Development of an Optimization Method for Determining Human Hand Link Lengths Based on Surface Measurement

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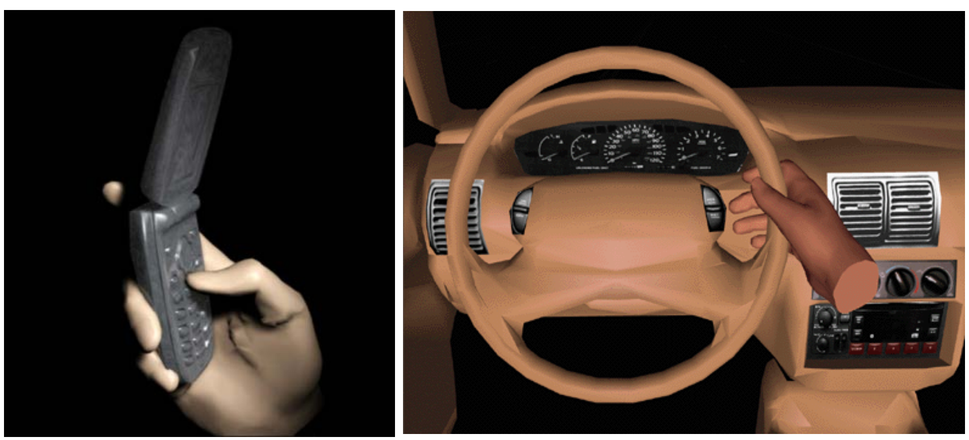
Agenda

- Background
- Objectives of the study
- Optimization method development
- Proposed optimization method evaluation
  - ✓ Materials and methods
  - ✓ Evaluation results
- Discussion

Importance of Human Hand Modeling

- Importance of human hand: object manipulation (grasping, positioning, holding, etc.), communication (sign language, gestures), etc.

- Importance of human hand modeling (HHM): applications in 3D computer-aided ergonomic design, robotics, virtual surgery, etc.

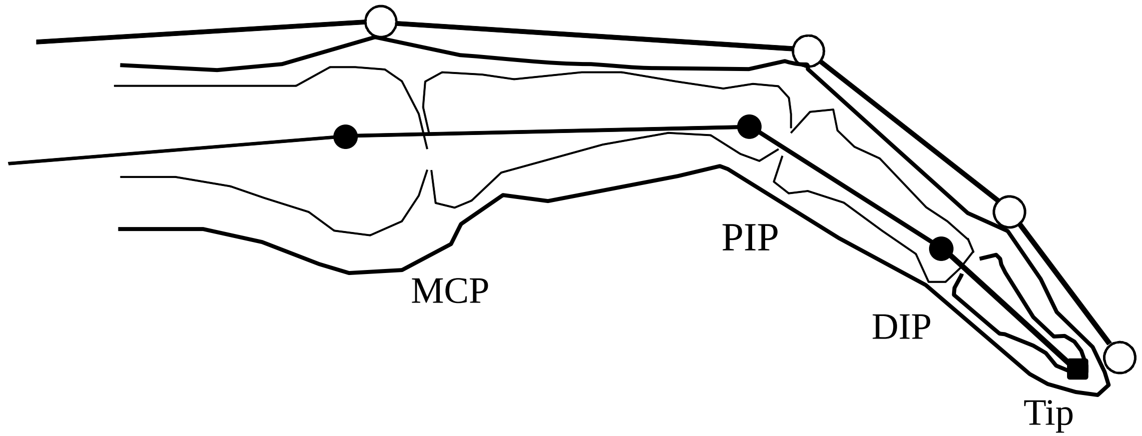


3D Computer-aided ergonomic design

Virtual surgery

Difficulty of Hand Link Length Estimation for HHM

- The link structure obtained from the 3D motion analysis system does not represent the underlying human skeletal structure



- A method for estimating hand link lengths based on 3D hand motion data is needed

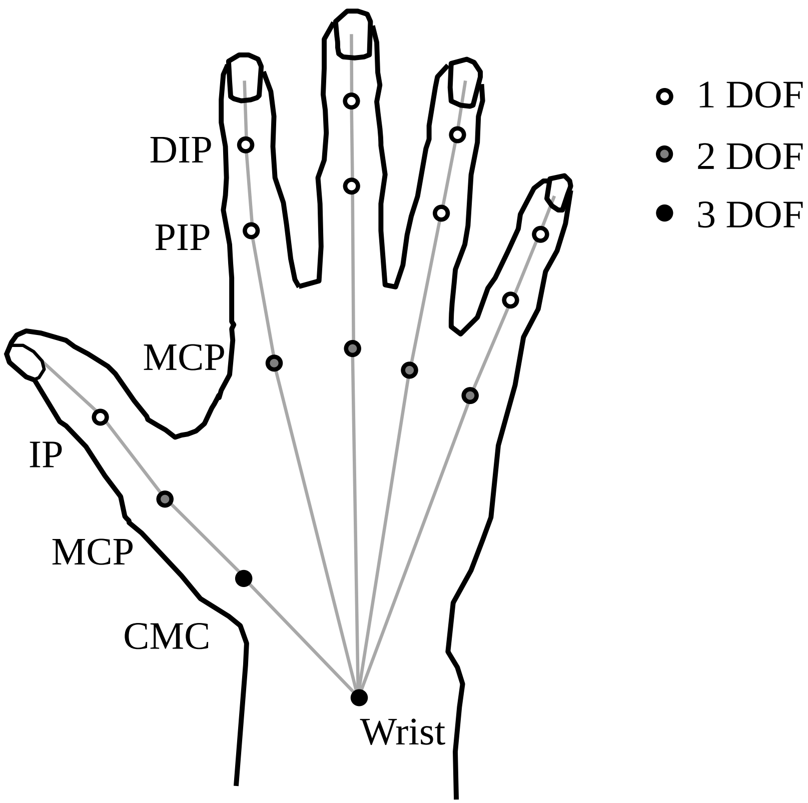
Objectives of the Study

1. Develop an optimization method for estimating hand link lengths based on 3D hand motion data

2. Evaluate the accuracy of the proposed optimization method with 3D hand motion data collected by an optoelectronic motion capture system

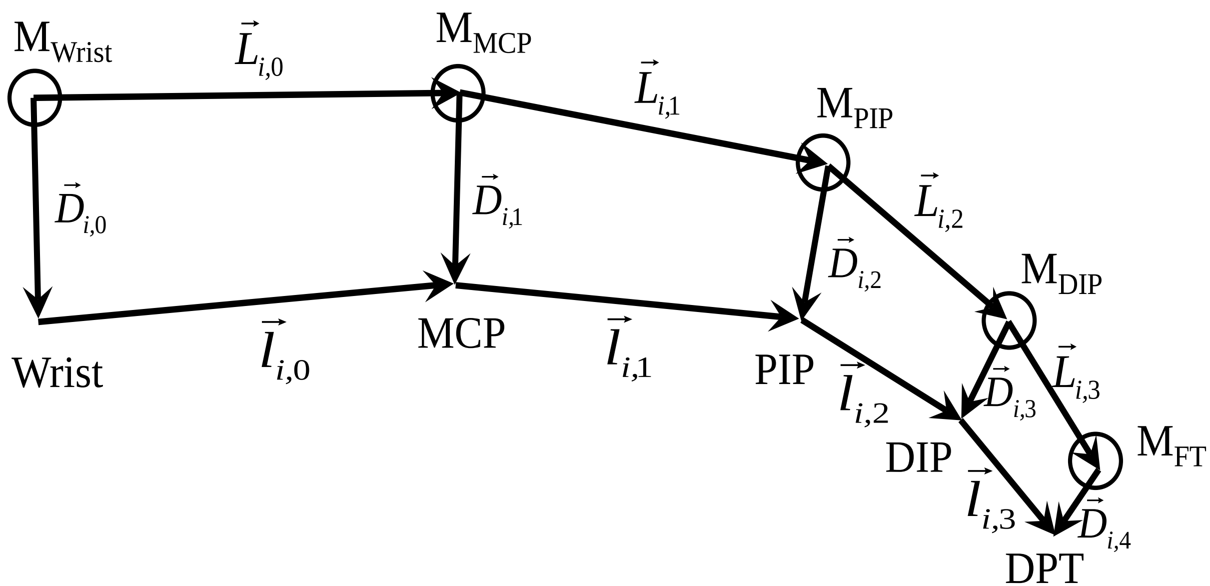
Optimization Method: Hand Kinematic Model

- Hand kinematic model: a rigid linkage system



Optimization Method: Geometric Model

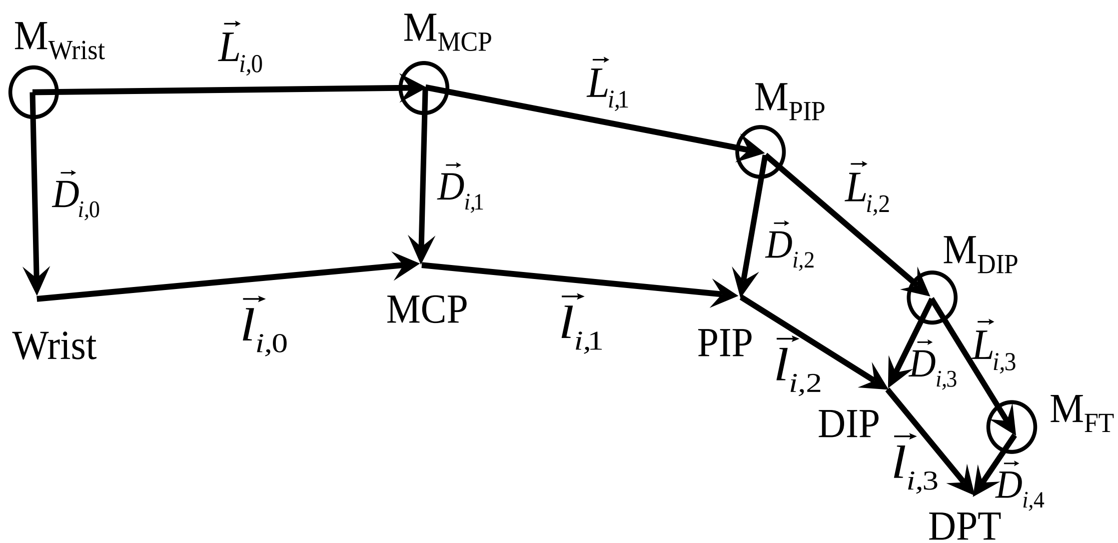
- Geometric relationship between the surface markers and joint centers of rotation



Optimization Method: Objective Function

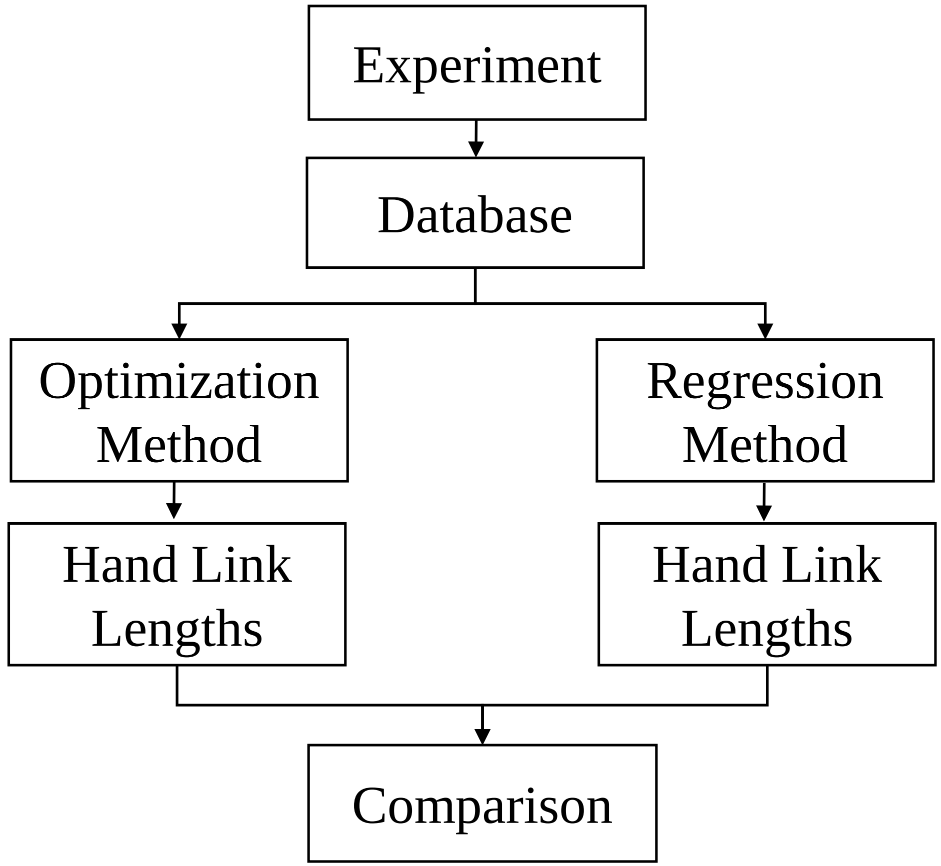
- Optimization routine
  - Minimizing the variation of hand link lengths and depths from surface marker to joint center of rotation during the entire hand movement

$$C_i = \sum_{t=1}^{T} \left\{ \sum_{k=0}^{3} \left[\left\| \vec{l}_{i,k}(t) \right\| - \left\| \vec{l}_{i,k} \right\| \right]^2 + \sum_{m=0}^{4} \left[\left\| \vec{D}_{i,m}(t) \right\| - \left\| \vec{D}_{i,m} \right\| \right]^2 \right\}$$



i = II, III, IV, V

Proposed Optimization Method Evaluation



- Hand link lengths
- Fingertip prediction error

Participants

- 18 right-handed male participants

Classification	Mean (S.D.)	Range	
		Minimum	Maximum
Age	26.3 (2.1)	23	28
Hand length (cm)	19.2 (10.1)	17.8	20.6
Hand width (cm)	9.3 (4.5)	8.2	9.5

- Selection criteria
  - ✓ Age: 20-29 years old
  - ✓ Health conditions: No history of injuries at the hand and wrist

Apparatus

- Optoelectronic motion capture system: 6 Hawk Digital Cameras® (Motion Analysis Corporation, CA, USA)

- Spherical retro-reflective markers

A layout of motion capture system

Diameter = 5 mm

n = 23

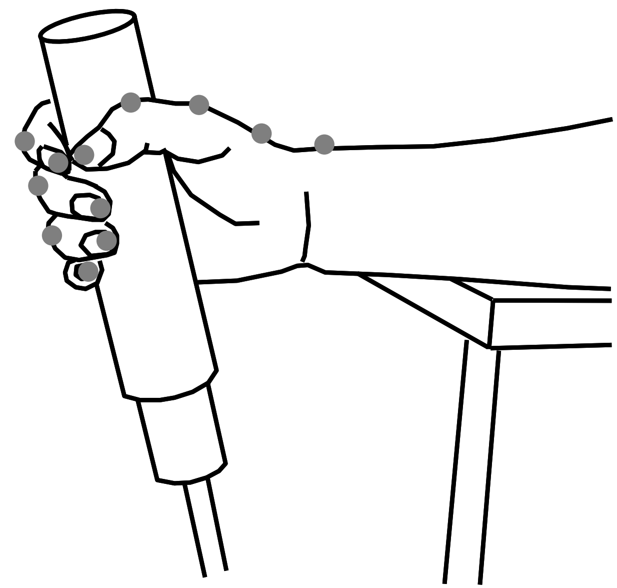
Surface marker set

Cylinder Gripping Task

- Participants were asked to grasp two different cylinders

Cylinder Size

Cylinder Gripping

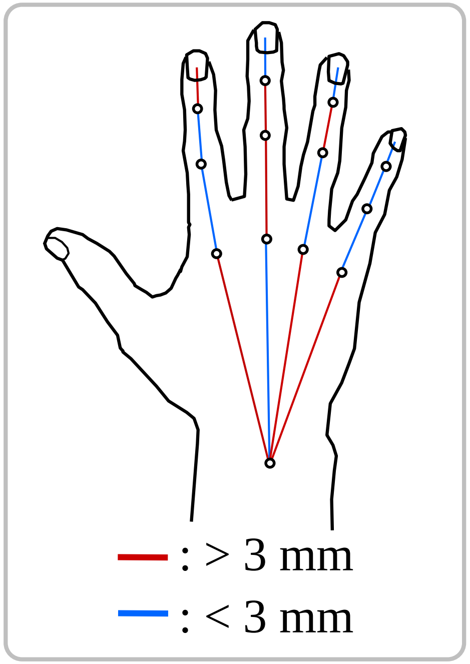


Evaluation Results

- Hand link lengths comparison to the regression method by Buchholz et al. (1992)
  - They are comparable; the smallest difference appear at the Wrist-MCP link of the middle finger, while the largest appear at the Wrist-MCP link of the ring finger

Root-Mean-Square (RMS) differences of hand link lengths by optimization method and regression method:

Digit	RMS differences (optimization – regression; mm)			
	Wrist-MCP	MCP-PIP	PIP-DIP	DIP-Tip
Index	3.1	2.1	2.4	3.3
Middle	1.9	3.8	3.8	2.4
Ring	5.4	2.2	3.3	2.7
Little	3.6	2.7	2.7	2.2



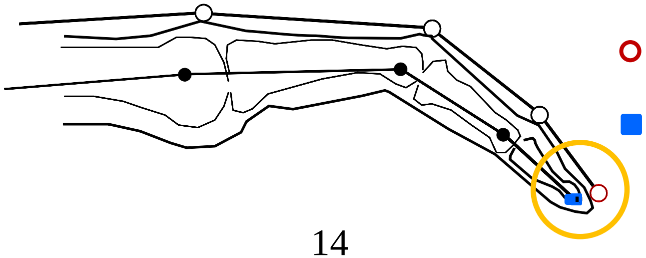
Evaluation Results (cont'd)

- Fingertip position prediction error comparison
  - The prediction error of the proposed optimization method is smaller than the regression method at each finder
  - The prediction error are higher at the index and middle fingers than the ring and little fingers for both of the two methods

RMS values of prediction error by optimization method and regression method:

Method	Index	Middle	Ring	little
Optimization method	6.9	5.7	3.2	2.8
Regression method	12.5	11.1	6.8	5.8

- Note that the predicted fingertip position is actually the distal phalange tip, which deviates the measured fingertip position



○: measured fingertip position

■: predicted fingertip position

Discussion

- The optimization method for determining human hand link lengths can be applied to human hand modeling required in many fields such as ergonomics, medical science.
- The optimization method increases the prediction accuracy of the human hand forward kinematic model compared to the regression method.
- However, the optimization method costs more than the regression method does.

Q & A

Thank you!