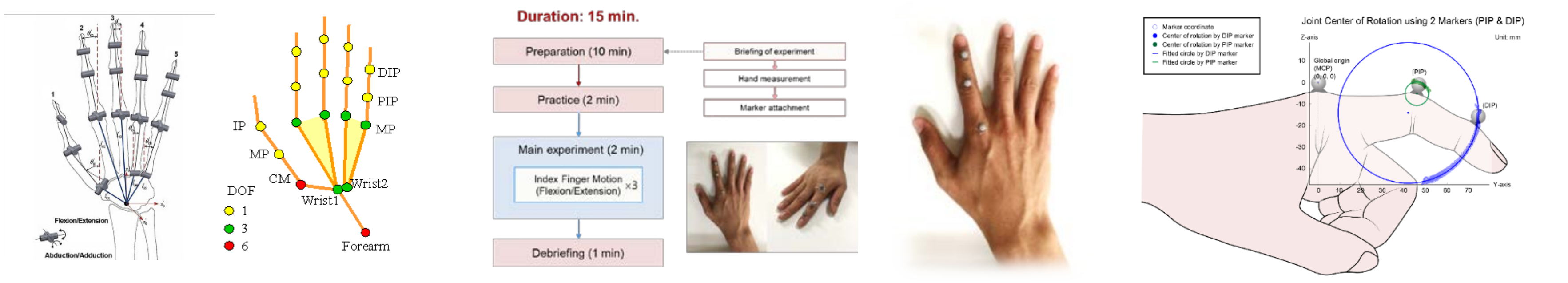
인접 마커 궤적을 이용한 손가락 관절 회전 중심 추정 방법



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2017 추계학술대회

Global Contributor to Eco-Techno-Humanopia

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포항공과대학교
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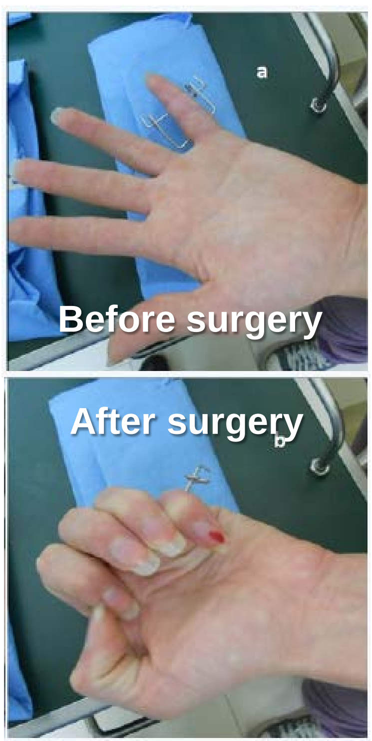
Ergonomic Design Technology Lab

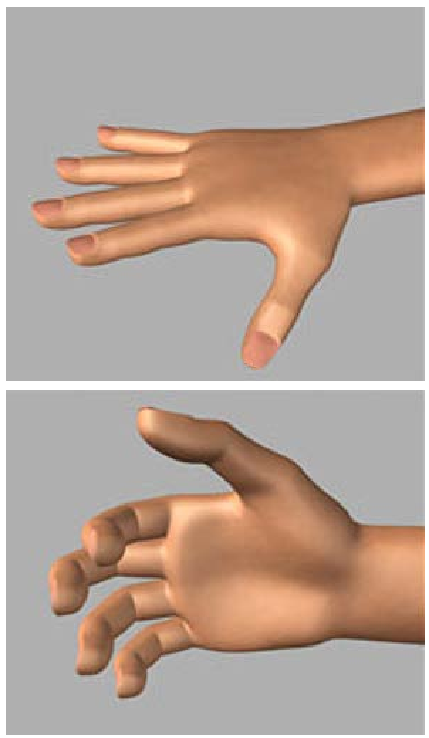
Digital Human Hand Modeling & 적용 분야

- Digital human hand modeling은 hand links 및 surface meshes로 구성되며 human hand simulation에 활용됨
- DHHM 적용 분야: 의료용 평가, hand animation, 인체측정, 인간공학적 제품설계

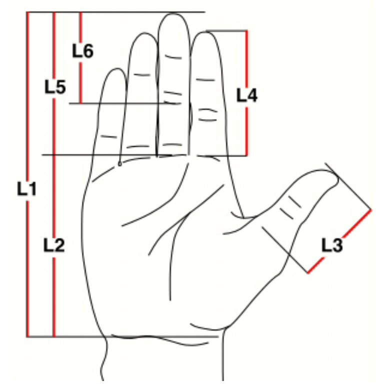
Clinical assessment



Hand animation



Hand anthropometry



Measured Items	Mean (SD) in mm		p-value
Hand length	D	169.21 ± 7.30	0.182
	I	168.93 ± 4.36	
Index finger Length	D	65.32 ± 3.61	0.655
	I	64.90 ± 1.61	
Medius finger length	D	72.75 ± 3.59	0.846
	I	72.54 ± 1.57	
Ring finger length	D	68.01 ± 3.88	0.246
	I	68.05 ± 2.14	
Little finger length	D	53.63 ± 3.98	0.54
	I	53.13 ± 1.28	
Palm length perpendicular	D	97.05 ± 5.09	0.854
	I	97.02 ± 3.15	
Hand breadth with thumb	D	76.91 ± 3.69	0.68
	I	75.84 ± 2.54	
Hand breadth with wrist	D	52.08 ± 3.16	0.15
	I	51.87 ± 2.58	
Hand thickness	D	26.29 ± 2.15	0.14
	I	26.14 ± 1.24	
Hand circumference	D	177.73 ± 9.0	0.94
	I	1776.24 ± 2.1	

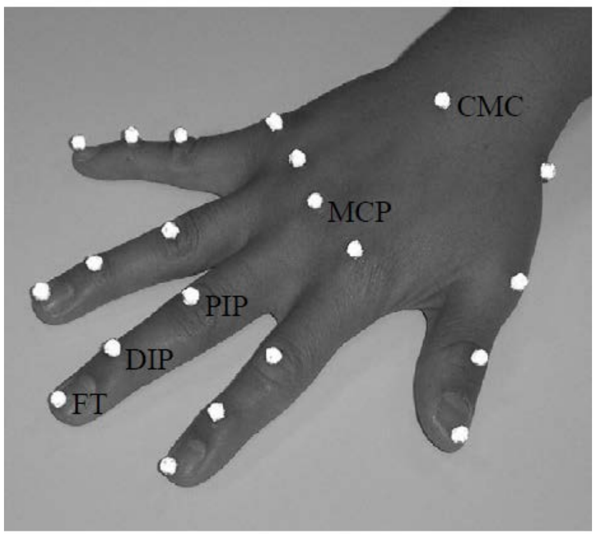
D: Direct measurement method, I: Indirect measurement method.

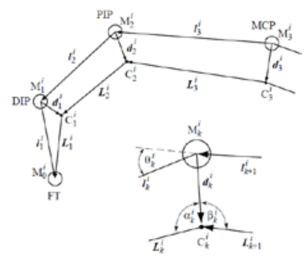
Ergonomic design

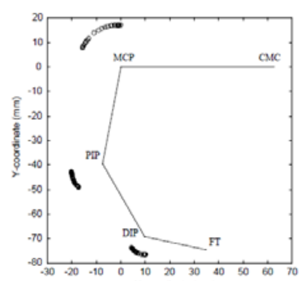
Hand Link Model 구축 방법

- 다양한 hand posture의 구현을 위해 Hand link model 생성 필요
- Hand link model 생성 시, hand joint center of rotation (COR)이 정확하게 정의되어야 함
- Hand joint COR 추정 기존 방법: Surface-based & Skeleton-based

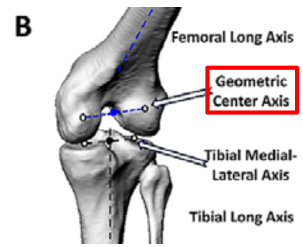
Surface-based hand joint COR estimation
(Zhang et al., 2003)



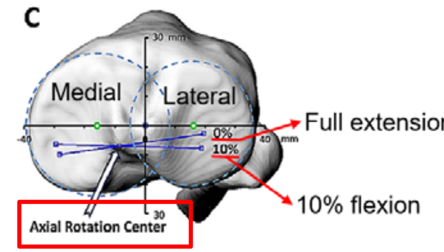




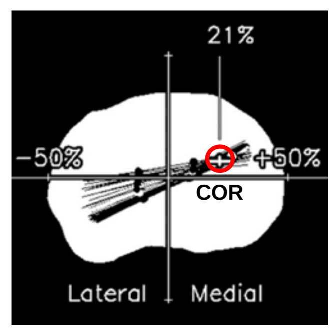
Skeleton-based hand joint COR estimation
(Yong Feng et al., 2015)

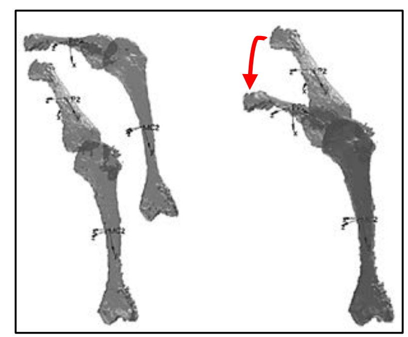


(Yamaguchi et al., 2008)



(Stillfried et al., 2010)





기존 Hand Joint COR 추정 방법의 한계

- Surface-based methods
  - ✓ High computation complexity and cost due to a lot of variables and large search ranges
  - ✓ Initial guess of COR locations
- Skeleton-based method
  - ✓ Time cost for MRI scanning (4 min for scanning a static hand posture, Stillfried et al., 2010)
  - ✓ Limited frame rate for hand motion

Complex computation

Zhang et al. (2003),
Complex computation to search ranges due to a lot of variables

The optimization routine minimizes the variation of internal link lengths over the entire movement (including both flexion and extension):

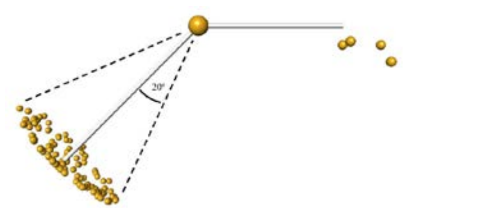
$$J^i = \sum_{k=1}^{3}\left\{\sum_{t=1}^{T}\left(\left|\boldsymbol{L}_k^i\right| - \left|\boldsymbol{l}_k^i(t) + \boldsymbol{d}_{k-1}^i(t) - \boldsymbol{d}_k^i(t)\right|\right)^2\right\} \quad (i = 2, \ldots, 5). \qquad (5)$$

Initial guess

Ehrig et al. (2006),
Require an initial guess of the joint COR from the true center

$$f_{\mathrm{geom}}(c, r_1, \ldots, r_m) = \sum_{j=1}^{m}\sum_{i=1}^{n}(\|p_{ij} - c\| - r_j)^2,$$

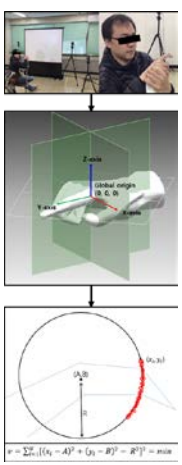
that the radii r_j in (1) can be computed directly as $r_j = (1/n)\sum_{i=1}^{n}\|p_{ij} - c\|$. Since at least an initial guess for c is required, other modified least-squares criterion methods have been proposed that do not require a starting estimate, originally by Delonge (1972) and Kåsa (1976):

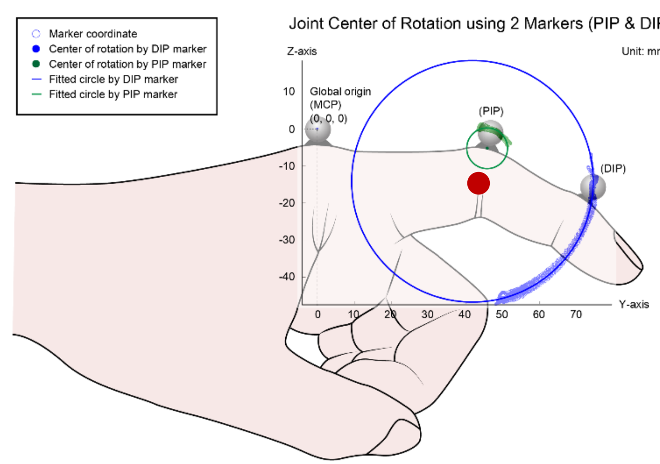


연구 목표

인접 Surface Marker 동작을 이용한 Hand joint COR (Center of Rotation) 추정

1. Circle fitting method를 이용하여 원위지절간관절 마커 동작을 이용한 근위지절간관절(proximal phalangeal (PIP) joint) 회전 중심(COR) 도출
2. 추정된 근위지절긴관절 회전 중심 (PIP joint COR) 검증

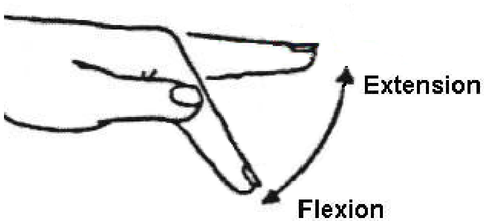




실험 절차

- 3단계: 실험 준비, 본 실험, and 사후 설문

Duration: 15 min.



Preparation (10 min)
↓
Practice (2 min)
↓
Main experiment (2 min)
Index Finger Motion (Flexion/Extension) ×3
↓
Debriefing (1 min)

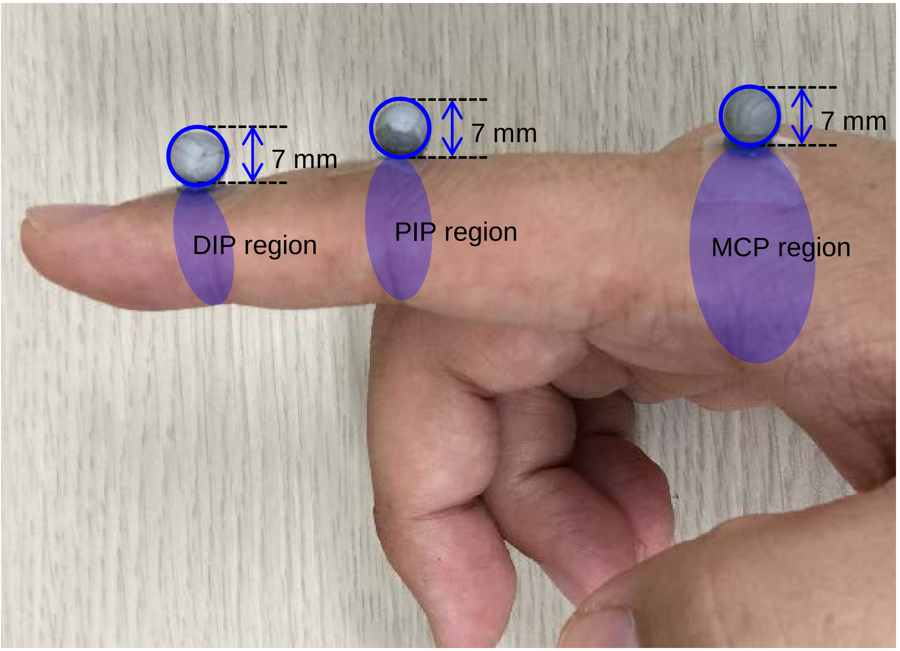
Preparation:
Briefing of experiment
↓
Hand size measurement
↓
Marker attachment

측정 장비

- 10 motion camera (Osprey, Motion Analysis Inc., USA)가 frequency of 60 Hz 로 손가락 굴곡 및 신전 운동(flexion and extension) 측정을 위해 사용됨
- 검지손가락 metacarpophalangeal (MCP), PIP, and DIP 관절 상단에 reflective marker (Ø = 7 mm)가 부착됨

Perspective view: experimental environment

Marker specification and adherence location



실험 참여자

- ❑ 다양한 손크기 그룹(small, medium, large)의 남성 실험참여자 3명이 모집됨
  - ✓ 근골격계 및 신경계 질환 경력이 없는 건강한 남성
- ❑ 손길이, 손너비, 검지손가락 두께(PIP joint 기준)가 caliper를 이용하여 측정됨

Unit: mm

Subject No.	Category	손길이	손너비	검지 손가락 두께
1	Small	168.5	77.6	15.2
2	Medium	181.1	82.4	15.4
3	Large	197.9	85.1	16.6
Mean		182.5	81.7	15.7
SD		14.7	3.8	0.8

- Small: 5^{th} %ile ~ 33^{th} %ile (153.0 mm ~ 180.0 mm) of Korean male (Size Korea, 2010)
- Medium: 34^{th} %ile ~ 66^{th} %ile (180.0 mm ~ 187.7 mm) of Korean male
- Large: 67^{th} %ile ~ 95^{th} %ile (187.7 mm ~ 198.3 mm) of Korean male

Task: Finger Motion

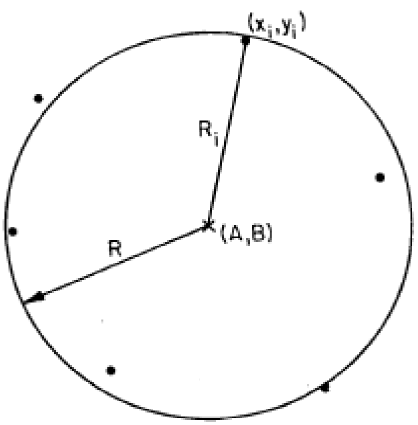
- 손가락 굴곡 및 신전 운동(flexion and extension motion of the PIP joint)

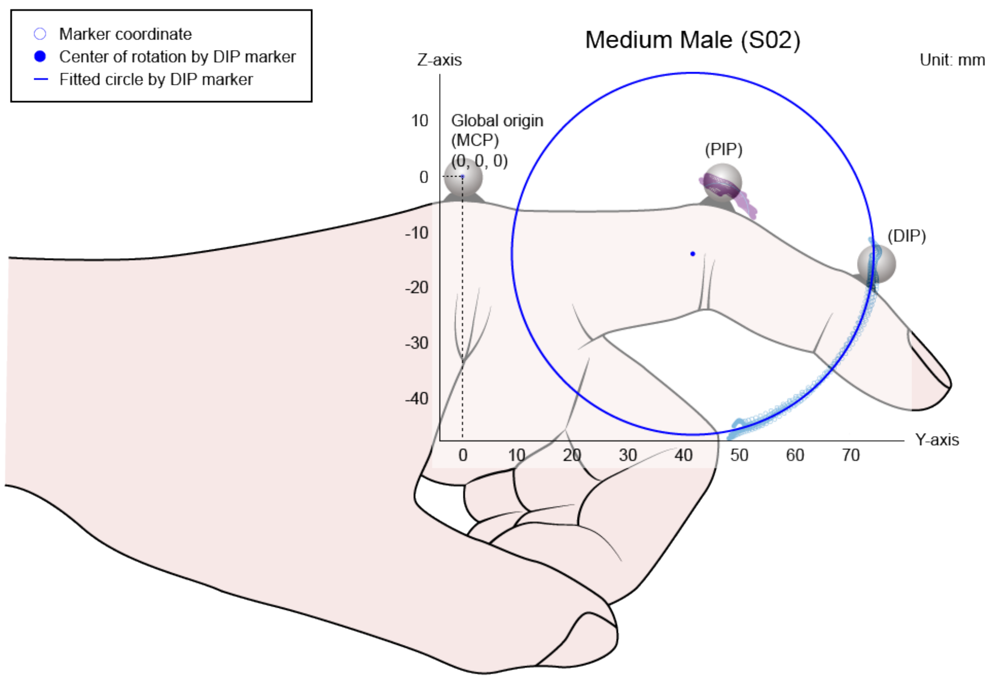
PIP Joint COR Estimation

- PIP 관절 회전중심은 circle fitting method와 DIP marker motion을 이용하여 추정됨
- The circle fitting method (Delonge-Kasa method, proposed by Kasa, 1976)
  - ✓ Fit a circle (center: (A, B); radius: *R*) over marker motion trajectory (x_i, y_i) by minimizing the least square error between the observed (R_i) and estimated (*R*) radii of the circle

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

$$\text{Where } R_i = (x_i - A)^2 + (y_i - B)^2$$



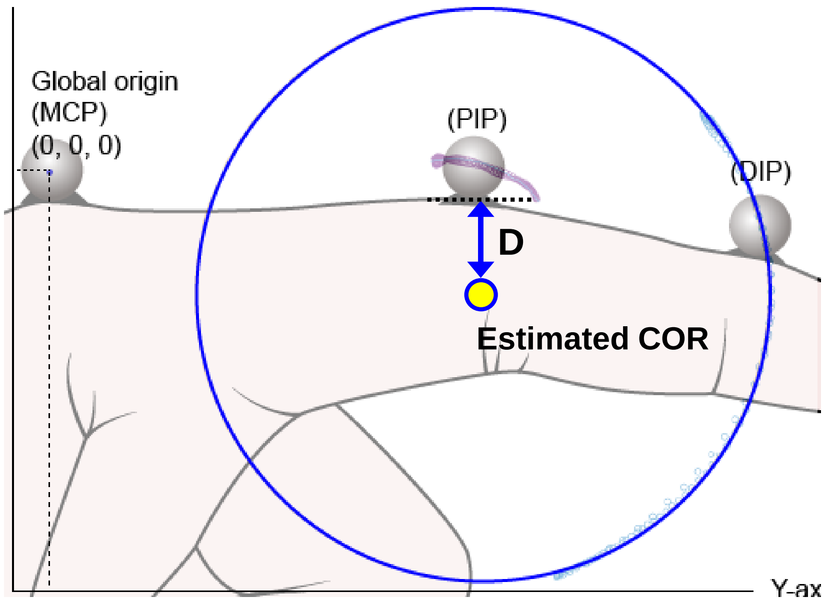


Results (1/2)

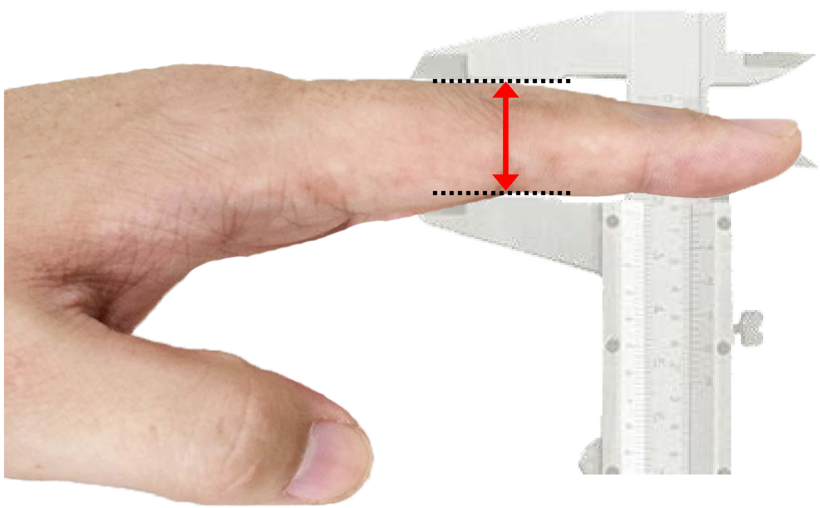
- PIP 관절 회전 중심 추정 결과는 marker 표면으로부터 관절 회전 중심 추정점까지의 거리와 PIP joint 두께를 비교하여 estimation error 측면에서 검증됨

Estimation error = D – ½ PIP joint depth

Distance from attaching point to estimated COR



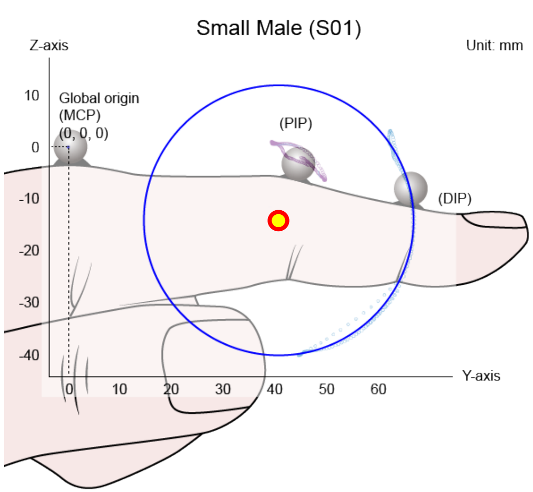
PIP joint depth (Reference)

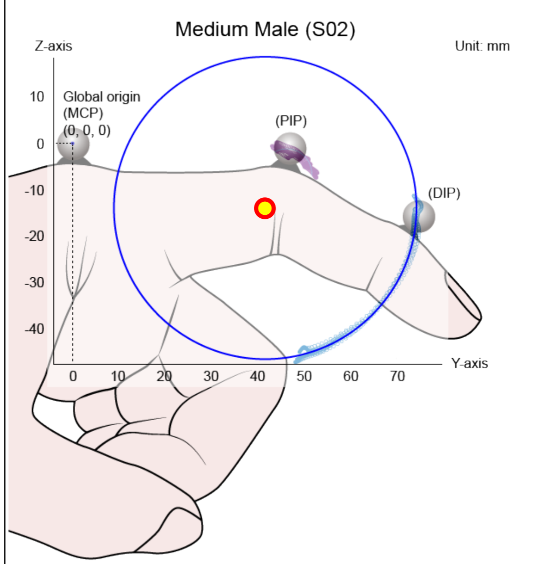


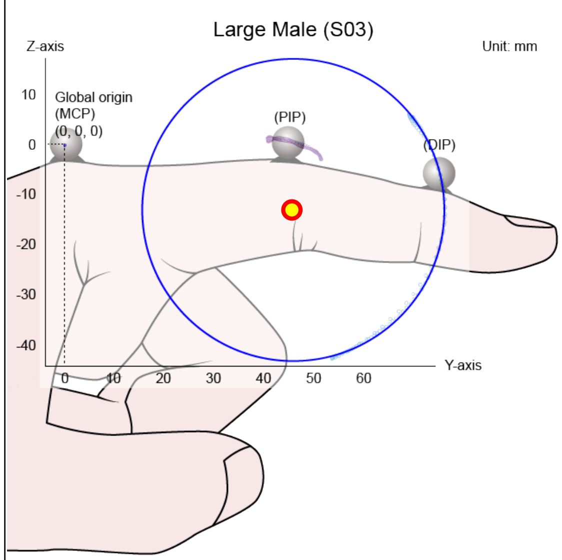
Results (2/2)

- 추정된 PIP 관절 회전 중심의 average error는 1.9 ± 0.6 mm로 파악됨
- 큰손이 작은손에 비해 average estimation error가 작은 경향을 보임

Average estimation error (mm)		
Subject 1 (Small hand)	Subject 2 (Medium hand)	Subject 3 (Large hand)
2.6	1.1	1.9

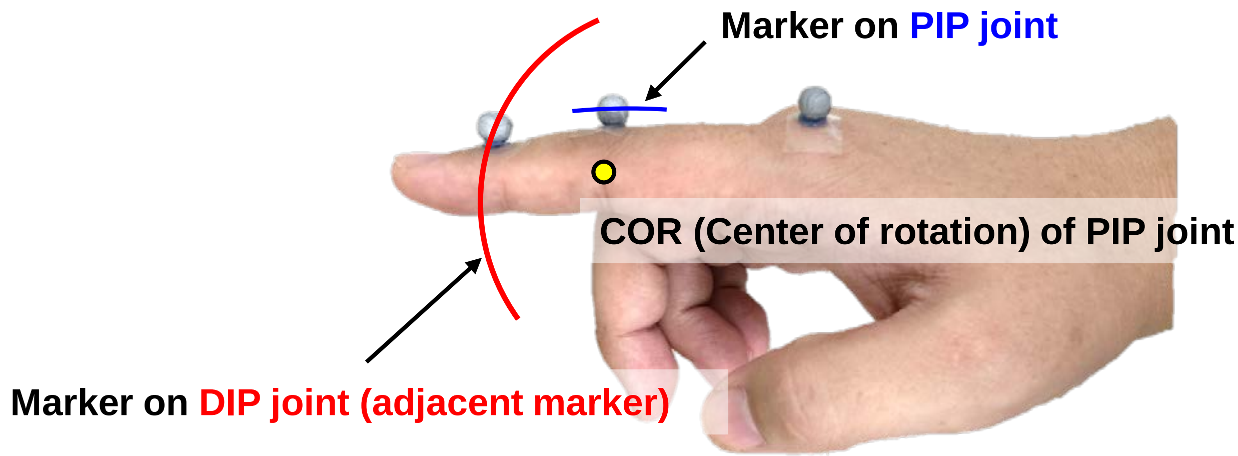






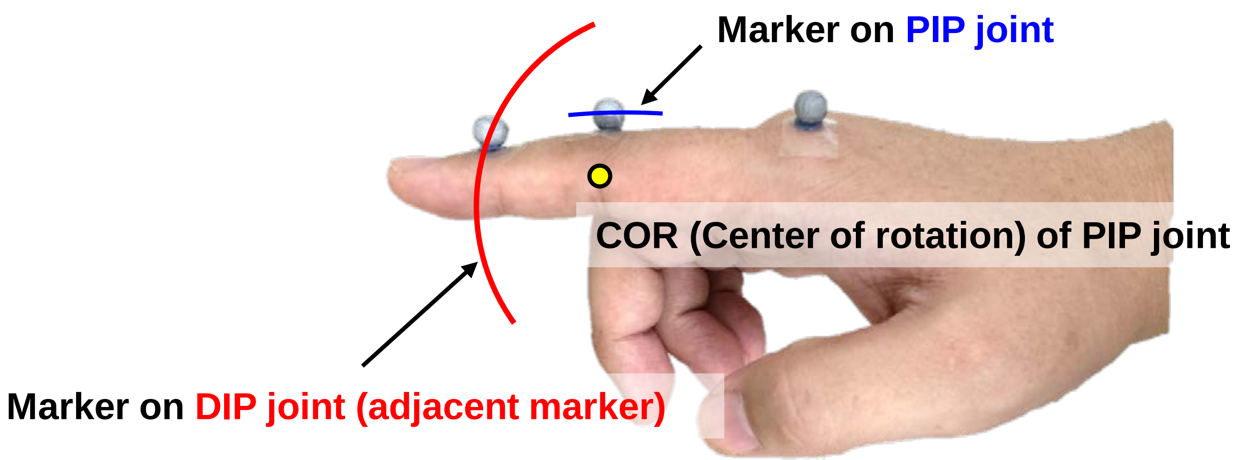
Discussion

- Estimation of PIP joint COR using DIP marker motion by the Delonge-Kasa method showed high accuracy in hand joint COR estimation (error = 1.9 ± 0.6 mm).
- Larger hands tended to show more accurate estimation of hand joint COR than small hand (accuracy improved by 0.7 to 1.5 mm).
- The Delonge-Kasa method does not require any complex computation or initial guess to estimate hand joint COR compared to existing studies.
- Estimation of PIP joint COR using DIP marker motion was preferred to using PIP marker motion since the Delonge-Kasa method requires a larger range of motion.



Discussion

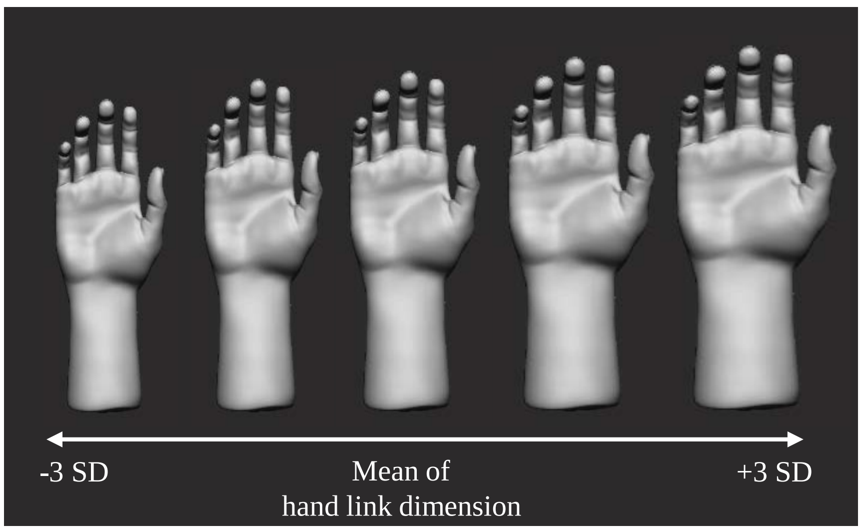
- Delonge-Kasa 방법 및 DIP marker motion을 적용한 PIP joint COR 추정 결과는 높은 정확도를 나타냄 (error = 1.9 ± 0.6 mm)
- 큰 크기의 손이 더 정확한 추정 결과를 유도하는 것으로 파악됨 (작은 손에 비해 정확도 0.7 mm ~ 1.5 mm 증가)
- The Delonge-Kasa method는 기존 연구와 비교하여 복잡한 연산이나 초기 값의 가정을 필요로 하지 않고 비교적 간단히 hand joint COR을 추정함
- PIP 관절 회전 중심 추정 시 PIP marker 보다 DIP marker 활용이 선호됨
  ⇒ Delonge-Kasa method는 joint COR 추정 시 큰 range of motion을 요구함



Future Study

- 다수의 실험참여자를 대상으로 실험 진행
- Hand joint dimension, hand size, hand joint COR 위치를 기반으로 한 statistical hand models 구축
- 추후 검증 시 CT image를 이용한 skeleton based method를 적용하여 실제 hand joint의 회전 중심 도출 예정

Development of statistical model of hand



Hand skeleton motion for finding ground truth joint COR

Q & A

THANK YOU FOR YOUR ATTENTION

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