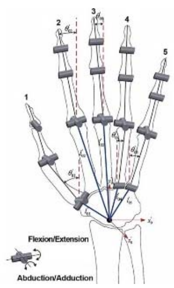
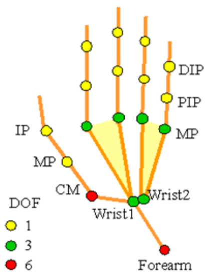
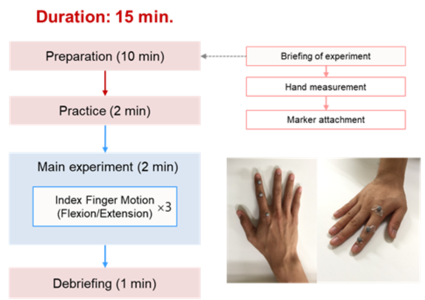
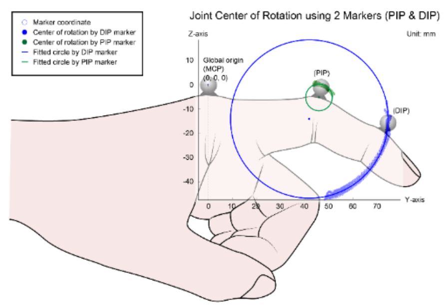
Estimation of Hand Joint Center of Rotation Using Surface Marker Motions









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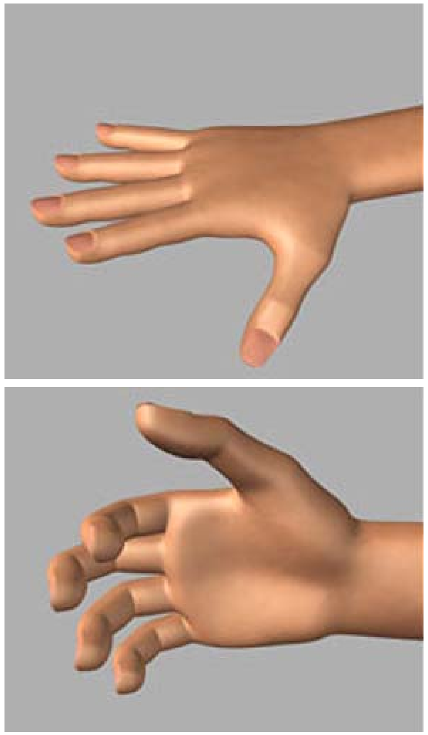
Contents

Digital Human Hand Modeling & Its Applications

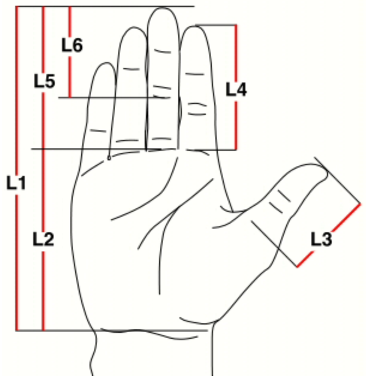
- Digital human hand modeling, consisting of modeling of hand links and surface meshes for simulation of human hand
- Application of DHHM: Clinical assessment, hand animation, anthropometry, ergonomic product design

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	

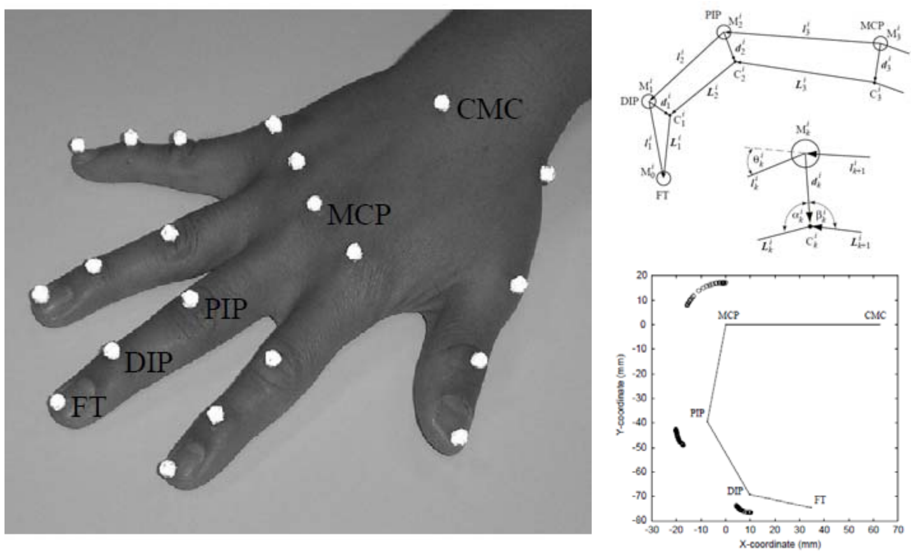
D: Direct measurement method, I: Indirect measurement method.

Ergonomic design

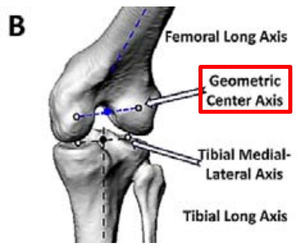
Hand Link Model Establishment Methods

- Hand link model is required for simulation of hand postures.
- To form a hand link model, hand joint center of rotation (COR) needs to be defined accurately
- Existing methods for estimation of hand joint COR: Surface-based and Skeleton-based

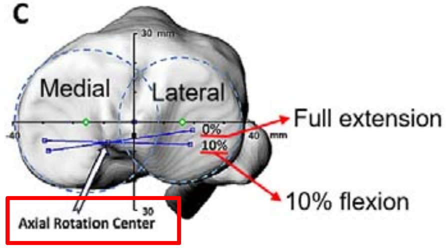
Surface-based hand joint COR estimation
(Zhang et al., 2003)



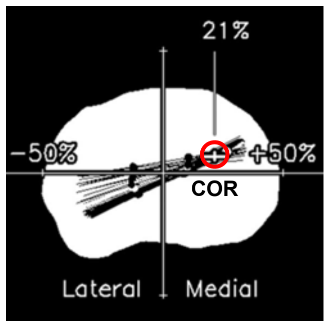
Skeleton-based hand joint COR estimation
(Yong Feng et al., 2015)

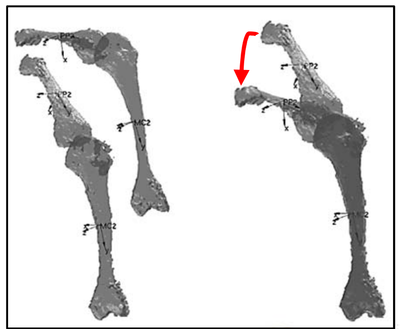


(Yamaguchi et al., 2008)



(Stillfried et al., 2010)





Limitations of Existing Hand Joint COR Estimation Methods

- 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):

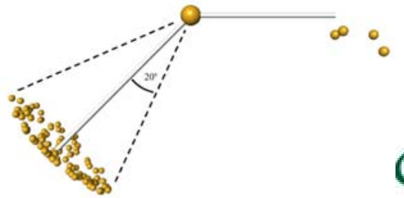
$$J^i = \sum_{k=1}^{3} \left\{ \sum_{t=1}^{T} \left(|\boldsymbol{L}_k^i| - |\boldsymbol{l}_k^i(t) + \boldsymbol{d}_{k-1}^i(t) - \boldsymbol{d}_k^i(t)| \right)^2 \right\} \quad (i = 2, \ldots, 5). \qquad (5)$$

Initial guess

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

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

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):

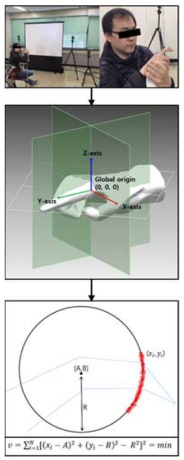


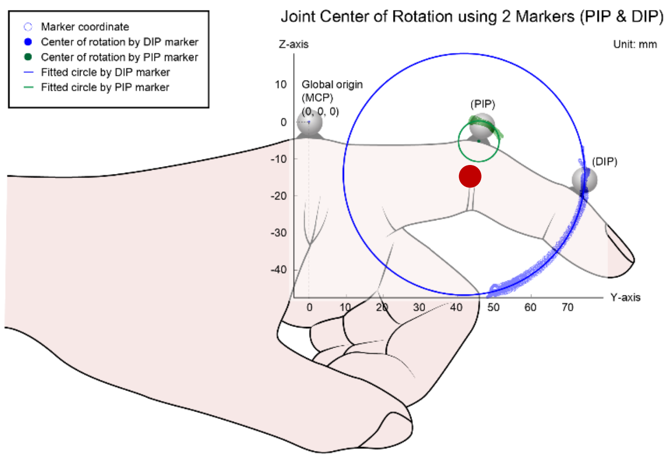
Objectives of the Study

To estimate hand joint COR (Center of Rotation)

Using its adjacent surface marker motions

1. Estimate proximal phalangeal (PIP) joint COR using distal phalangeal (DIP) surface marker motions by a circle fitting method
2. Validate the estimated PIP joint COR





Experiment Procedure

- Three-step experiment: pre-test, main test, and debriefing

Duration: 15 min.

Preparation (10 min)
← Briefing of experiment → Hand size measurement → Marker attachment

↓

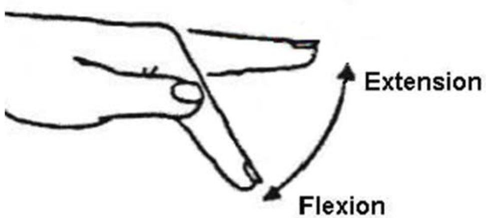
Practice (2 min)

↓

Main experiment (2 min)
- Index Finger Motion (Flexion/Extension) ×3

↓

Debriefing (1 min)

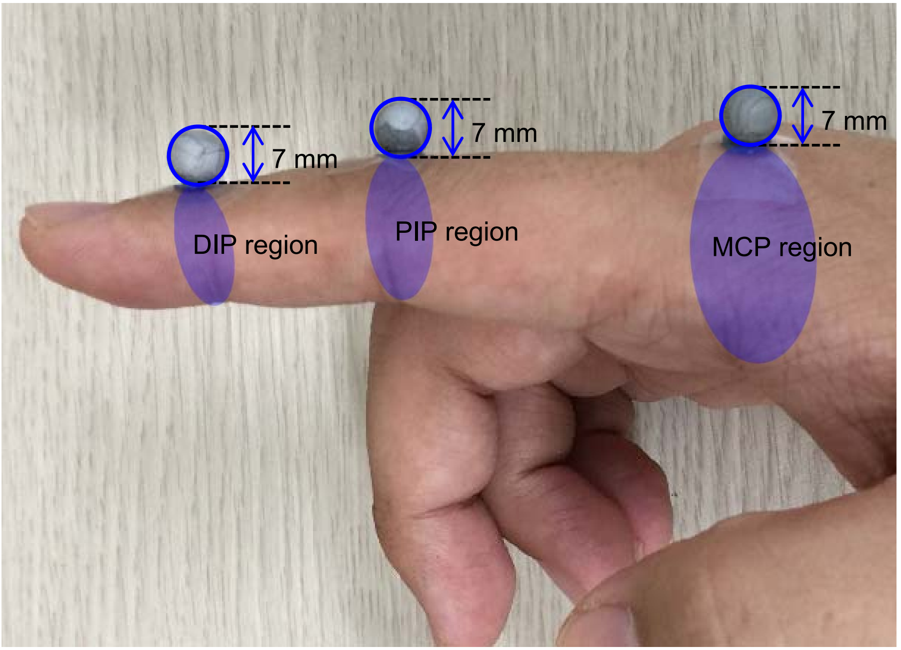


Apparatus

- 10 motion cameras (Osprey, Motion Analysis Inc., USA) were used to capture finger flexion and extension motion with a frequency of 60 Hz.
- Reflective markers (Ø = 7 mm) attached to the surface of the index finger at metacarpophalangeal (MCP), PIP, and DIP joints

Perspective view: experimental environment

Marker specification and adherence location



Participants

- Three healthy male subjects with different hand sizes (small, medium, and large) were recruited (no neurological or musculoskeletal disorders in the hand).
- Hand length, hand breadth, and PIP joint depth of the index finger were measured using a caliper.

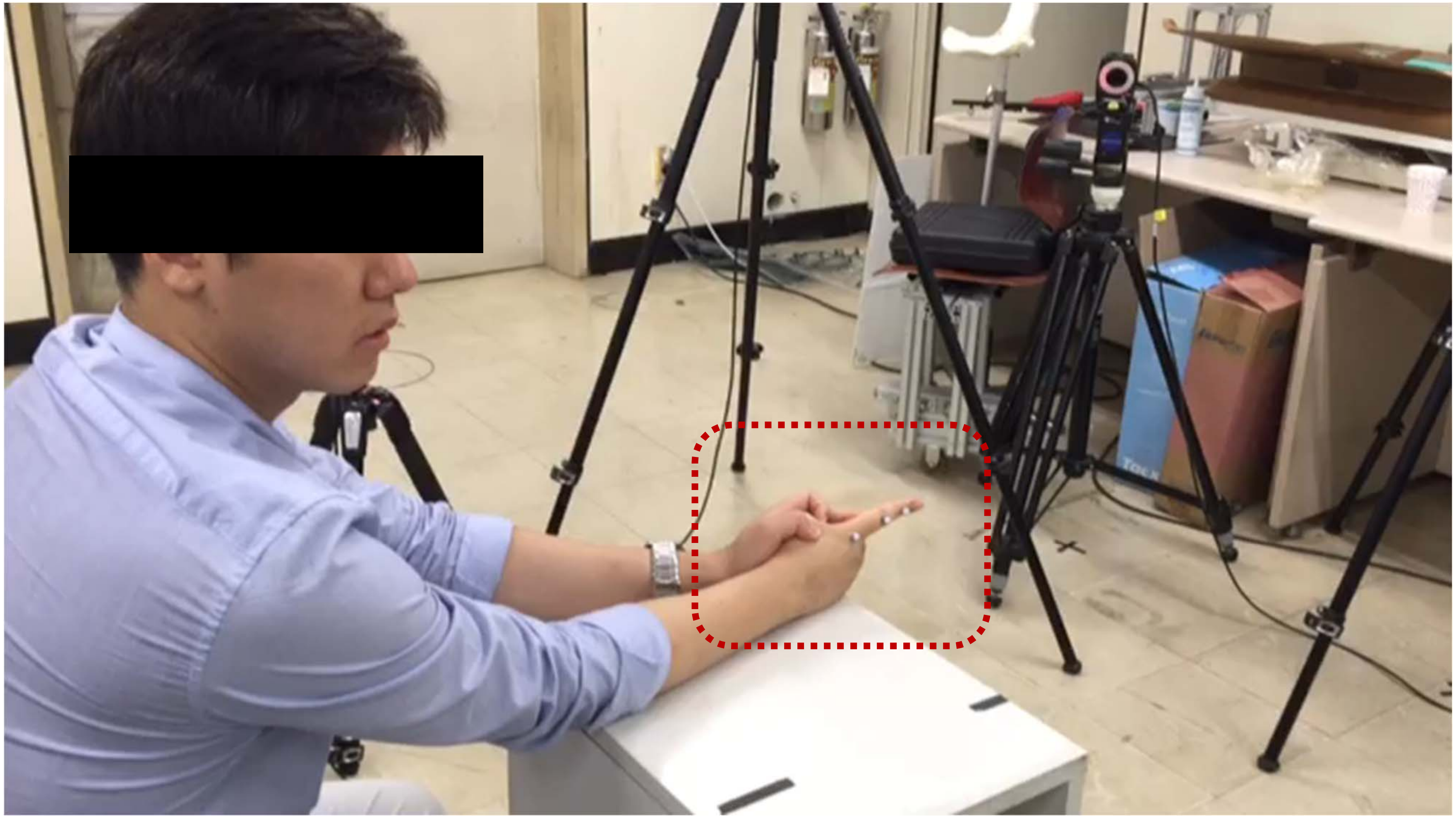
Unit: mm

Subject No.	Category	Hand length	Hand breadth	Index finger depth at PIP joint
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

- Flexion and extension motion of the PIP joint

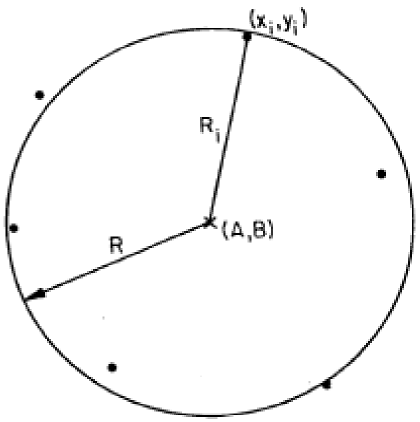


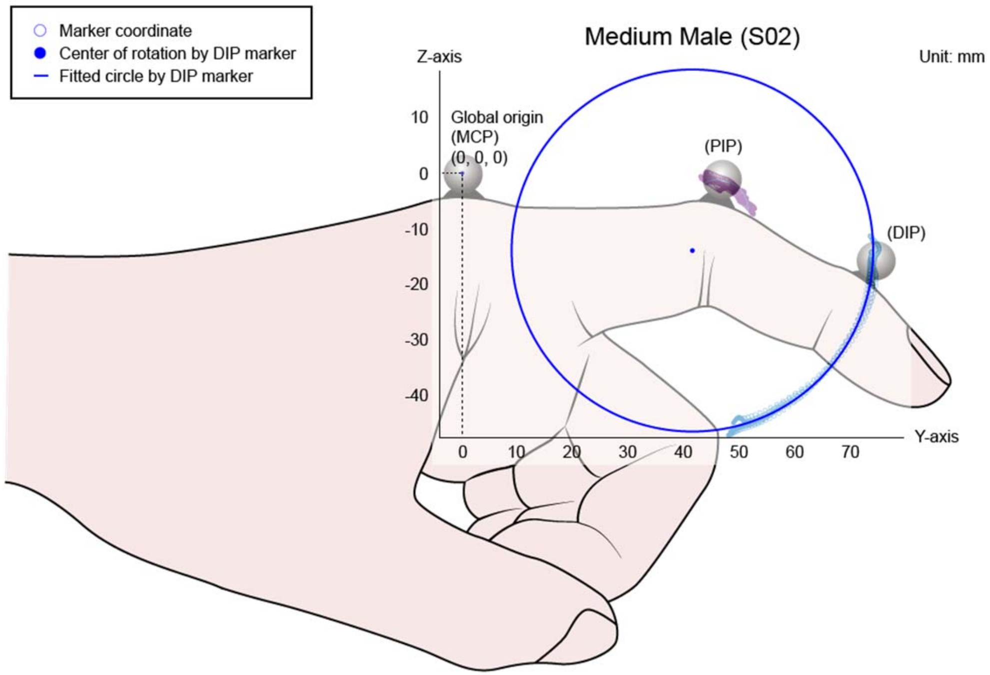
PIP Joint COR Estimation

- PIP joint COR estimated using DIP marker motion by a circle fitting method
- 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

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

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



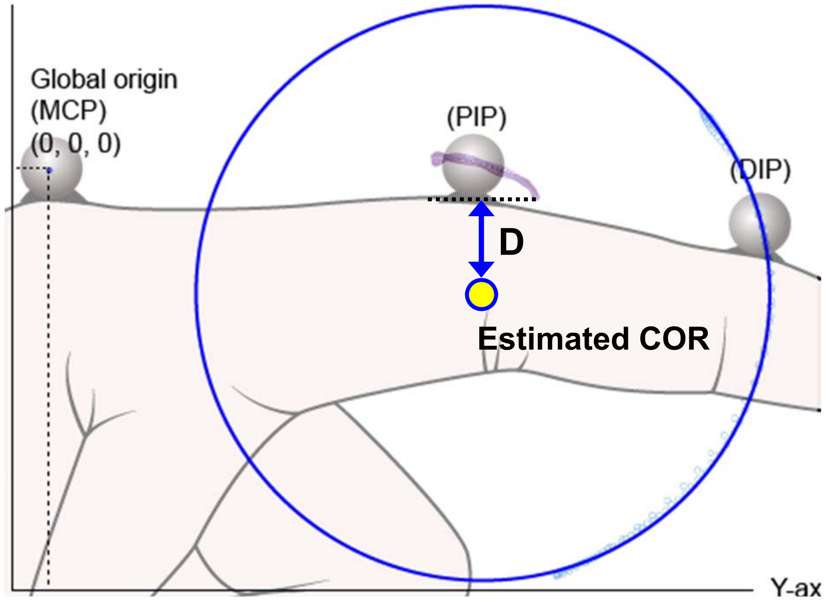


Results (1/2)

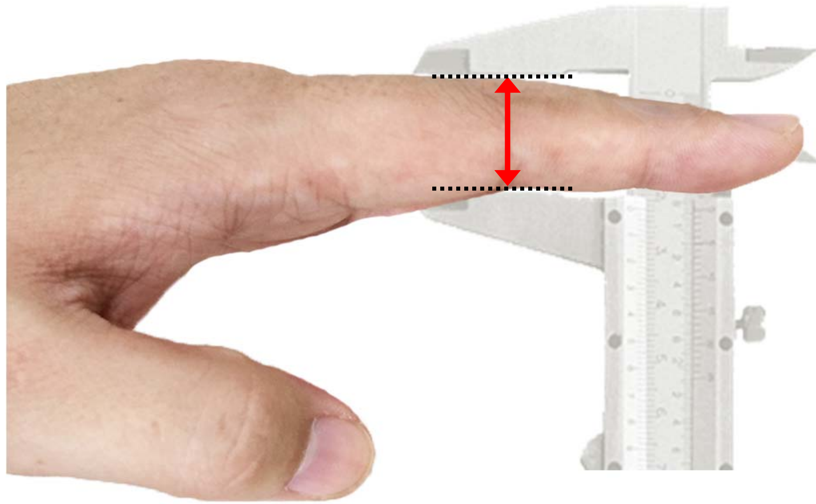
- The estimated PIP joint COR was validated by comparison of the distance from the attaching point of the surface marker to the estimated PIP joint COR (D) to half of the PIP joint depth

Estimation error = D – ½ PIP joint depth

Distance from attaching point to estimated COR

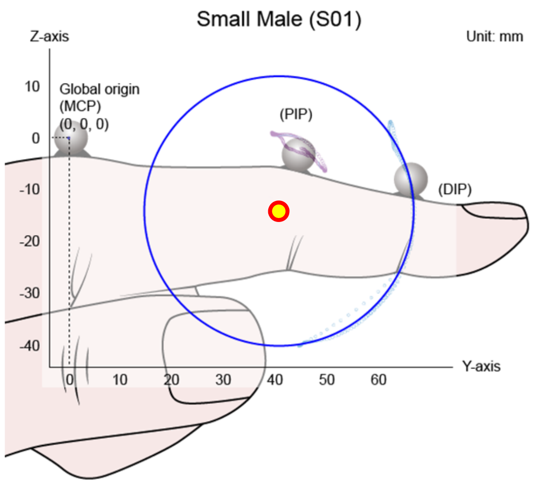
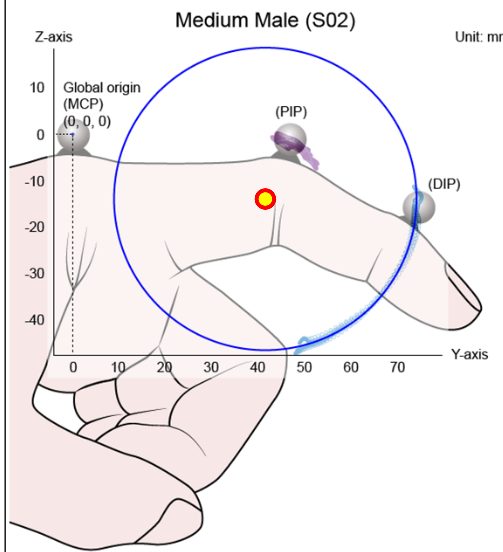
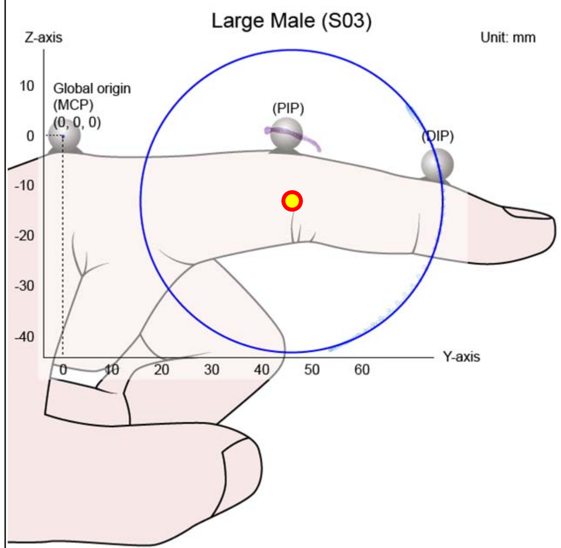


PIP joint depth (Reference)



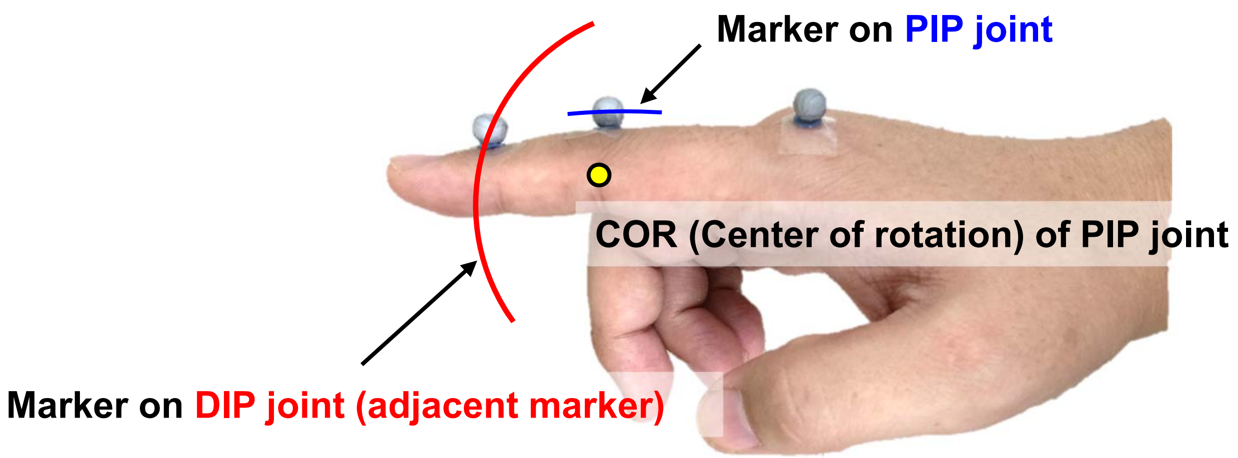
Results (2/2)

- The average error of the estimated PIP joint COR was 1.9 ± 0.6 mm
- Larger hands showed smaller error than small hand

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

Discussion

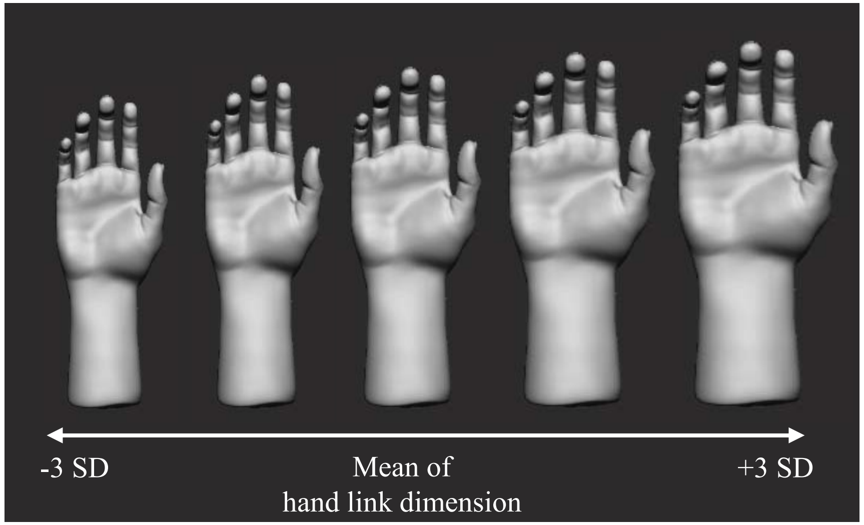
- Estimation of PIP joint COR using DIP marker motion by the Delonge-Kasa method showed high accuracy in hand joint COR estimation (error = 1.9 ± 0.6 mm).
- Larger hands tended to show more accurate estimation of hand joint COR than small hand (accuracy improved by 0.7 to 1.5 mm).
- The Delonge-Kasa 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.



Future Study

- More participants need to be recruited.
- Statistical models of the joint COR position can be established based on hand joint dimensions and hand sizes.
- For further validation, the motion of hand skeleton reconstructed from CT images can be used to find the ground truth joint COR.

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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