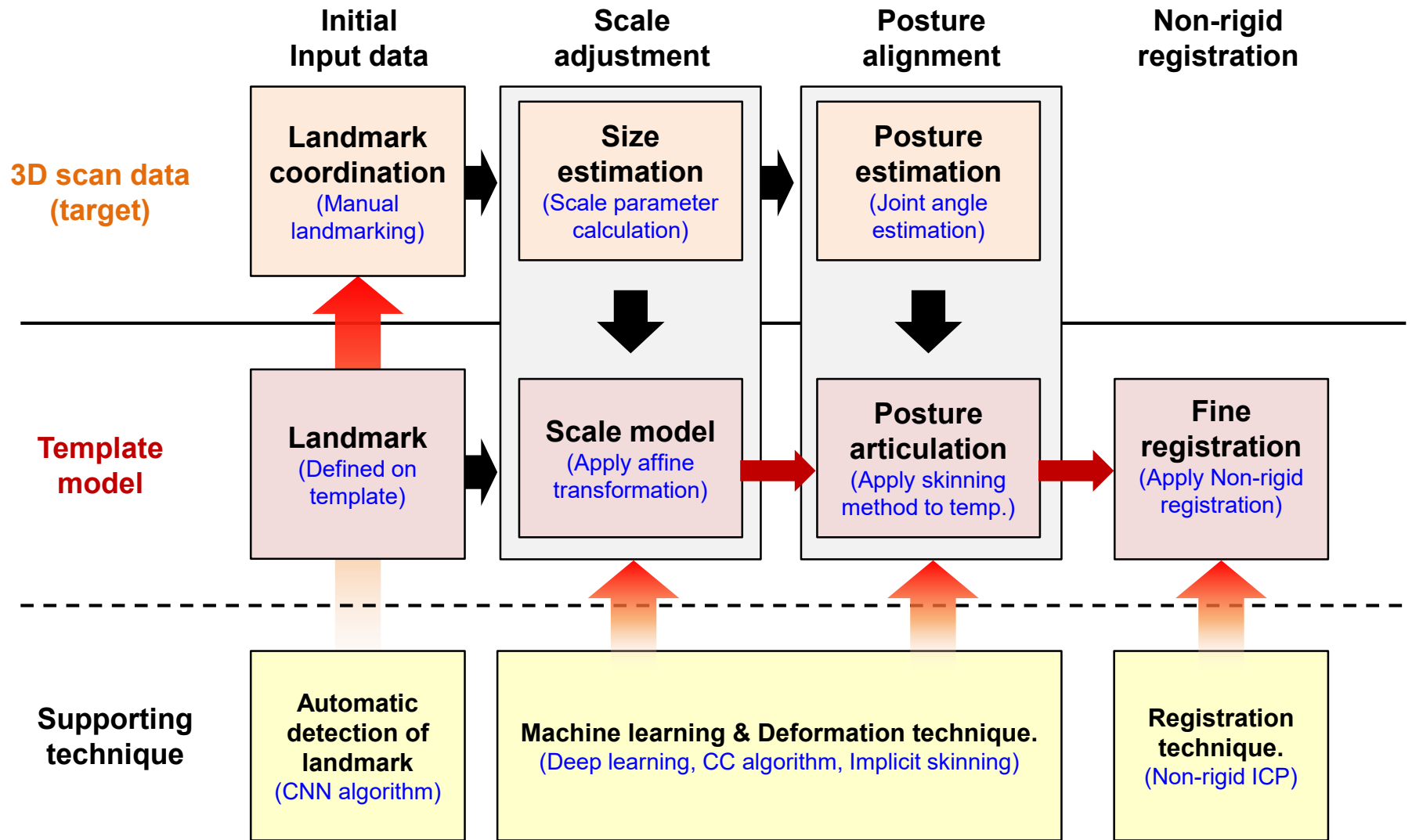
1. **Deformable Human Template Model** 개발
2. **Template Registration Process** 정립
3. **Registration Algorithm** 개발
4. Template (Body, Hand) **정렬 결과**



Big Picture: Template Model 기반 제품 설계 기술



Big Picture: Registration 기술 개발

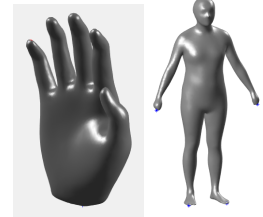


Source: Allen et al., 2003; Angelov et al., 2005; Pishchulin et al., 2017

연구 절차

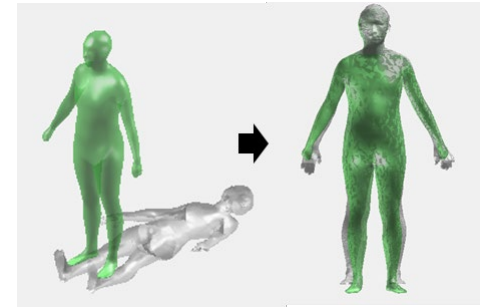
S1. Deformable Human Template Model 개발

- Body, Hand template model
- Link structure, segmentation
- Dual Quaternion based skinning



S2. Template Model Registration Process 정립

- Initial registration
- Size adjustment
- Posture fitting



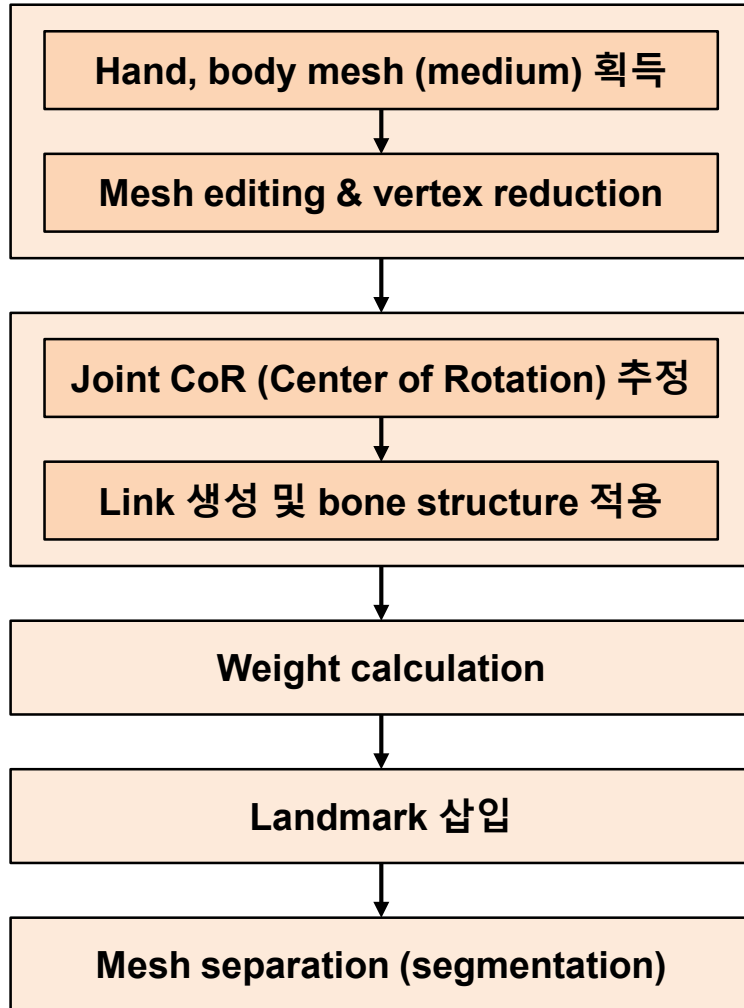
S3. Template Registration Algorithm 개발

- Vogel's method based correspondence pair generation
- Registration order (medial to lateral)

S4. Body, Hand Template Registration

- Application to 3D hand, body scan data
- Registration performance analysis

S1. Deformable Human Template Model 개발

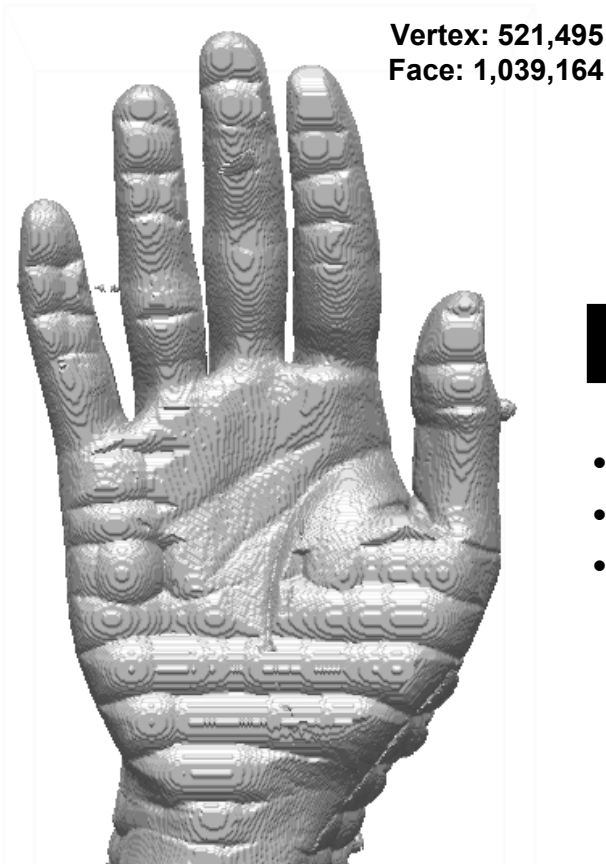


- Size Korea 2010 medium size male에 해당하는 손 및 전신 scan 및 후처리
- Vertex reduction: target vertex 15,000 ~ 20,000 되도록 mesh reduction 수행
- 선행 연구(Lim, 2018) 결과를 이용하여 CoR 도출 (Delong Kasa Method 활용, fixed CoR 도출)
- Link model 생성 및 skeletal structure 적용
- Weight: hand mesh 상의 vertex의 상대적인 중요도
- CoR로부터 거리를 기반으로 계산됨
- Blender S/W를 이용하여 연산
- 손등: 59개 landmark
- 손바닥: 16개 landmark
- 전신: 49개 landmark
- Hand: 17개 region segmentation
- Body: 15개 region segmentation

HTM 개발: Surface Model

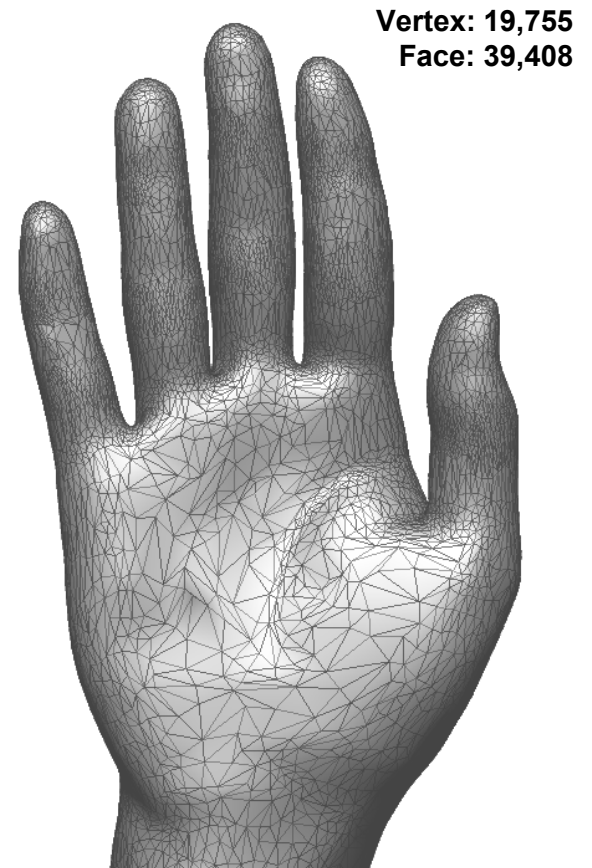
□ 평균 크기(50th%ile)의 3D hand scan을 가공하여 human template model 개발

Original CT-Scan (Medium size)



- Hole filling
- Smoothing
- Symmetrizing

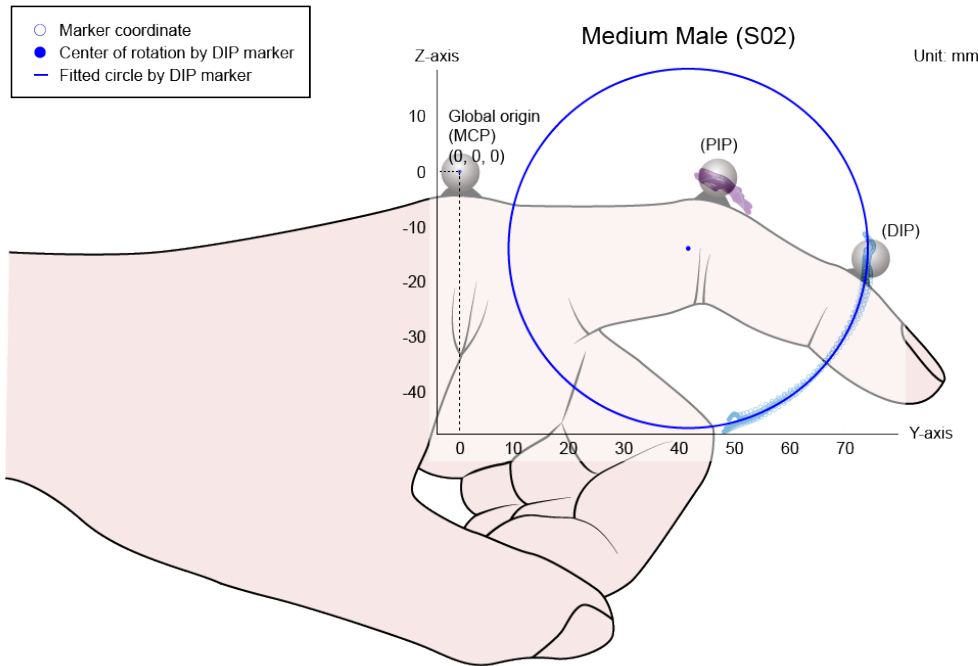
Hand Template 예시



HTM 개발: Joint Center of Rotation

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

Accurate hand joint CoR

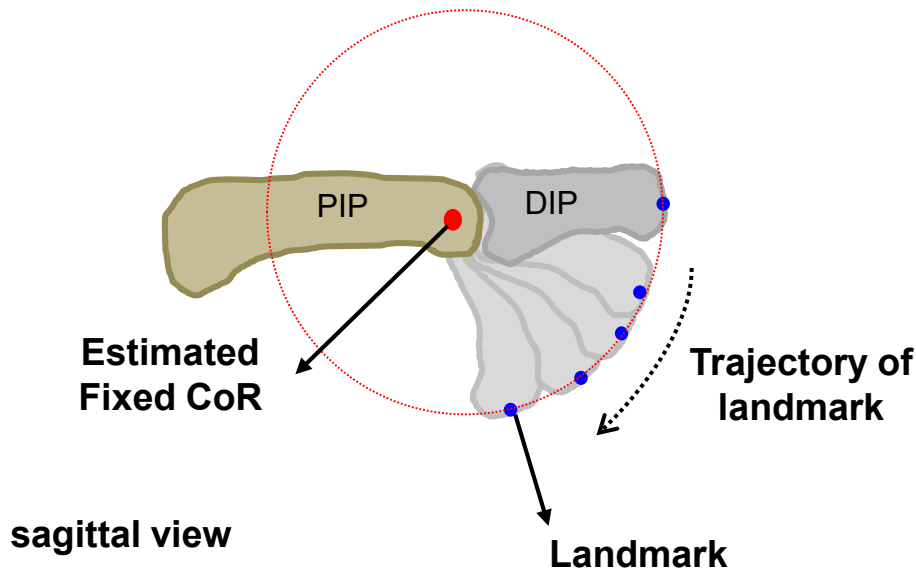


Hand joint CoR 적용 예



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

- Delong-Kasa 방법 적용: **landmark trajectory**를 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 trajectory**에 **least square error**를 최소화하는 **circle fitting** 및 **center of rotation** 도출



Least square error criterion:

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

* 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

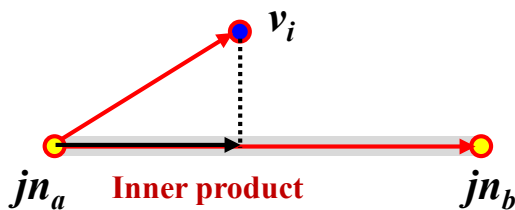
CoR 기반 hand link 생성 (digits 1~5)



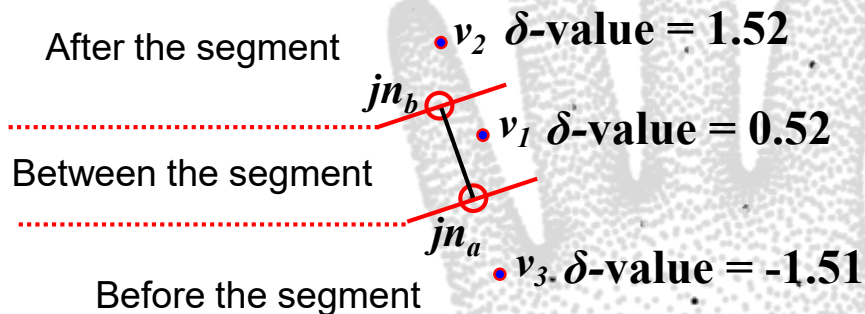
HTM 개발: Skinning Weight Calculation (1/3)

- 관절 회전 중심에 대한 **점군(vertex)의 skinning weight** (range: 0 ~ 1) 연산
- **Skinning weight**는 관절의 회전 시 **각 점이 받는 변형의 영향력**으로 **점**으로부터 **인접한 관절들까지의 상대적인 거리(delta, δ)**를 고려하여 **계산됨**
 - $\delta < 0$: if the point projection is **before** the segment
 - $0 < \delta < 1$: if the point projection is **inside the segment**
 - $\delta > 1$: if the point projection is **after** the segment

$$\delta = \frac{(v_i - jn_a) \cdot (jn_b - jn_a)}{\|jn_b - jn_a\|^2}$$



- jn_a is influent joint
- jn_b is child joint of jn_a



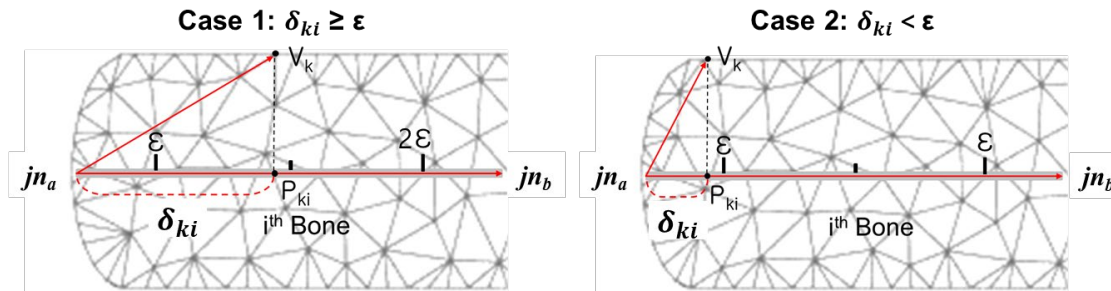
HTM 개발: Skinning Weight Calculation (2/3)

□ Skinning weight can be calculated with the delta value(δ)

1) Delta ratio (Li et al., 2018)

$$\omega_{ki} = \begin{cases} 1, & \delta_{ki} \geq \varepsilon \\ \frac{\delta_{ki}}{\sum_{j=i}^q \delta_{kj}}, & \delta_{ki} < \varepsilon \end{cases}$$

If δ_{ki} is greater than the threshold(ε), skinning weight(ω_{ki}) is 1
 If δ_{ki} is smaller than the threshold(ε), which means close enough to the joint, ω_{ki} is the ratio of δ_{ki} to the δ_{kj} of all adjacent bones



2) Distribution function (Flores and Sanchez, 2015)

✓ Skinning weight(ω_{ki}) is calculated with the Gaussian distribution function $f(\delta)$

$$f(\delta) = ae^{-\frac{(\delta-0.5)^2}{2c^2}} \quad a = 1.3, c = 0.25$$

a: maximum value of $f(\delta)$

c: constant, controlling inflection point

HTM 개발: Skinning Weight Calculation (3/3)

□ 22개 joint별 vertex i 에 대한 상대적 영향력을 joint-vertex 거리를 이용하여 자동 계산

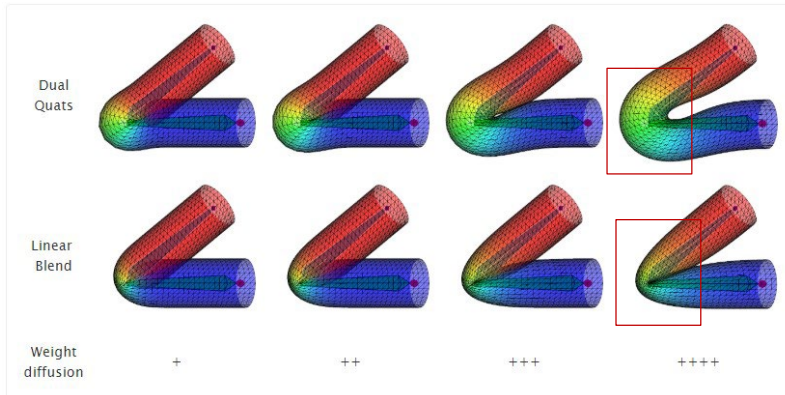
vertex	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J17	J18	J19	J20	J21	J22	
1	0.000	0.000	0.000	0.144	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.821	
2	0.000	0.000	0.000	0.202	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.770	
3	0.000	0.000	0.000	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.864	
4	0.000	0.000	0.000	0.170	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.786	
5	0.000	0.000	0.000	0.233	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.732	
6	0.000	0.000	0.000	0.305	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.667	
7	0.000	0.000	0.000	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.865	
8	0.000	0.000	0.000	0.141	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.831	
9	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.890	
10	0.000	0.000	0.000	0.131	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.831	
11	0.000	0.000	0.000	0.201	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.780	
12	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.777	
13	0.000	0.000	0.000	0.221	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.735	
14	0.000	0.000	0.000	0.292	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.684	
15	0.000	0.000	0.000	0.303	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.652	
16	0.000	0.000	0.000	0.108	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.869	
17	0.000	0.000	0.000	0.106	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.874	
18	0.000	0.000	0.000	0.146	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.834	
19	0.000	0.000	0.000	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.869	
20	0.000	0.000	0.000	0.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.832	
21	0.000	0.000	0.000	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.892	
22	0.000	0.000	0.000	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.908	
23	0.000	0.000	0.000	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.894	
24	0.000	0.000	0.000	0.281	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.699	
25	0.000	0.000	0.000	0.197	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.786	
26	0.000	0.000	0.000	0.277	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.707	
27	0.000	0.000	0.000	0.148	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.817	
28	0.000	0.000	0.000	0.205	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.732	
...
6984	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.981	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.003	

합: joint 1, 5, 9, 13, 17, 21은 motion이 없거나 tip 위치

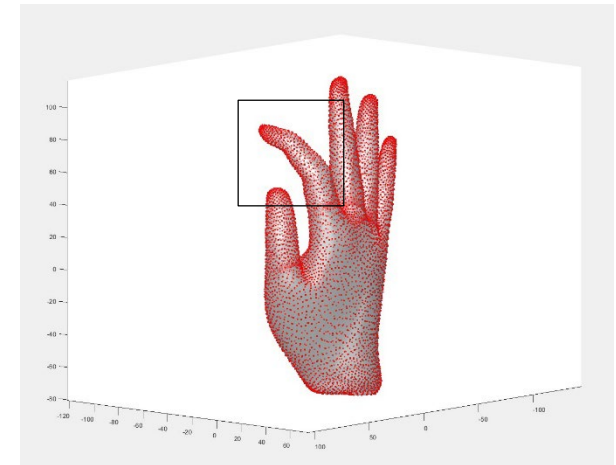
HTM 개발: Surface Deformation (DQS)

- 선형적 표면 변형 방법인 Linear Blend Skinning (LBS)에 volume loss, candy wrapper problem을 보완한 **Dual Quaternion Skinning (DQS)**을 적용함
- **DQS 방법의 회전 변환은 quaternion 수**를 이용하여 연산됨
 - Dual quaternions (q) consist of a scalar part (w), a vector part (x, y, z), & quaternion units (i, j, k)
 $\rightarrow q = w + ix + jy + kz$

Comparison of DQS & LBS
with Different Influence Weights



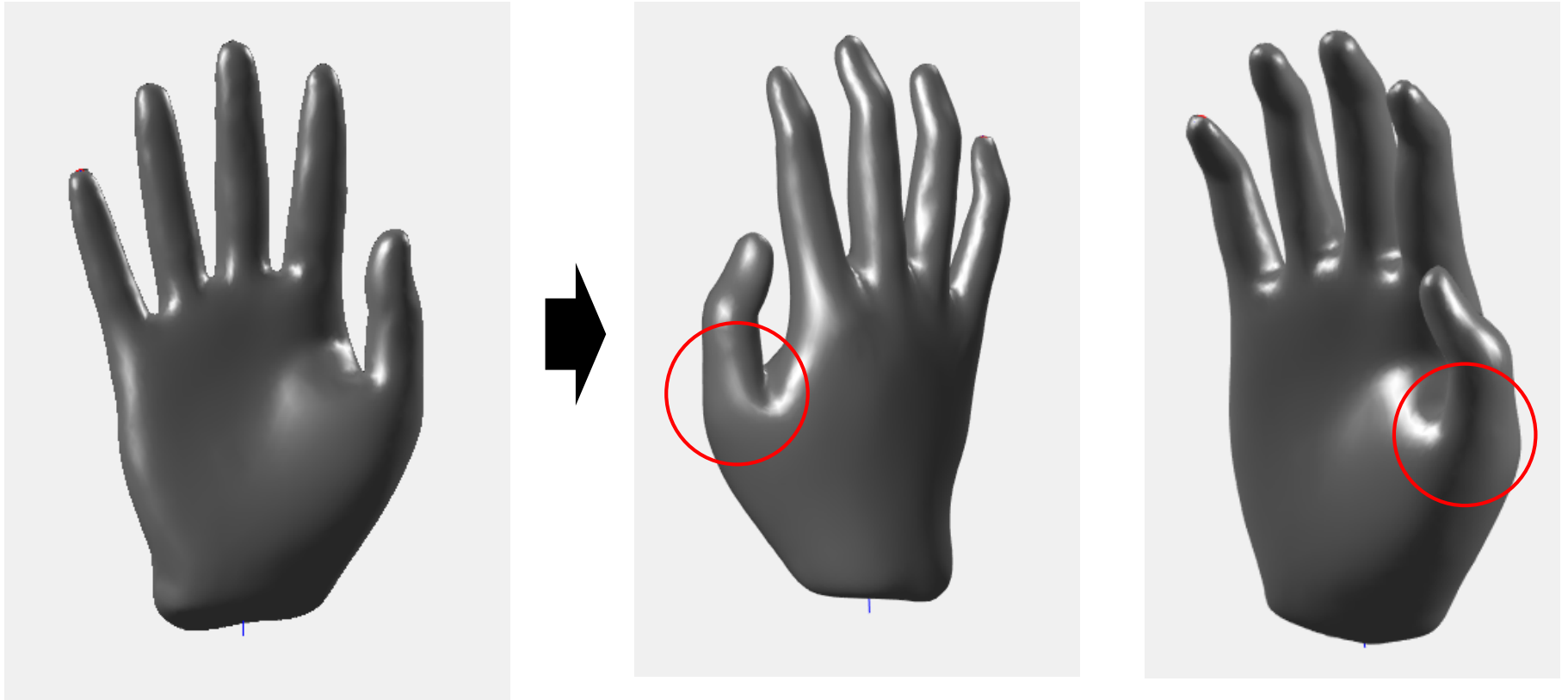
Hand Deformation with DQS on MATLAB



Surface Deformation (DQS): Hand Template

- Hand template model의 표면 변형 적용 예시

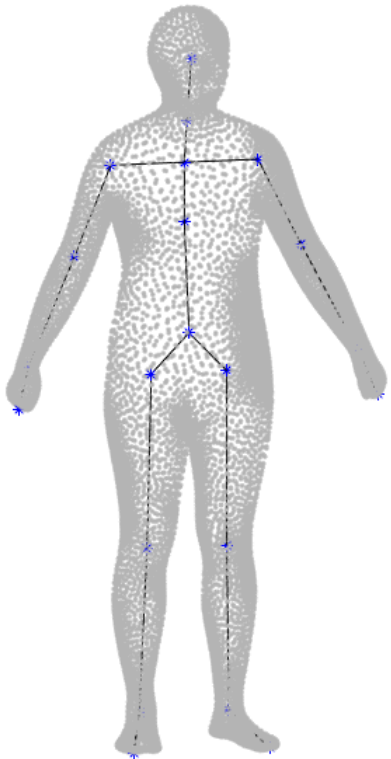
Hand Template 자세 변형 시 Surface Deformation 적용 예



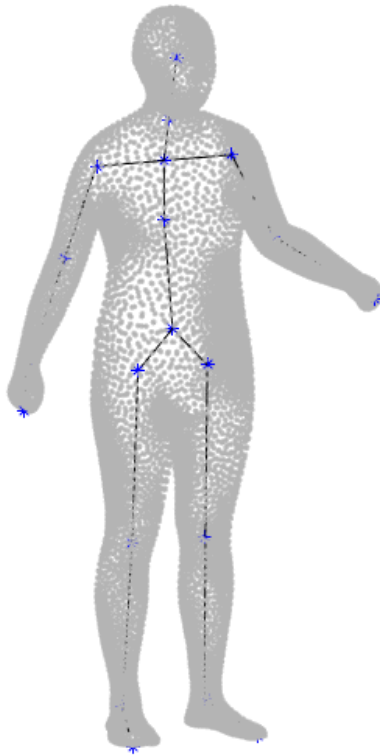
Surface Deformation (DQS): Body Template

□ Body template model의 표면 변형 적용 예시

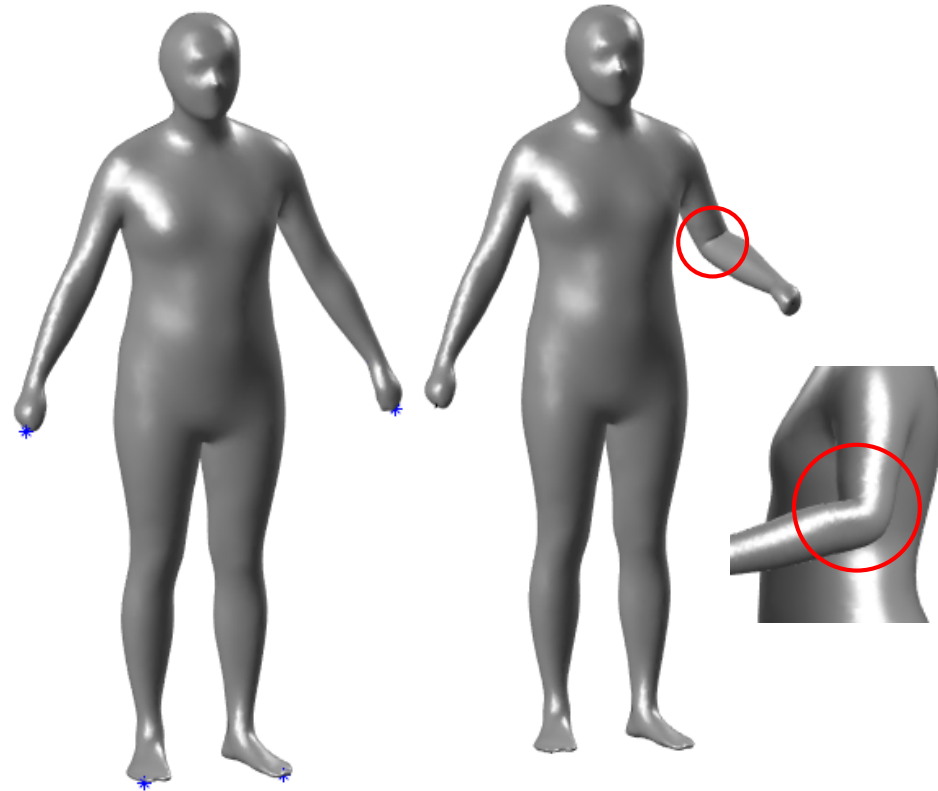
기본 자세의 Template



변형된 자세의 Template



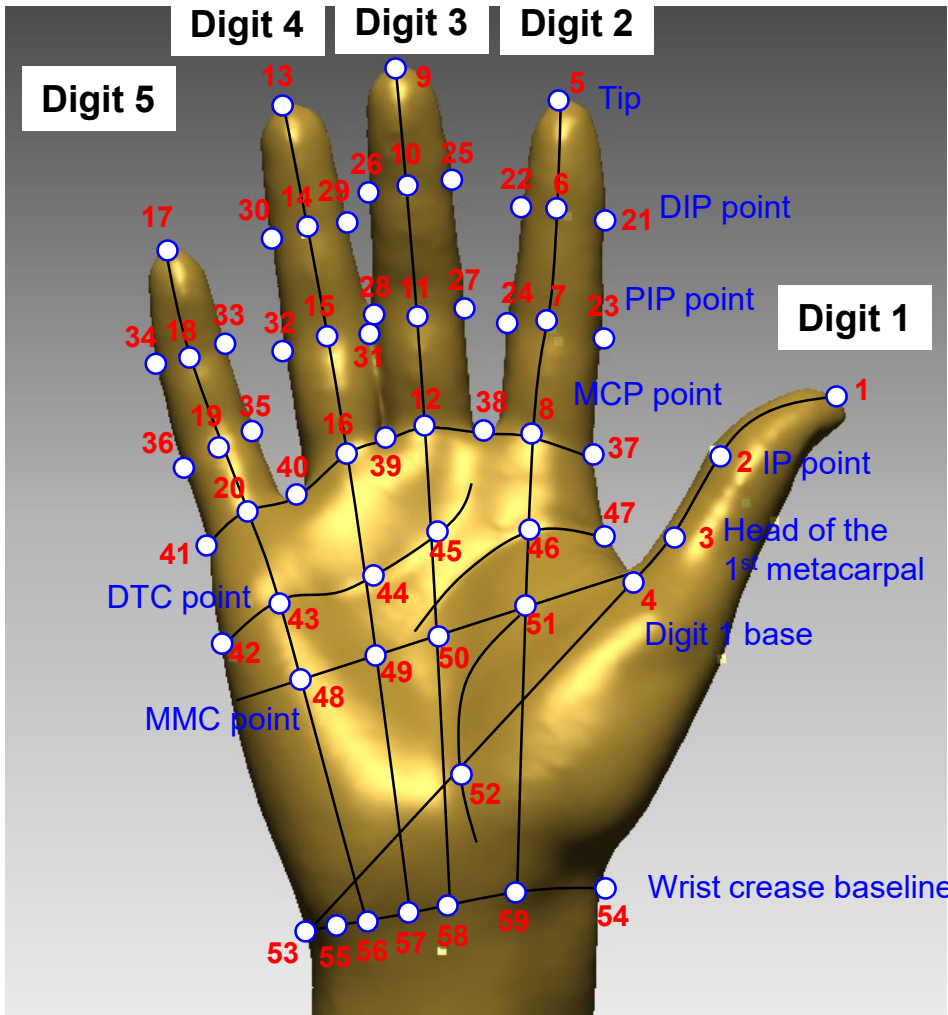
Surface Deformation 적용



HTM 개발: Hand Landmark 예시

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

75개 hand landmark

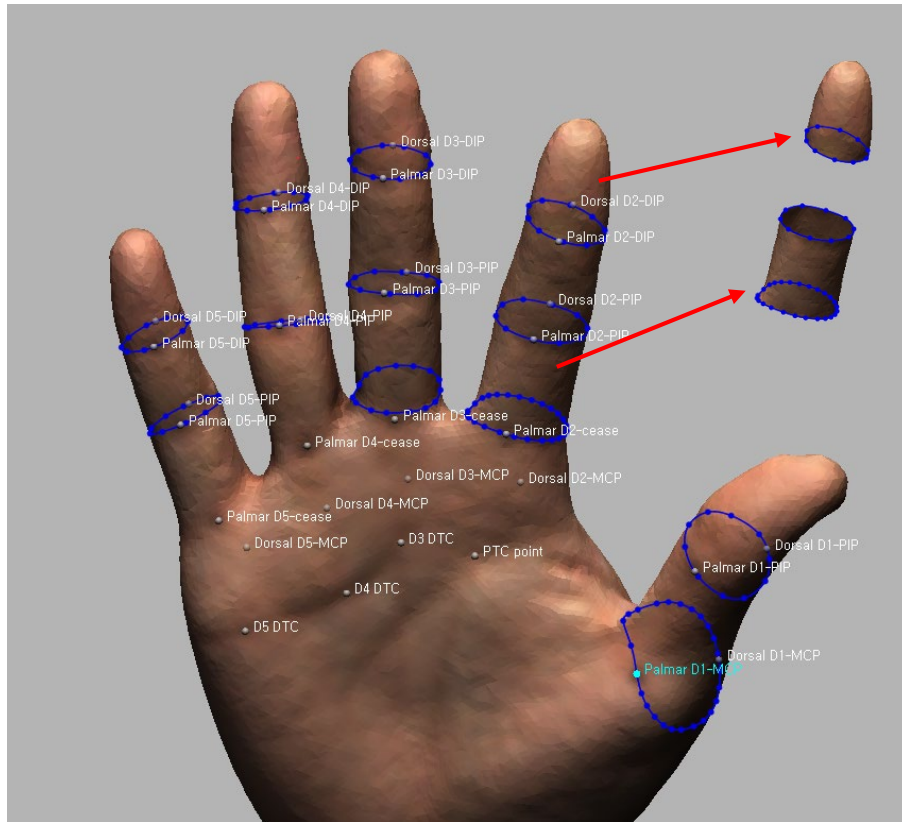


No.	Name	No.	Name
1	The tip of digit 1	21	Digit 2 distal interphalangeal joint - radial
2	Digit 1 interphalangeal joint	22	Digit 2 distal interphalangeal joint - ulnar
3	Head of the first metacarpal	23	Digit 2 proximal interphalangeal joint – radial
4	The base of digit 1	24	Digit 2 proximal interphalangeal 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: Segmentation

□ 인체 부위별 joint를 중심으로 15~17개 영역으로 mesh 분할 수행

Hand mesh separation 예



Human Template Segmentation 예시

Hand template (17 segments)

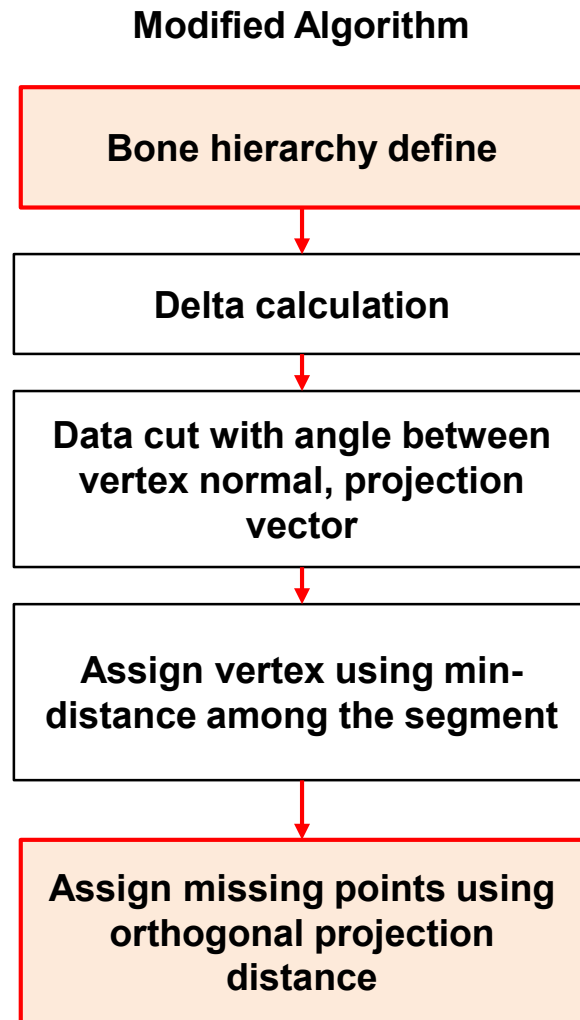
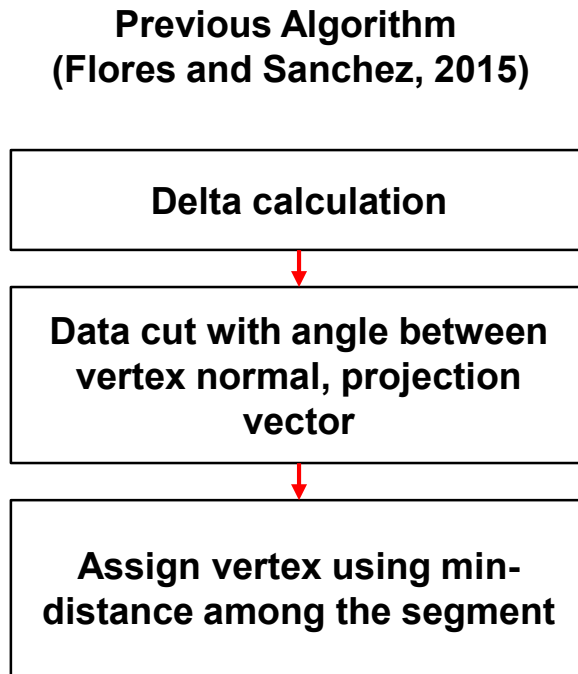


Body template (15 segments)



Segmentation Process

- 기존 연구(Flores & Sanchez, 2015)의 **segmentation algorithm**을 보완하여 hand 및 body **template model segmentation** 수행



Hand Template Model 개발 결과

CoR coordination

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

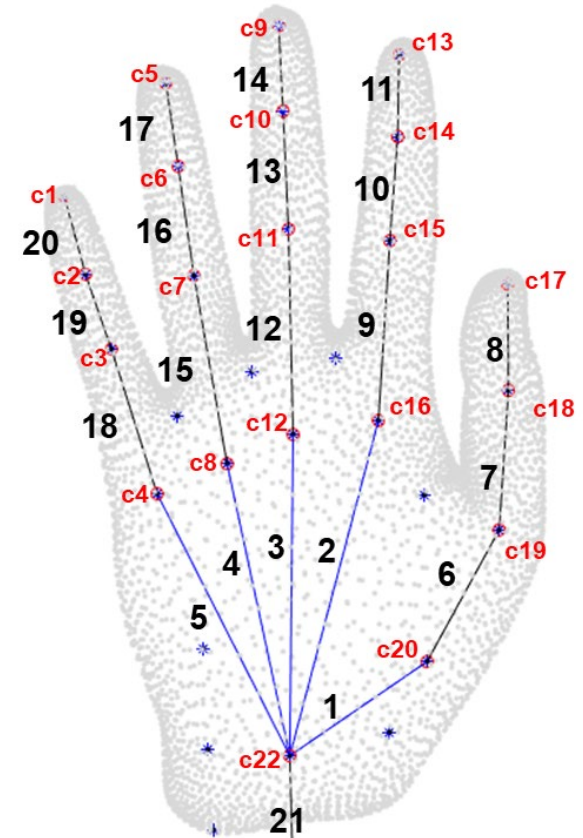
Hand region segmentation

of segments: 17



Hand bond & joint CoR

of link: 21, # of joints: 21



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

Full-Body Template Model 개발 결과

CoR coordination

Joint CoR	x	y	z
1	0.00	145.76	960.00
2	89.16	145.76	867.95
3	94.30	166.14	459.33
4	105.52	194.22	72.72
5	160.46	27.46	8.21
6	-89.16	145.76	867.95
7	-94.30	166.14	459.33
8	-105.52	194.22	72.72
9	-160.46	27.46	8.21
10	0.00	190.88	1210.39
11	0.00	190.88	1348.84
12	0.00	165.33	1450.00
13	0.00	125.33	1600.00
14	173.64	190.88	1348.84
15	267.94	151.12	1153.05
16	386.15	102.17	913.10
17	423.73	59.44	813.39
18	-173.64	190.88	1348.84
19	-264.16	152.93	1141.86
20	-386.51	119.19	898.69
21	-423.73	59.44	813.39

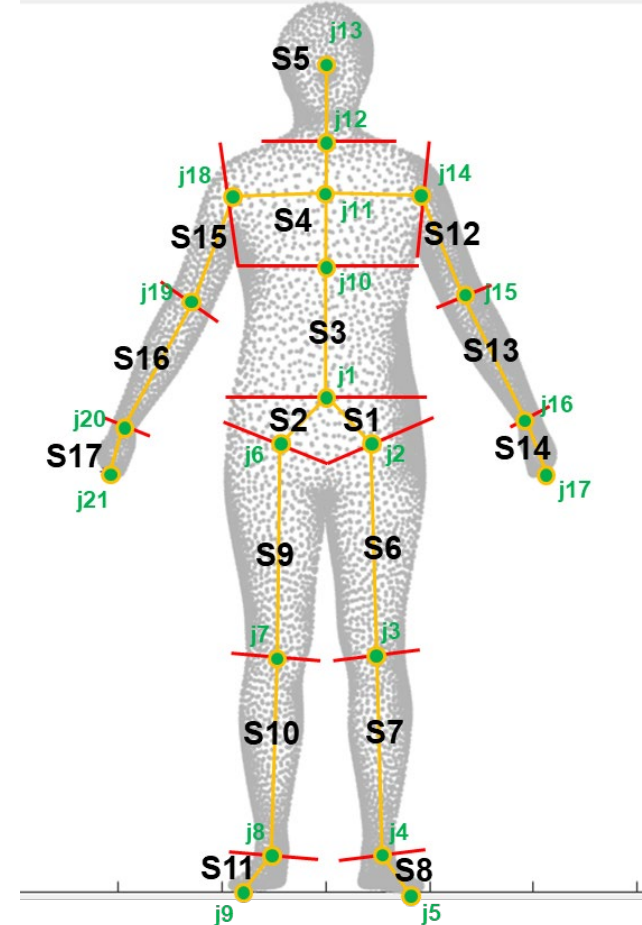
Full-body region segmentation

of segments: 15



Full-body skeletal Structure

of link: 17, # of joints: 19



S2. Human Template Registration 절차

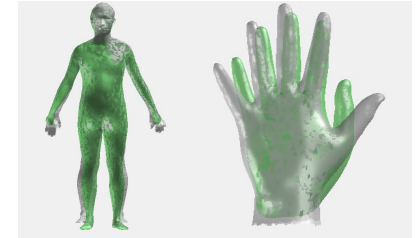
S1. Initial Registration

S2. Main Body (Torso, Palm) Registration

S3. Articulated Body Segment Registration in order (medial → distal, central → lateral)

S4. Fine Fitting (non-rigid ICP registration)

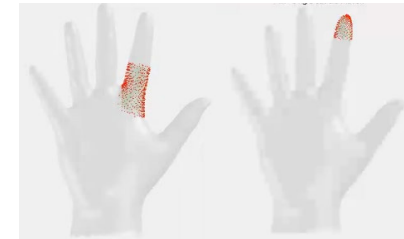
- Input landmark 기반 크기, 방향 조절
- Absolute Orientation Problem Solver 활용



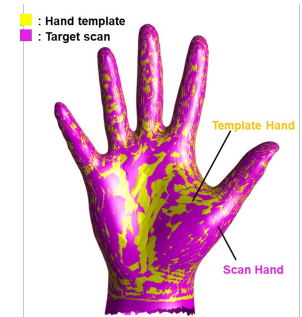
- 중심이 되는 부위 (torso, palm)의 정렬 수행



- 상위 관절에서 하위 관절 순으로 인체 세부 부위 정렬

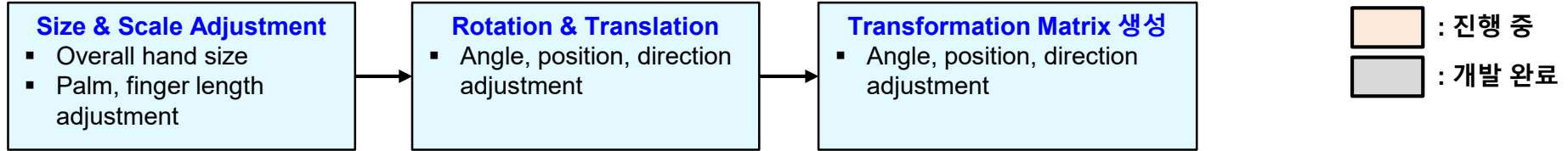


- Non-rigid (deformable) 정렬 방법을 적용하여 표면 미세 정렬

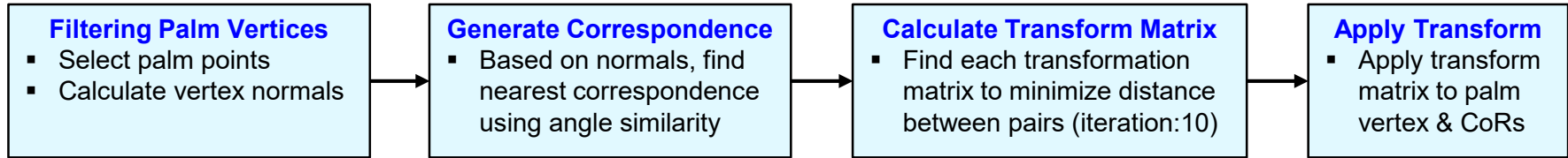


Template Registration 세부 절차 예시: Hand Template

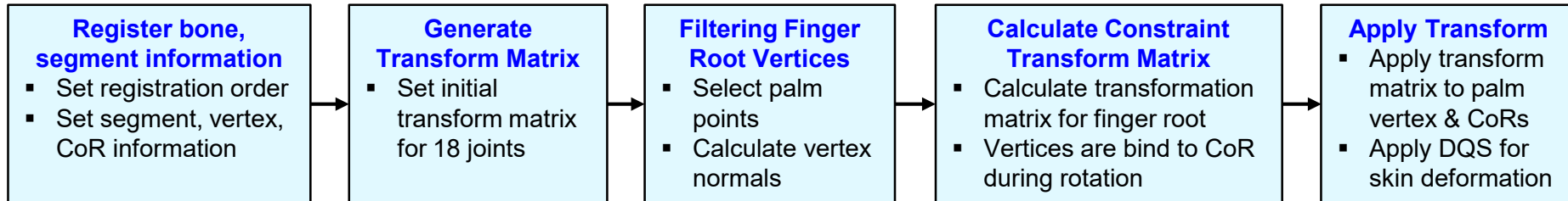
Initial Rough Registration



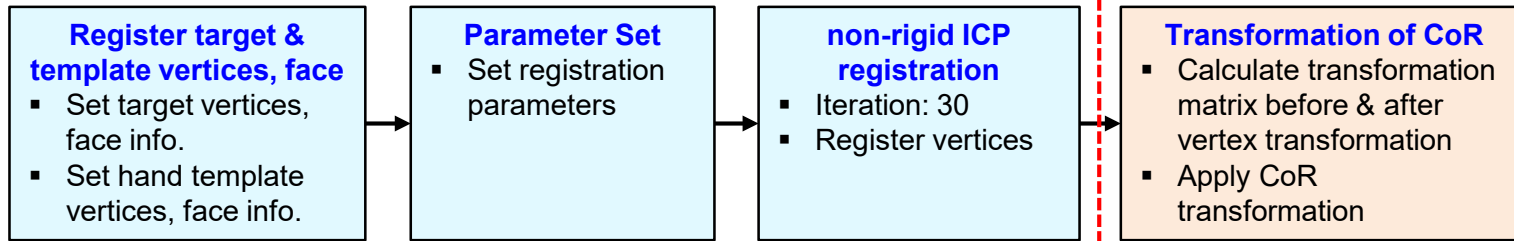
Palm Registration



Finger Root Registration → Finger Segment Registration



Fine Registration (non-rigid ICP)



Hand Template Registration: Video



S2-1. 초기 정렬 (1/2)

- 입력된 landmark를 기반으로 Absolute Orientation Problem Solver (Horn, 1987)을 활용하여 template model을 scan target과 유사한 크기, 방향으로 초기 정렬 수행
 - **Objective:** Register 2 surfaces to obtain a global rotation and translation relationship of precise body motion
 - **Method:** Minimize the sum of the distances between the 2 surfaces

Absolute Orientation Problem Solver 구성 예시

Input data

3 x N matrix

- N columns that each refers to **3 source point's** coordinates (= **scanned data landmarks**)
- N columns that each refers to **3 target point's** coordinates (= **template**)

By resolving following problem...

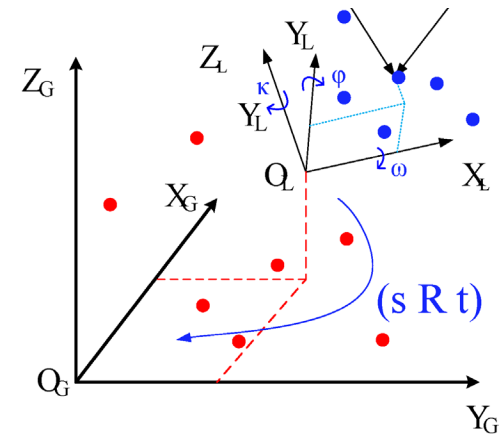
$$\sum_i ||R * A(:, i) + T - B(:, i)||^2$$

Output data

- Rotation matrix R
- Translation matrix T

R : estimated rotation matrix
 T : estimated translation matrix
 s : estimated scale factor
 M : homogenous coordinate transform matrix

$$[s * R, T, [0, \dots, 0, 1]]$$



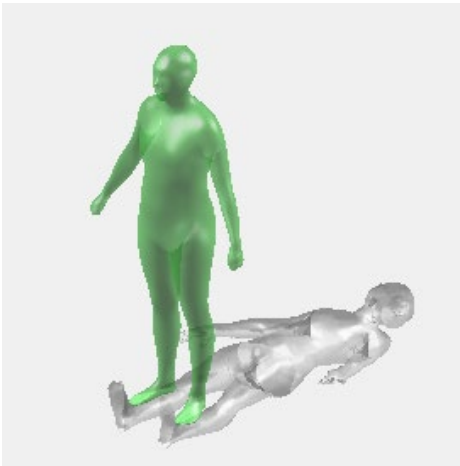
S2-1. 초기 정렬 (2/2)

□ 입력된 landmark를 기반으로 Absolute Orientation Problem Solver (Horn, 1987)을 활용하여 template model을 scan target과 유사한 크기, 방향으로 초기 정렬 수행

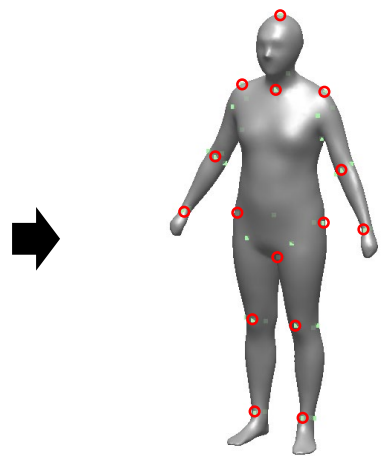
■ : Human template
■ : Target scan

Body
Template

Before Registration



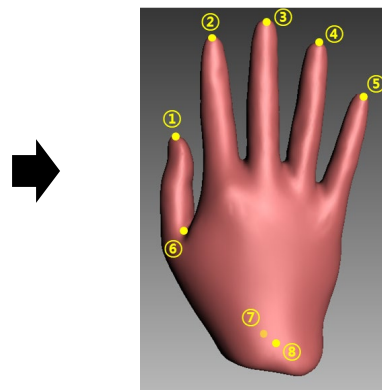
Landmarks Input



Initial Registration

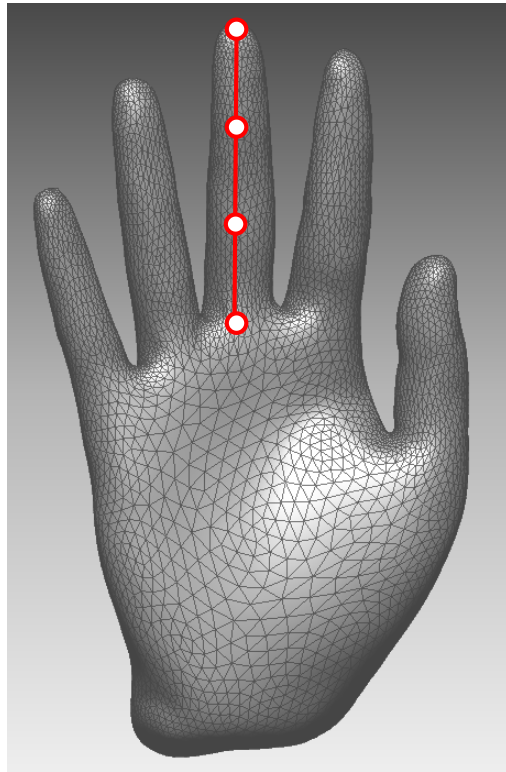


Hand
Template



S2-2. Segment별 크기 조절

- 각 인체 부위에 삽입된 인체참조점을 이용하여 template model의 **segment별 크기**를 **scan data와 유사하도록 조정**
- 크기 조절 시 **관절 회전 중심(Center of Rotation)**도 일관되게 **변환**



입력된 Landmarks 정보

손길이비율 변수 적용 변환



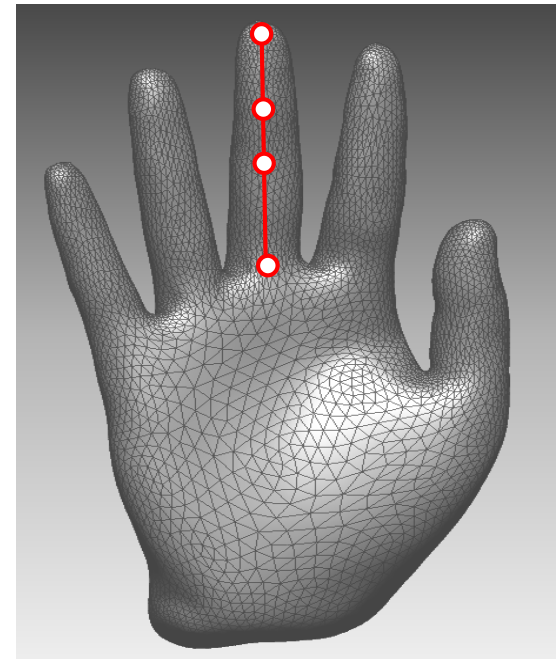
Template

- A: 0.3
- B: 0.4
- C: 0.3



Scan

- A: 0.3
- B: 0.5
- C: 0.2



S2-3. Correspondence Pair 생성

- 초기 정렬된 template 및 scan data 점군들 사이의 **correspondence pair 생성**
- Correspondence pair는 **vertex normal 방향의 유사한 정도**(각도 차이 < 30°), **점 사이 거리를 고려하여 Vogel's method**(Transportation problem solver)를 적용하여 생성

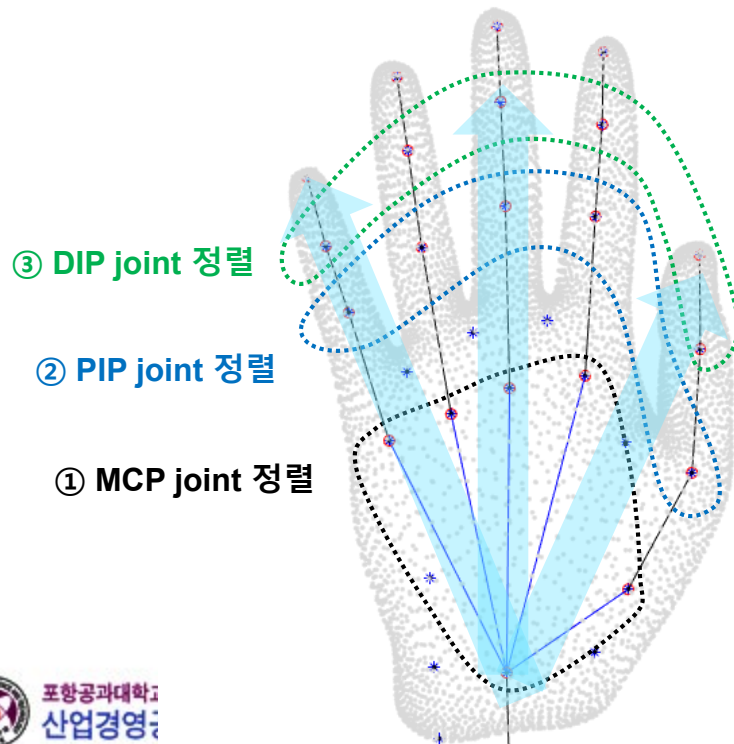
Pair 생성 결과 예: $V_3 - P_1, V_2 - P_2, V_1 - P_3, V_n - P_m$ Objective Function = min.(overall cost)

		Template vertices (size = n)					Supply
		V_1	V_2	V_3	...	V_n	
Scan points (size = m)	P_1	22.1	25.1	3.1	...	44.1	1
	P_2	44.5	1.2	3.5	...	12.2	1
	P_3	2.2	2.9	8.9	...	26.1	1
	1
	P_m	5.6	25.2	33.1	...	2.2	1
Demand		1	1	1	1	1	Overall cost

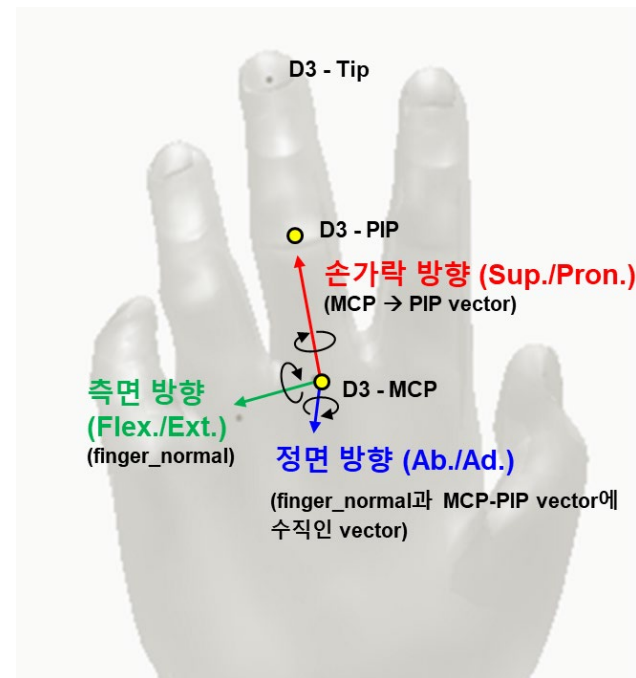
S2-4. 순차적 관절체별 정렬: Hand Template

- 생성된 correspondence pair의 거리합이 최소가 되도록 template model의 자세 변환값 탐색 및 **순차적 적용**
- Template model의 **자세 변환**은 **인체 관절의 자유도를 고려**하여 설정된 **관절들의 회전축을 중심으로 최대 동작 범위 내에서 최적화 방법**(quasi-Newton method)을 이용하여 수행됨

Hand Template 관절체 정렬 순서



Hand Template 관절 회전축 구성 예시

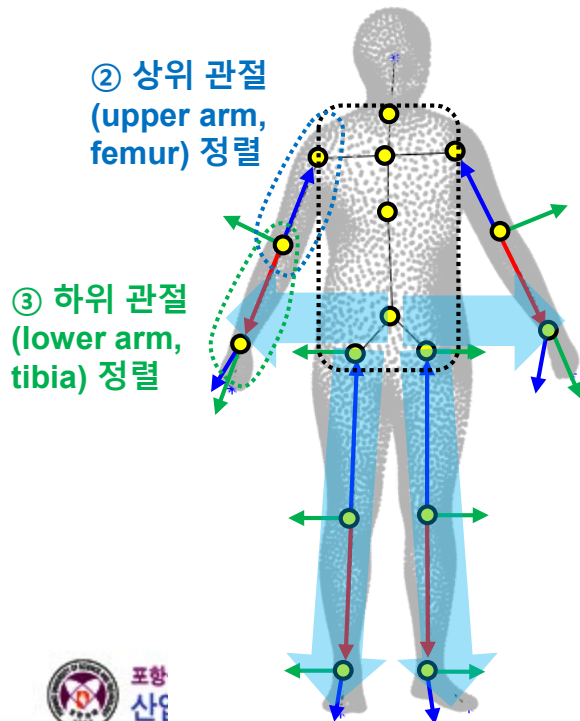


S2-4. 순차적 관절체별 정렬: Body Template

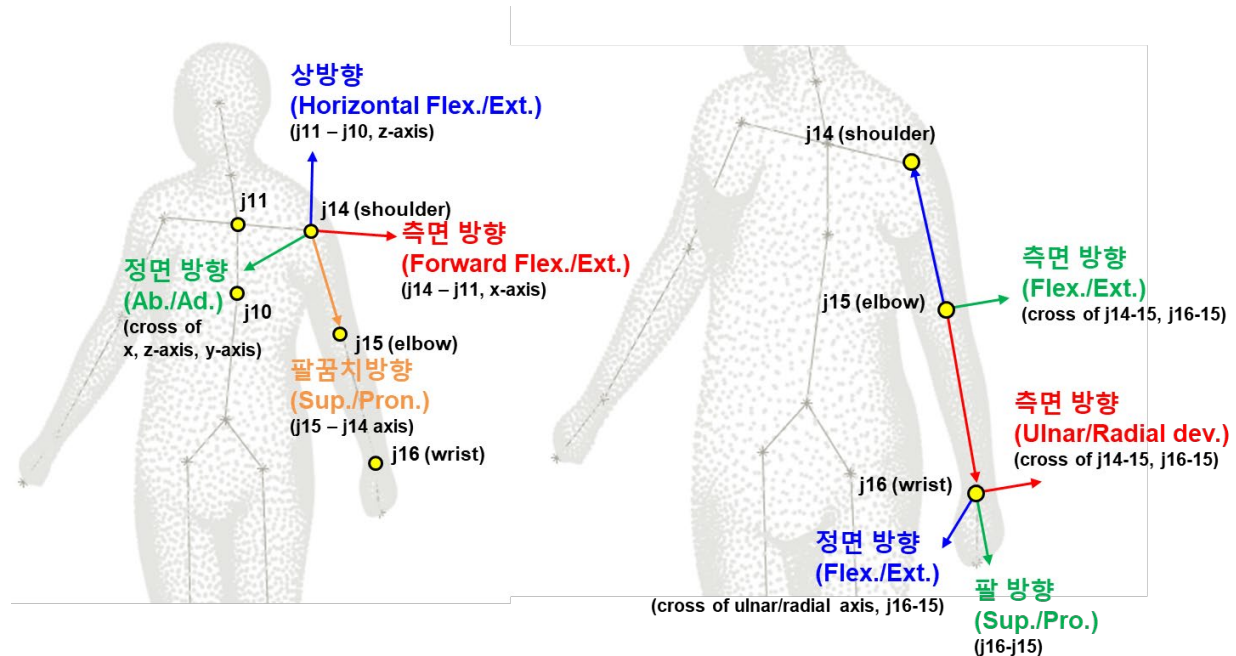
- Body template model의 관절체 정렬은 (1) torso, (2) upper arm, femur, (3) lower arm, tibia 순으로 수행됨
- Hand template model은 (1) palm, (2) finger root (MCP joint), (3) finger segments (PIP, DIP joint) 순으로 수행됨

Body Template 관절체 정렬 순서

① Torso 정렬



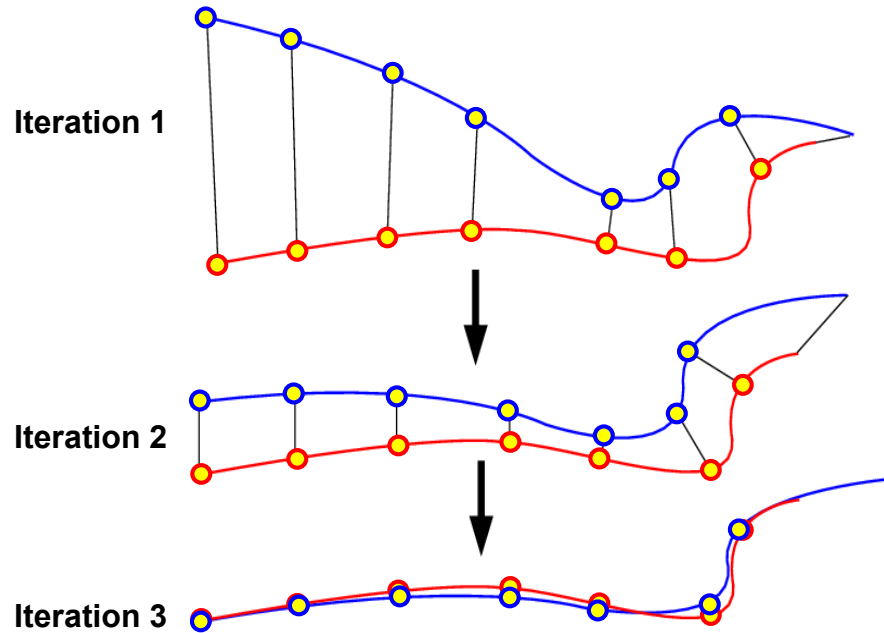
Body Template 관절 회전축 구성 예시



S2-5. 미세 정렬 (non-rigid ICP Registration)

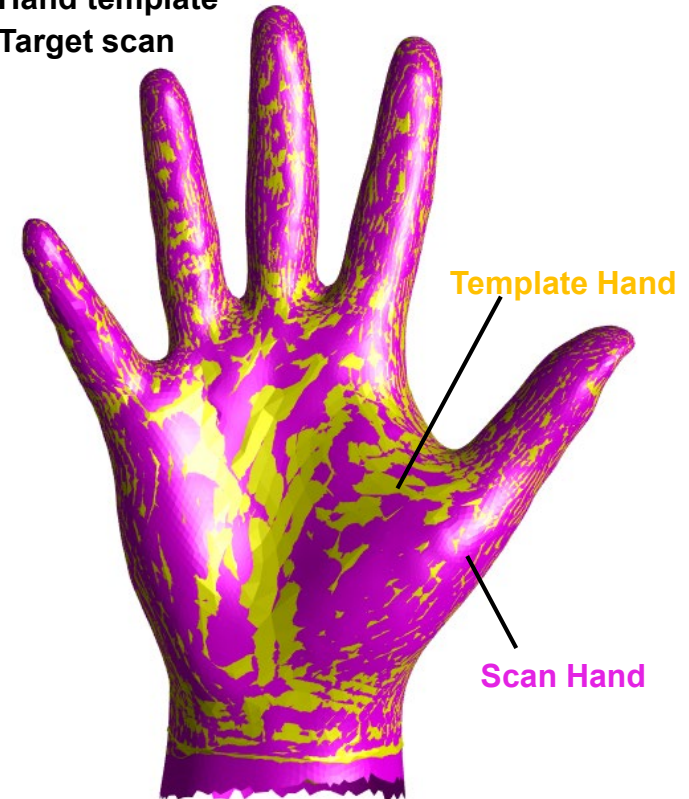
- 자세가 정렬된 template model은 non-rigid ICP 정렬 방법을 이용하여 scan data에 미세 정렬됨

Non-rigid Iterative Closest Point (ICP) registration

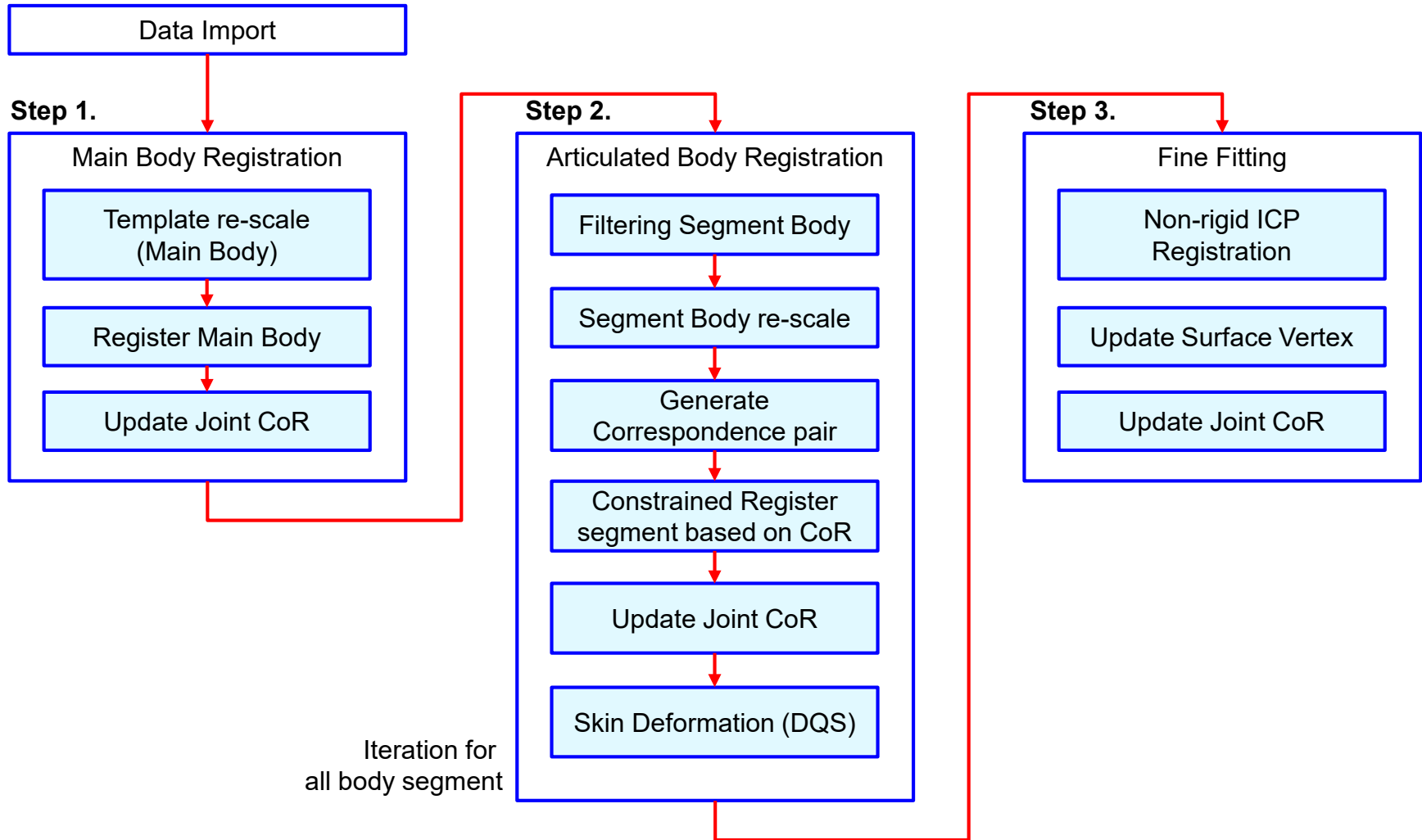


ICP registration 결과 예시

- : Hand template
- : Target scan

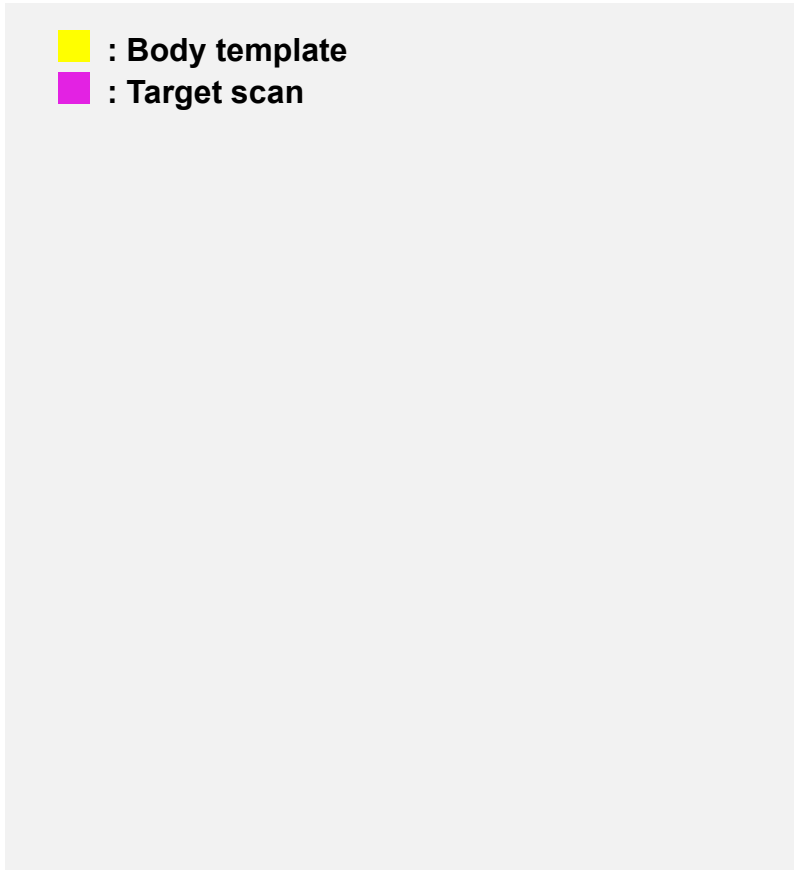


S3. Template Registration Algorithm

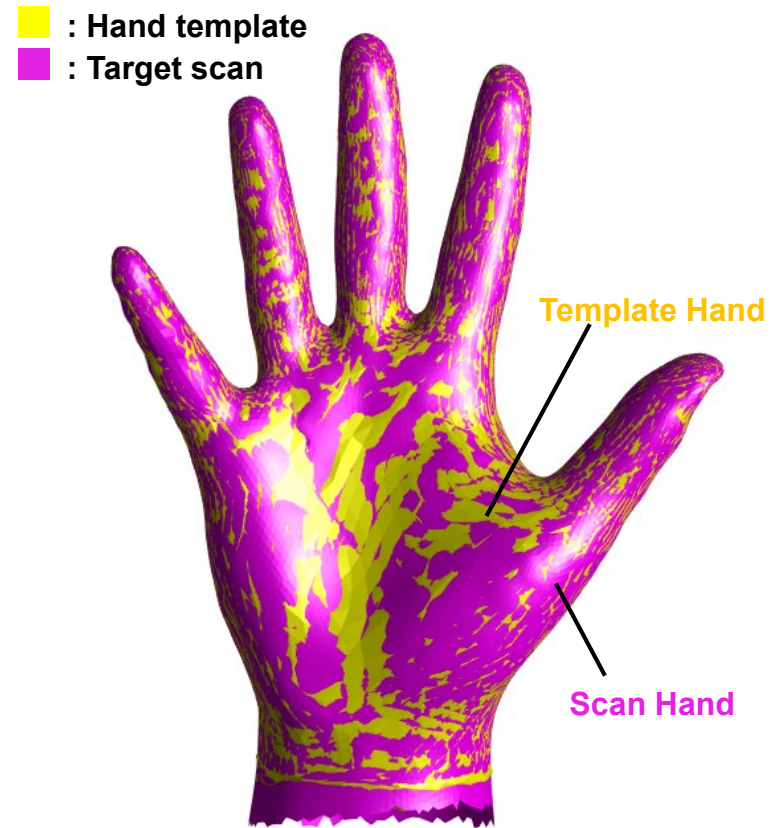


S4. Template Registration 결과: Performance

□ 정렬된 template model과 scan data 사이 거리는 0.6 ~ 0.9 mm (RMS) 로 파악됨



Body Template Registration 결과: 0.89 mm
정렬 시간: 39.4 sec.



Hand Template Registration 결과: 0.63 mm (RMS)
정렬 시간: 22.5 sec.

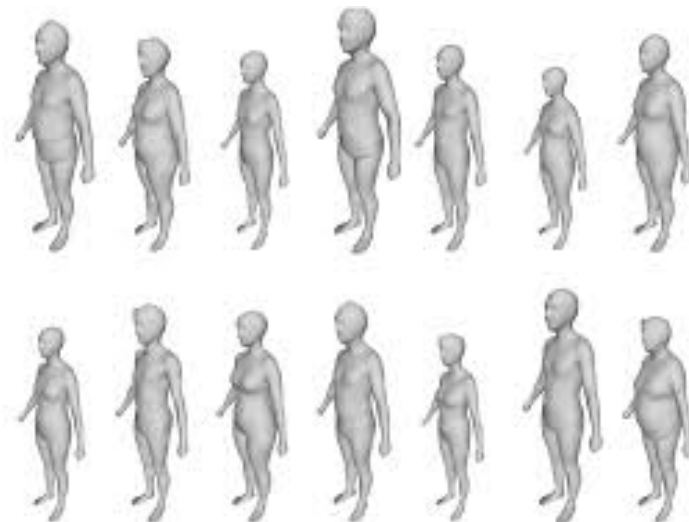
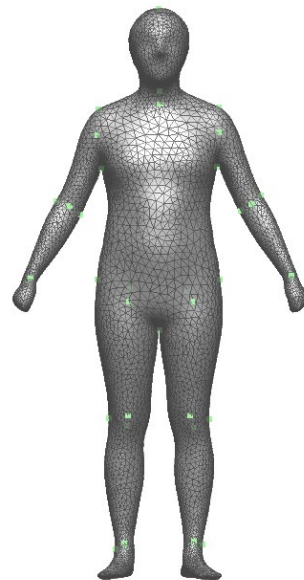
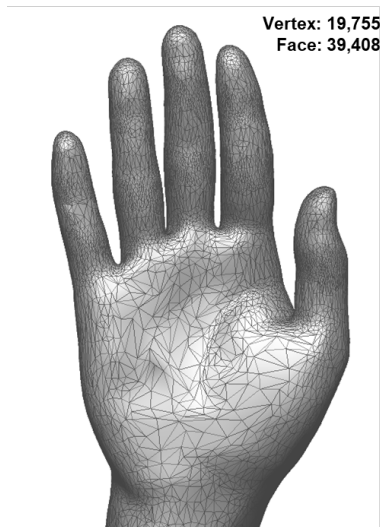
Discussion (1/3)

□ 한국인 인체 특성을 고려한 **deformable human template model 개발**

- 한국인 평균 형상(50th %ile)을 이용한 body, hand template model 개발
- 한국인의 세부 관절 치수 특성 적용

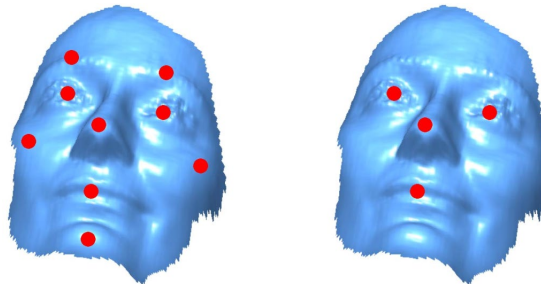
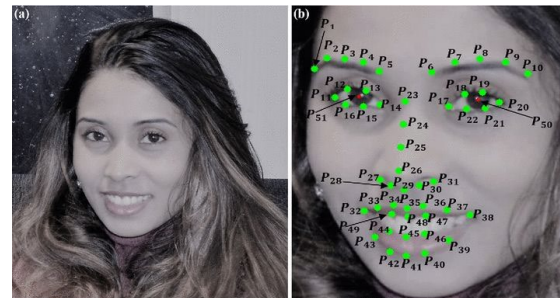
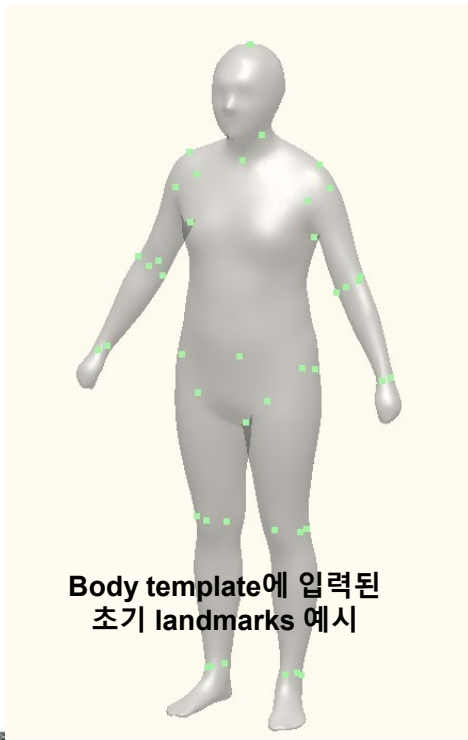
□ 한국인 인체 형상 학습을 위한 **template model registration 방법** 개발

- 정렬 후 template model의 고유 구조로 인체 형상 기계 학습 적용 가능
- 대용량 한국인 인체 형상 data 학습 후 한국인 인체 형상 분포 분석

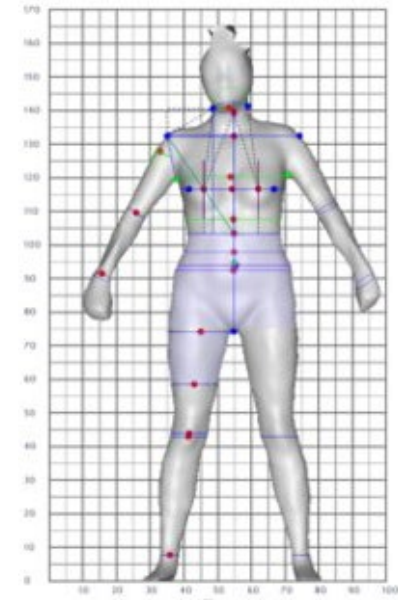


Discussion (2/3)

- 다수의 한국인 전신, 손 scan data에 정렬하며 개발된 기술의 성능(처리 속도, 정확도) 개선 및 검증 필요
- 본 연구에서는 세부 인체 부위 치수 조정 시 기 입력 landmark(20~30개)를 활용, 추후 CNN, RNN 등의 AI technique을 적용하여 automatic detection 적용 필요



(c) Candidate landmark points
(d) Final landmark points
Automatic landmark detection 예시 (Mehryar et al. 2010)



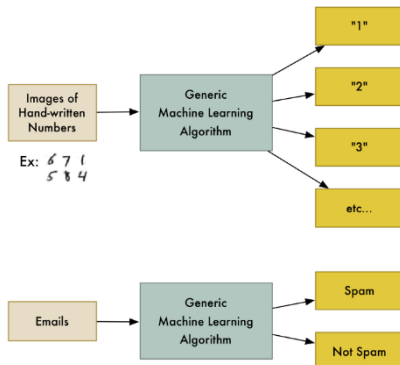
Body landmark identification 예시 (Braganca et al. 2008)

Discussion (3/3)

□ Fine fitting 단계 이후 **CoR 변환에 대한 추가 기술 개발 필요**

- Template vertices와 joint CoR의 관계에 기반한 **추정 모델 개발 필요**
 1. **Machine Learning**: surface points 및 CoR 학습 \Rightarrow 변환된 surface points로 CoR 추정
 2. **Coherent Point Drift (CPD)**: surface points와 일관되도록 정렬하며 CoR 변환
 3. **Bounded Biharmonic Weights (BBW)**: CoR을 control points로 registration 적용
 4. **Linear Regression**: template 상의 특정점을 선정하여 CoR을 추정하는 식 개발

Machine Learning (Supervised)

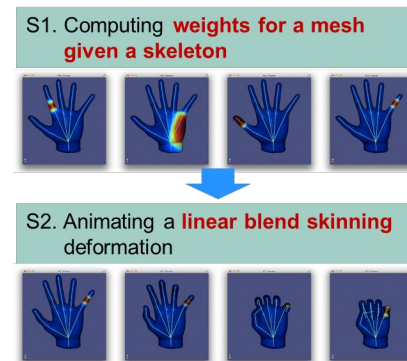


CPD registration

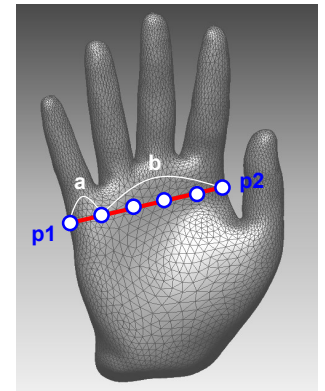


CPD registration:
Shape registration;
All data points move coherently

BBW registration



Regression method



Q & A

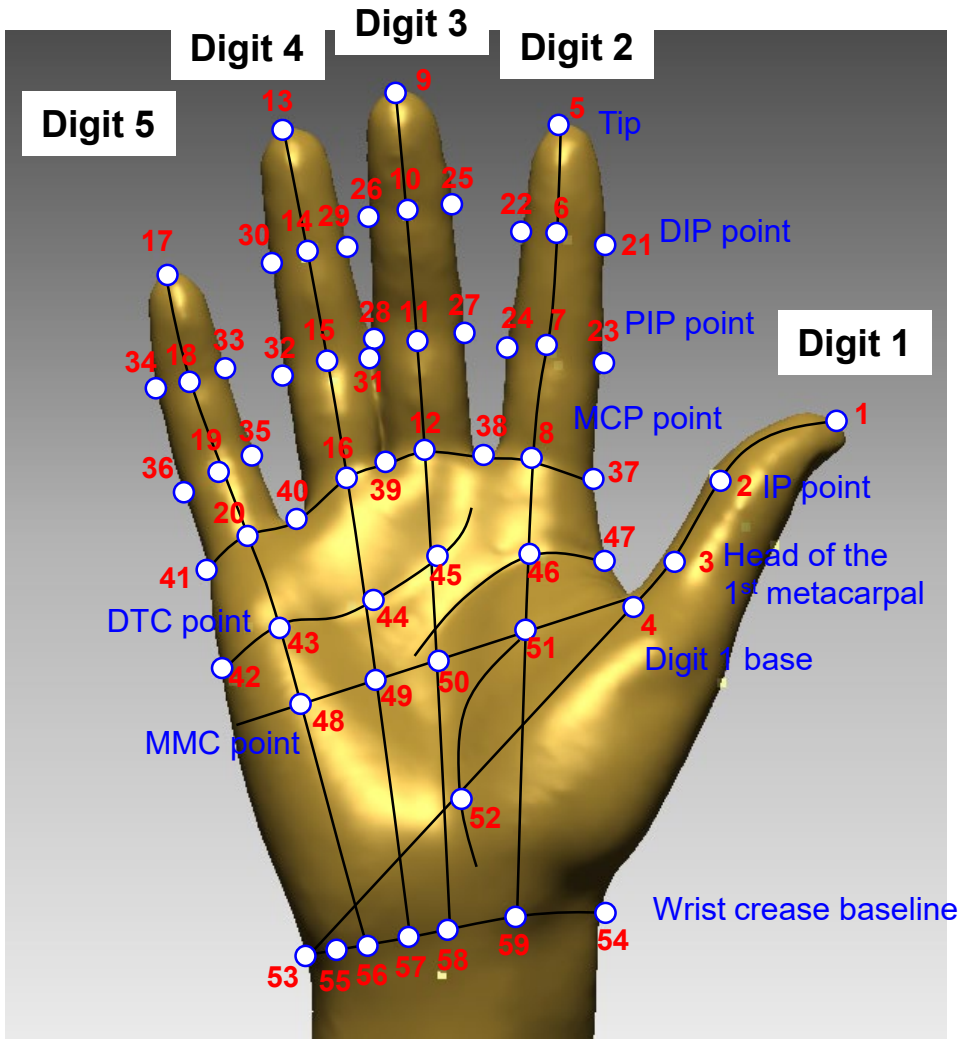
경청해 주셔서 감사합니다. ☺



본 연구는 한국연구재단의 중견연구자 지원사업(NRF-2018R1A2A2A05023299)과 산업통상자원부의 미래첨단 사용자편의서비스 기반조성사업(R0004840, 2020)의 지원을 받아 수행되었습니다.

HTM 개발: Hand Landmark (2/3)

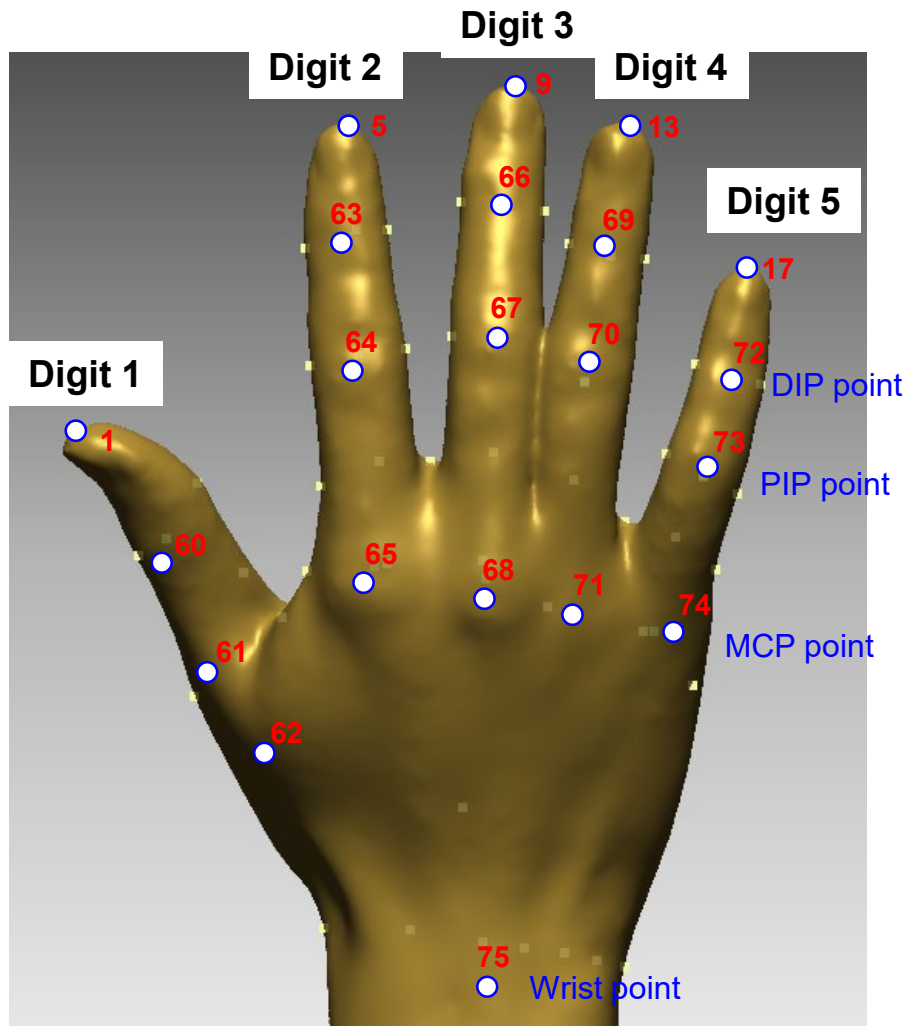
손바닥 부위의 주요 landmark 59개 선정



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)

Template Registration 문헌 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 Registration 문헌 검색 결과

S1. **Keywords 조합**을 통한 journal paper 검색

Title-abs-key를 이용하여 검색

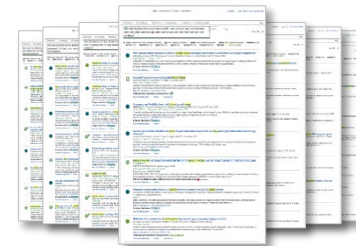
유관 분야로 검색 제한함

(예: computer graphics, ergonomics)

85 건



S2. **Title screening**을 통한 1차 선별



36 건



S3. **Abstract screening**을 통한 2차 선별



33 건



S4. 관련도에 따라 **최종 review 대상 논문** 선별

상: 11건

중: 2건

13 건

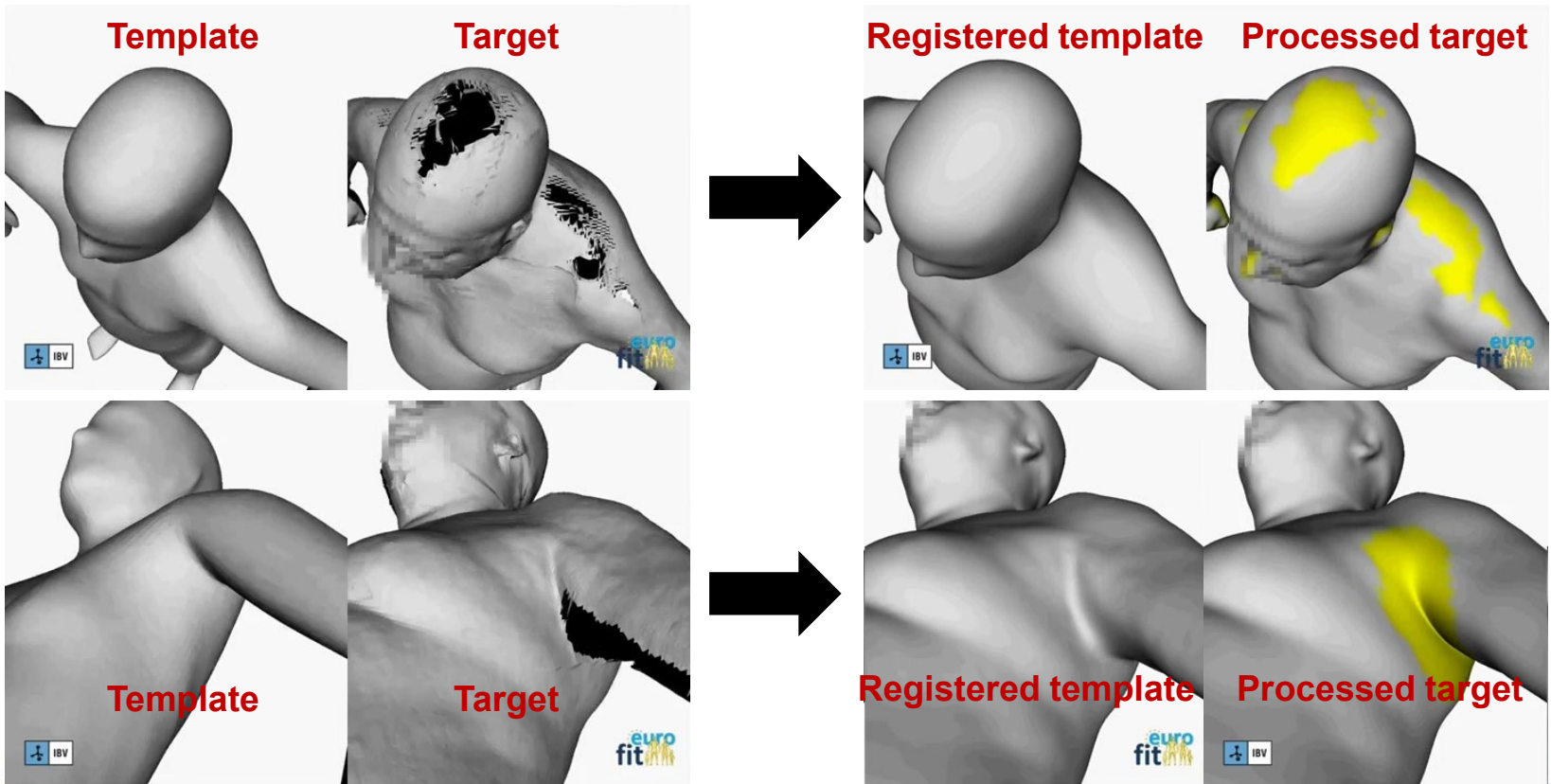
Template Registration Paper List

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

HTM Application: Template Registration (1/3)

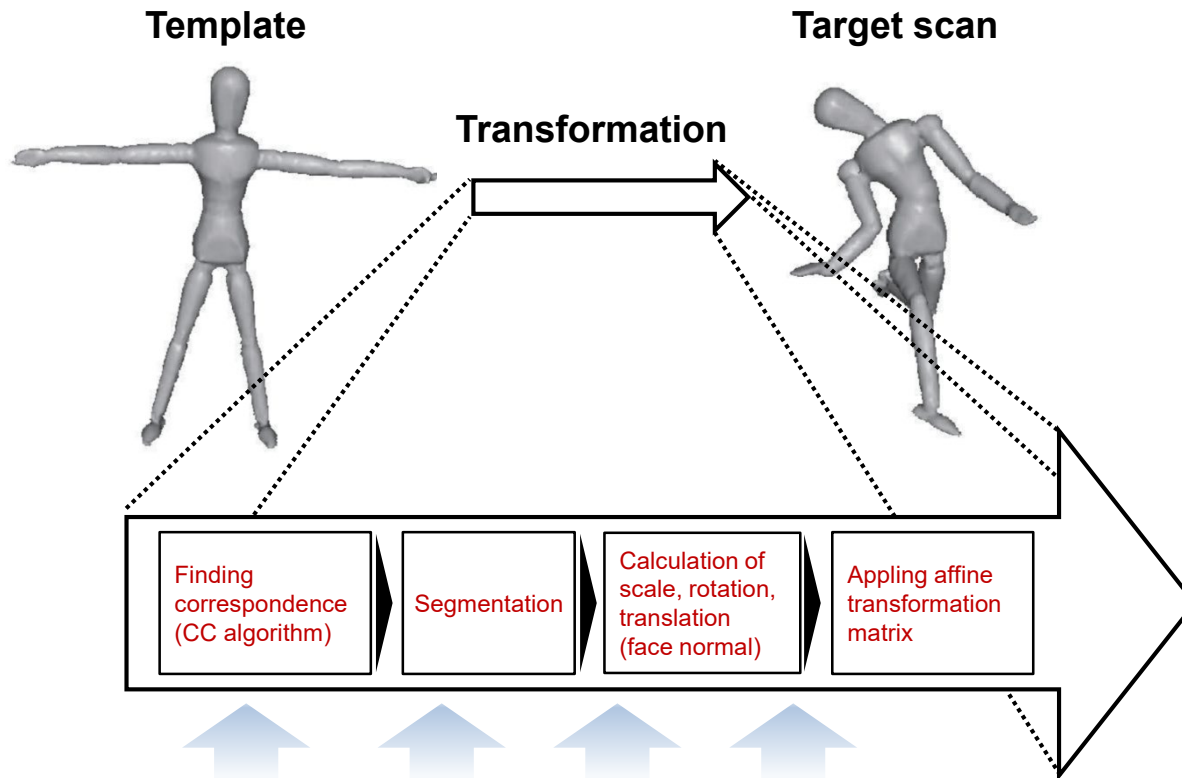
- 표준 자세(standing posture)로 측정된 3D body scan에 Template Model을 정렬
- Template registration 방법은 기존 3D scan 시 획득이 어려운 **접힘부 등의 missing part**에 대하여 기존 인체 **database**를 이용한 보강 시 유용함

Human Body Template Model을 이용한 형상 보강 예



HTM Application: Template Registration (2/3)

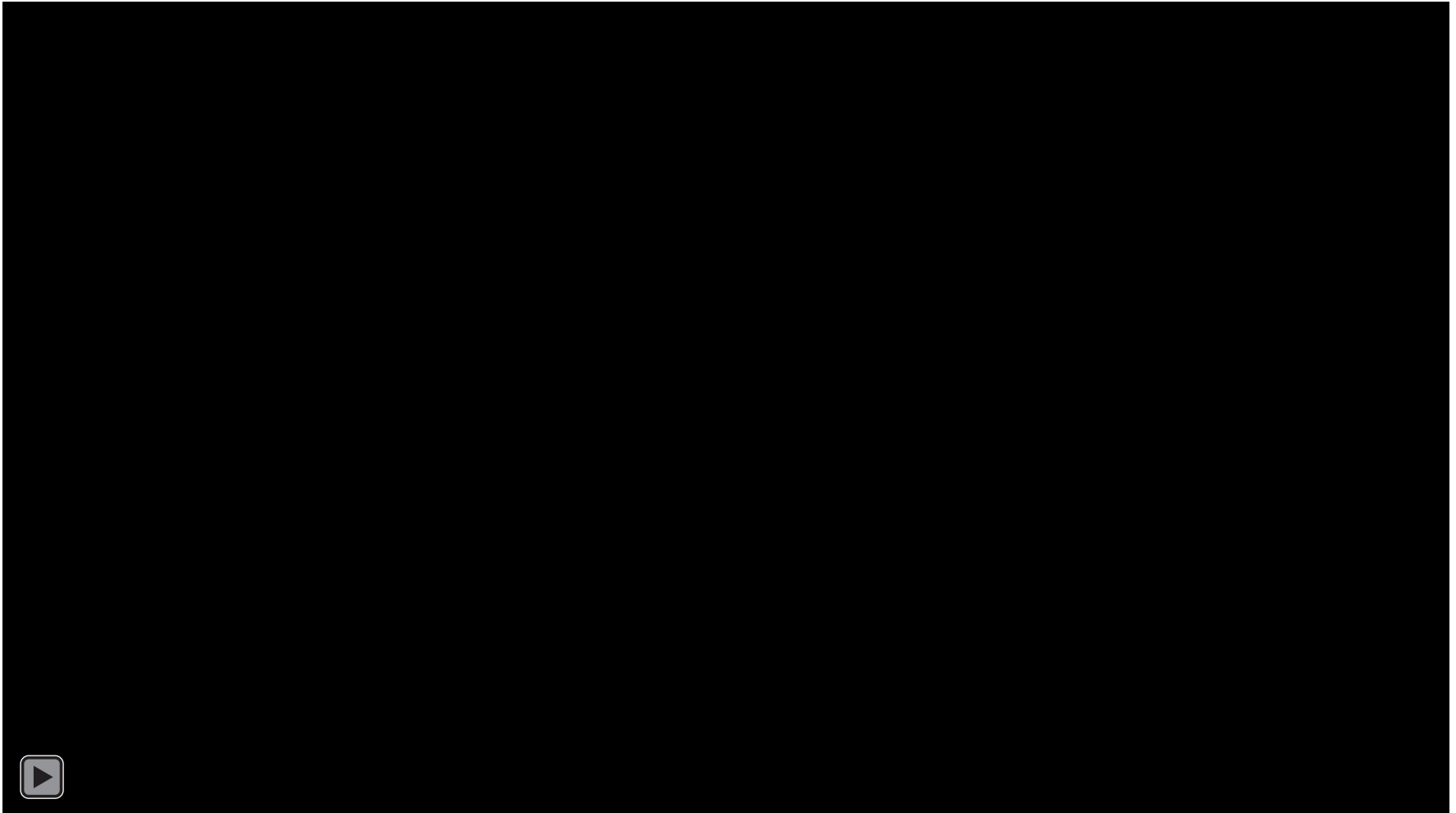
- ❑ Template의 vertex i 와 target scan의 vertex j 의 mapping 및 transform 문제
- ❑ Mapping 시 CC algorithm 적용, transform 시 affine transformation 적용



- **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)

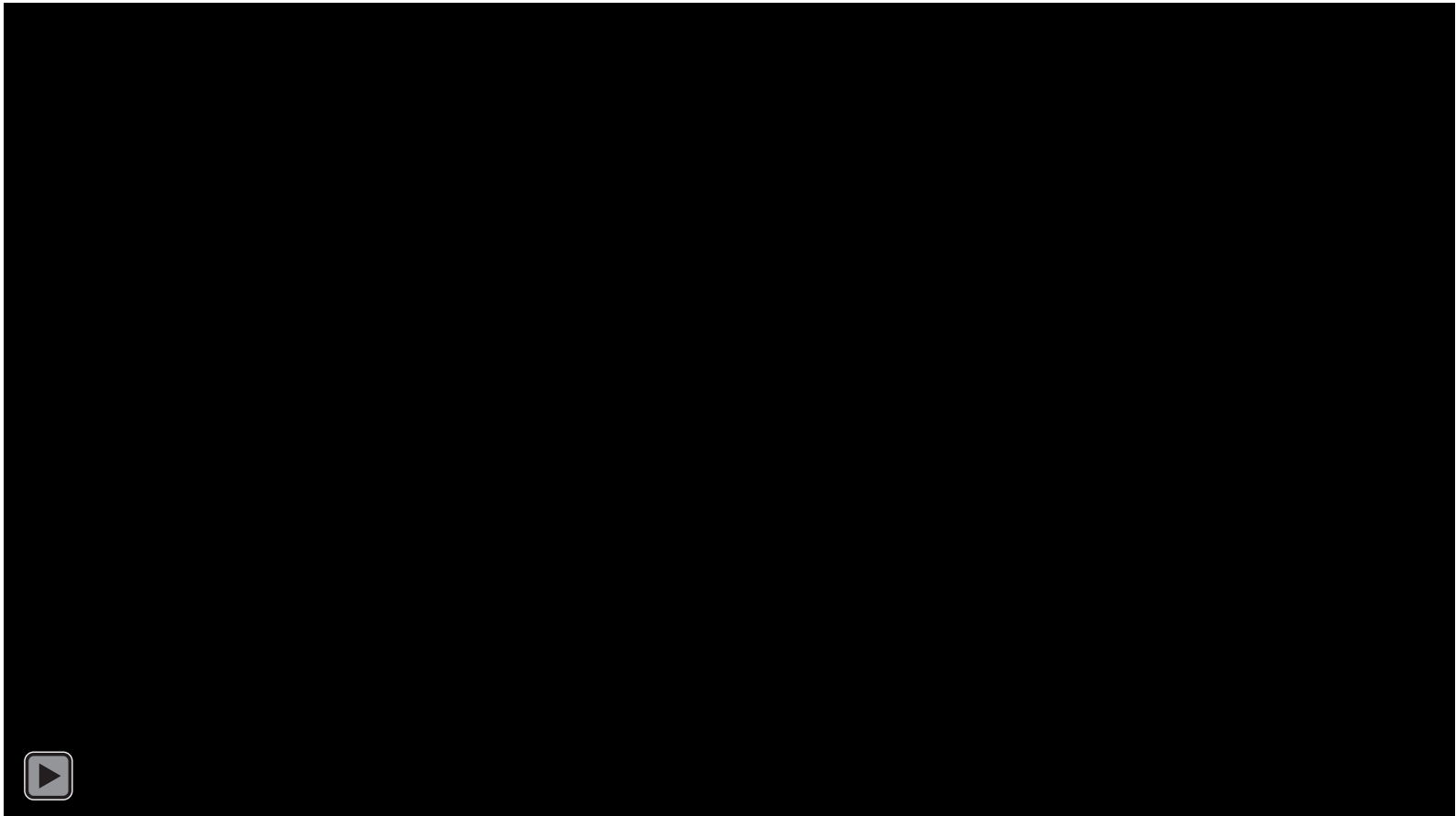
Template Registration (IBV, Spain): Video

Posing of Template \Rightarrow **Pre-processing** of Body Scan \Rightarrow **Fitting** of Template to Body Scan



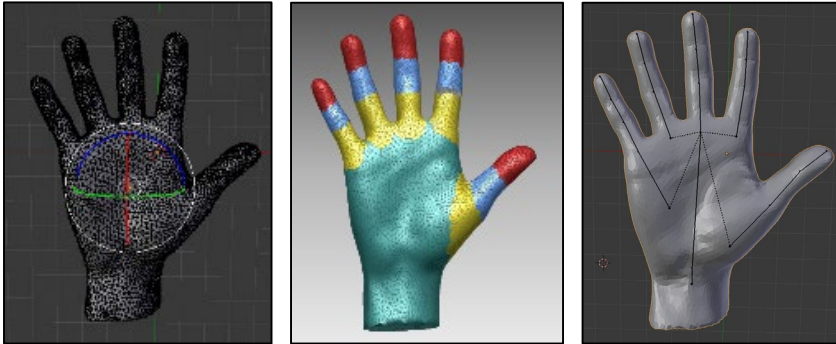
Template Registration (Hao Li): Video

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



HTM Application: Posture Control 적용 예 (Implicit Skinning)

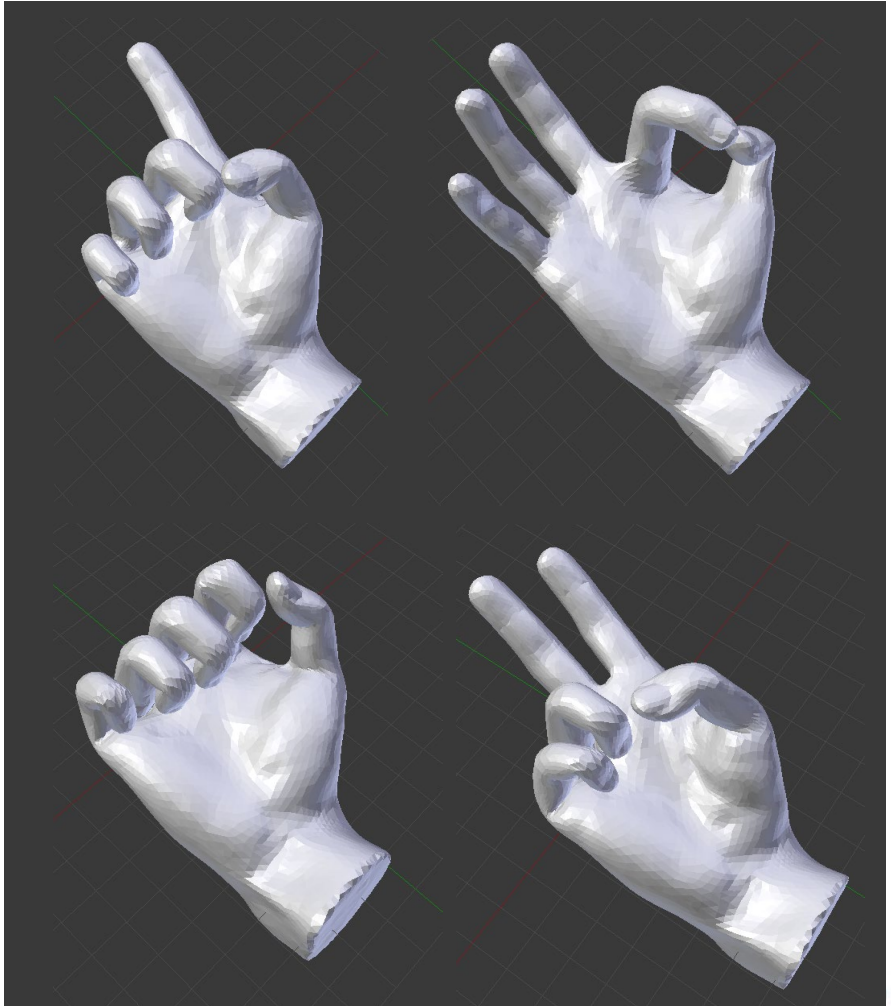
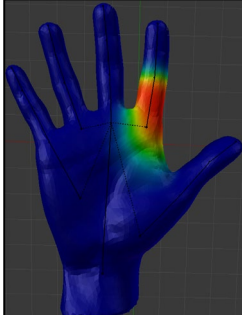
- 중립 자세의 hand template에 **implicit skinning** 방법을 적용하여 자연스러운 변형이 적용된 손 자세 도출



	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	0
3	0	0	0	0.084782	0.914681	0	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	0
5	0	0	0	0.722384	0.269977	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0.057907	0.731907	0.176847	0	0.008072	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0.211347	0.787342	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0.823375	0.165023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.880217	0.070066	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0.826396	0	0	0	0.095995	0	0	0.016578	0	0	0	0	0	0	0	0	0	0	0
11	0.8864012	0	0	0	0.032736	0	0	0.016931	0	0	0.019149	0	0	0	0	0	0	0	0
12	0.841049	0	0	0	0	0	0	0.033861	0	0	0.09145	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0.40074	0.594672	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0.807075	0.179067	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0.887548	0.107986	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0.807793	0.186725	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0.618889	0.378106	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0.146477	0.852736	0	0	0	0	0	0	0	0	0
19	0.500819	0	0	0	0.339226	0	0	0.142091	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0.105464	0.878444	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0.95064	0.041161	0	0	0	0	0	0	0	0
22	0.009079	0	0	0	0	0	0	0	0	0.894658	0	0	0.039807	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0.321645	0.673262	0	0	0	0	0	0	0	0

```

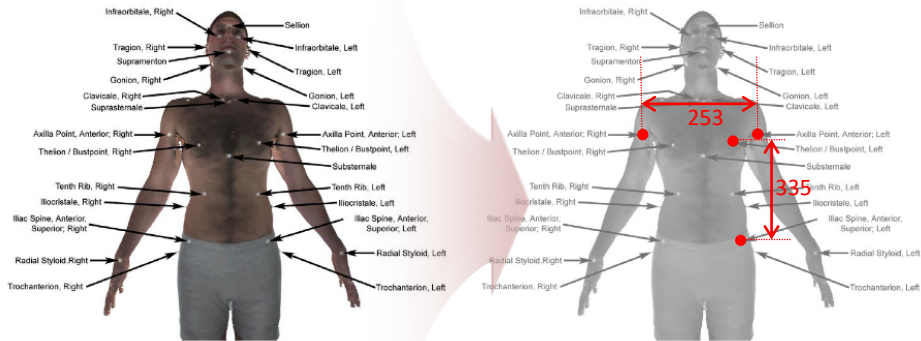
1 # Blender script to export the skinning weights in csv
2 import bpy
3
4 vertices = bpy.data.objects["hand"].data.vertices
5 group_names = [g.name for g in bpy.data.objects["hand"].vertex_groups]
6 bones_count = len(group_names)
7
8 file = open("zc_weights_1.csv", "w")
9 str = ",".join([name for name in group_names])
10 file.write(str + "\n")
11
12 for v in vertices:
13     weights = [0 for i in range(bones_count)]
14     for g in v.groups:
15         weights[g.group] = g.weight
16     #str1 = ",".join(["%.6f" % co for co in v.co])
17     str2 = ",".join(["%.6f" % w for w in weights])
18     file.write(str2 + "\n")
19 file.close()
    
```



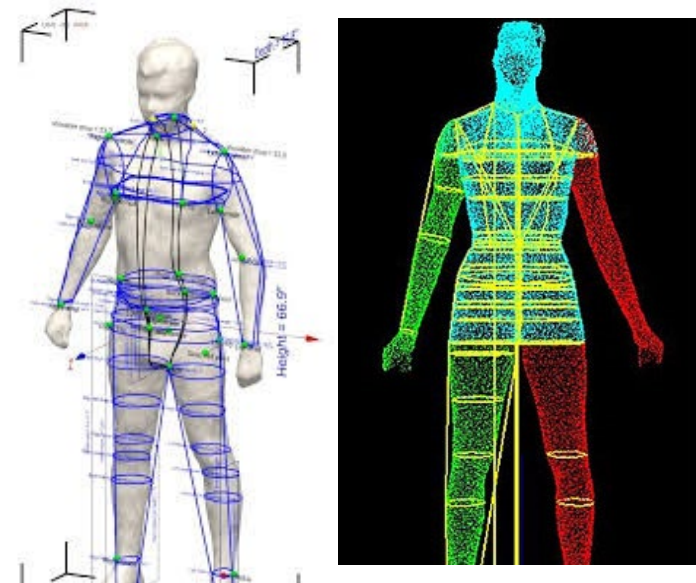
HTM Application: Automatic Anthropometry

- HTM 상에 기존에 정의된 landmark에 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 정렬되어 변형된 HBTM 상의 landmark를 활용하여 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

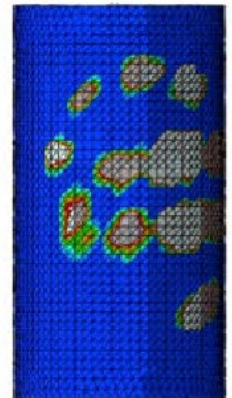
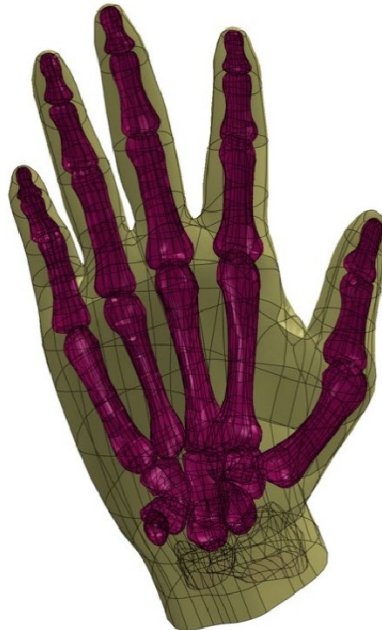
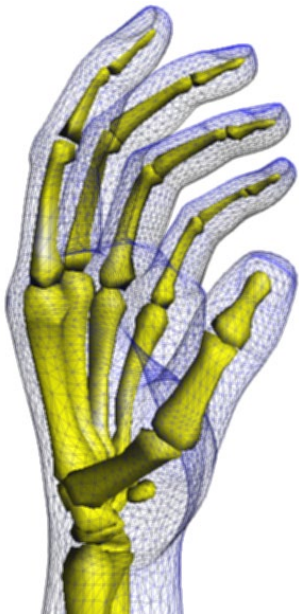
유한 요소 인체 모델(Hand Model) 개발 예시

Pressure estimation 예시

James et al. (2012)

Harih and Tada (2016)

Harih et al. (2017)



HTM Application: Product Design

- **Template model의 치수 및 형상 정보를 제품 설계 인자(design dimension)와 연동하면** 사용자의 인체 크기 및 형상에 따른 **맞춤형 제품 형상 설계 시 효율적으로 활용 가능함**

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

