Development and Evaluation of a 25-DOF Hand Kinematic Model

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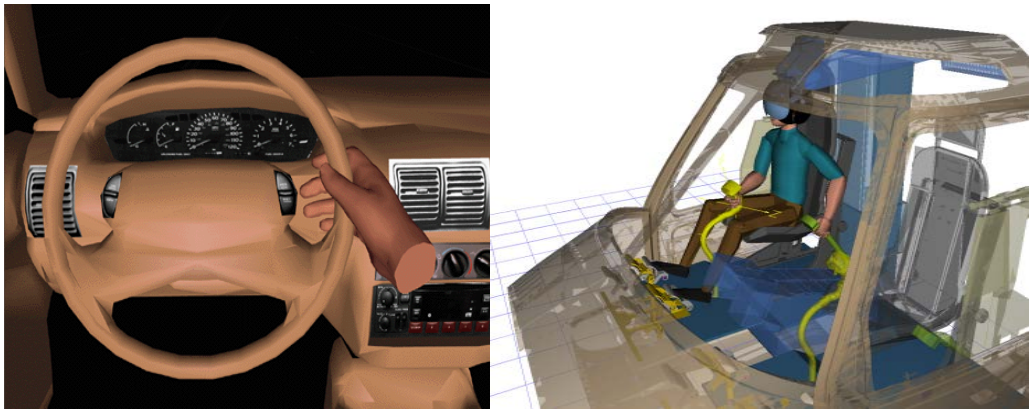
Agenda

- Introduction
  - ✓ Background
  - ✓ Objectives
- Hand Kinematic Model Development
- Hand Kinematic Model Evaluation
  - ✓ Methods
  - ✓ Results
- Discussion

Background

- Importance of human hand: object manipulation (grasping, positioning, holding, etc.), communication (sign language, gestures), etc.
- Importance of virtual human hand: applications in 3D computer-aided ergonomic design, virtual surgery, computer games, etc.



Computer-aided ergonomic design
(Left: Automobile; Right: Helicopter)

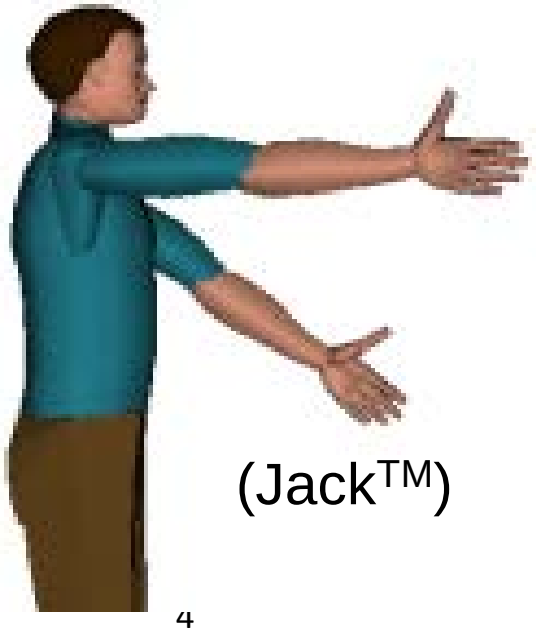
Virtual surgery

Hand model used for ergonomic design

- Hand model can adjust every hand segment length according to an arbitrary individual hand length, and the model is accurate

- Limitations of the existing commercial hand models, like the hand model in Jack™: Lacking accuracy, and ambiguous in defining the sizes of percentile models*

*Nierop, 2007



(Jack™)

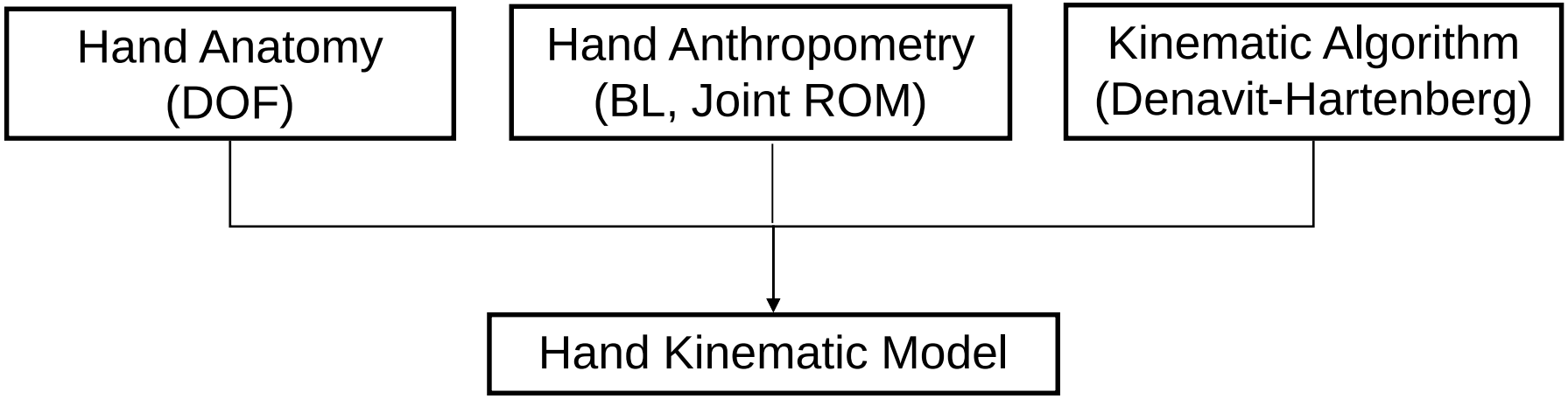
Objectives

1. Develop a hand kinematic model which is adjustable at each hand bone segment length according to the hand length

2. Evaluate the accuracy of the hand model with hand motion data collected by an optoelectronic motion capture system

Hand Kinematic Model

- Hand kinematic model development process



Note: DOF: Degree of freedom
BL: Bone length
ROM: range of motion

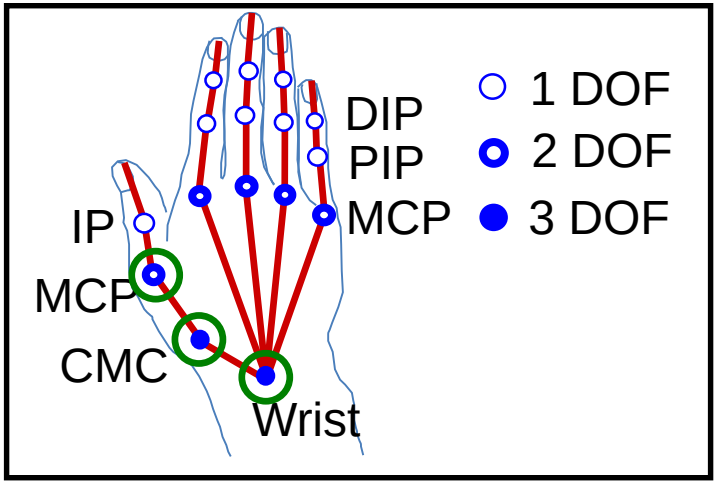
Hand Anatomy

DOFs survey

Joints	Fingers					Wrist joint	Total
	Thumb	Index	Middle	Ring	Little		
Carpometacarpal (CMC)	2[3*] (3)					2(3)	22(25)
Metacarpophalangeal (MCP)	2[1**](2)	2	2	2	2		
Interphalangeal (IP)	1						
Proximalinterphalangeal (PIP)		1	1	1	1		
Distalinterphalangeal (DIP)		1	1	1	1		

*Buchholz, 1989; **Jack™

(): DOFs of the new model



(DOFs of the new model)

Features of the new model

✓ Comprehensive DOFs (25 totally)

Hand Anthropometry

- Comparison study on ratio of the bone length to hand length

Source	Classification	Index			
		MCP	PIP	IP	DIP
Buchholz, 1992[1]	Ratio*HL	0.46*HL	0.25*HL	0.14*HL	0.10*HL
Greiner, 1991[2]		0.32*HL	0.26*HL	0.14*HL	0.12*HL
Buchholz, 1992[1]	R^2	0.96	0.99	0.79	0.73
Greiner, 1991[2]		0.43	0.25	0.34	0.18

[1]Based on 2 female and 4 male hands

[2]Based on 59 male hands

HL: Hand Length
BL: Bone Length

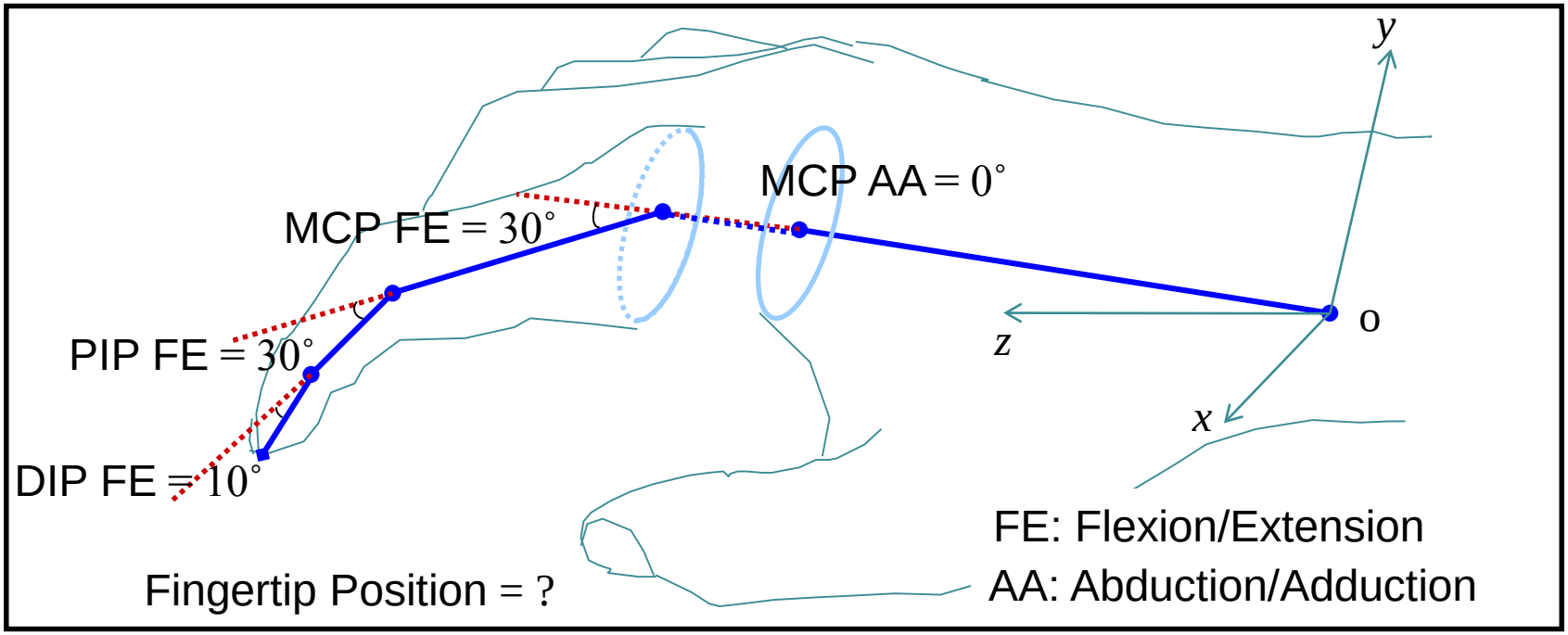
- Buchholz's data were adopted, later a study for measuring hand bone length would be conducted by another member using X-ray.

Forward Kinematics (Denavit-Hartenberg Method)

- Decide fingertip position given hand posture (i.e., joint angles)

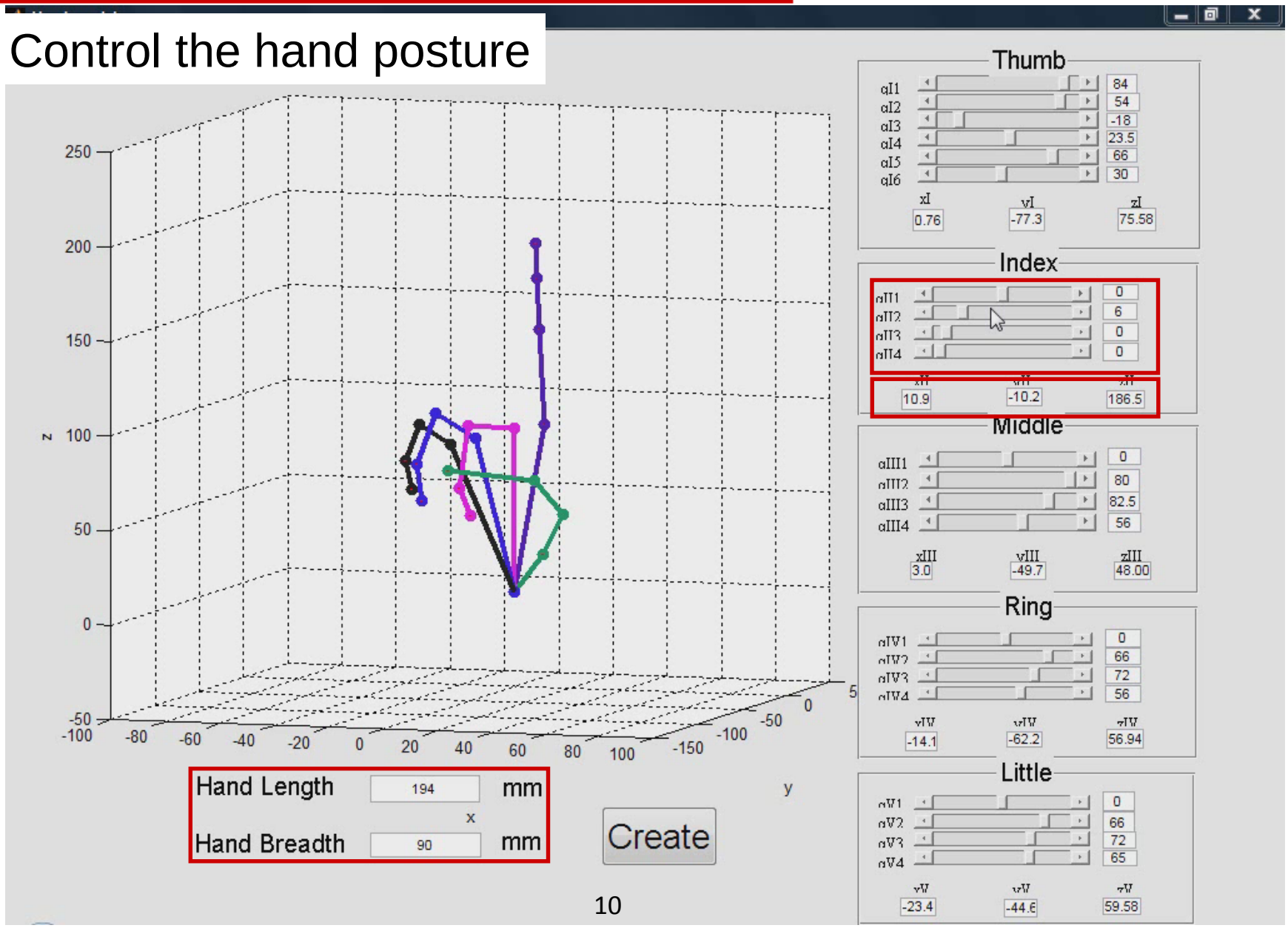
$$\mathbf{P} = f(\Theta)$$

$\mathbf{P}$: Fingertip Position Vector, Θ: Vector of Joint Angles



The 25-DOF Hand Model

Control the hand posture



Evaluation Process

Experiment

Data Processing

Joint Angles

Forward Kinematics

Measured Fingertip Positions

Predicted Fingertip Positions

Prediction Error

Participants

- Five male and right-handed participants

Classification	Mean (S.D.)	Range	
		Minimum	Maximum
Age	26.4 (2.1)	24	29
Hand Length (cm)	19.2 (10.1)	17.8	20.6
Hand Width (cm)	9.0 (5.1)	8.4	9.8

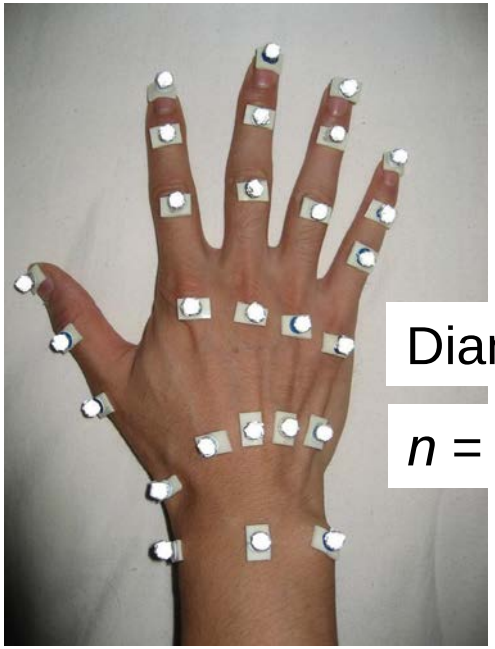
- Selection criteria
  - ✓ Age: 20-30 years old
  - ✓ Health conditions: No history of injuries at the hand or wrist

Apparatus

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

- Spherical retro-reflective markers

A Layout of Motion Capture System



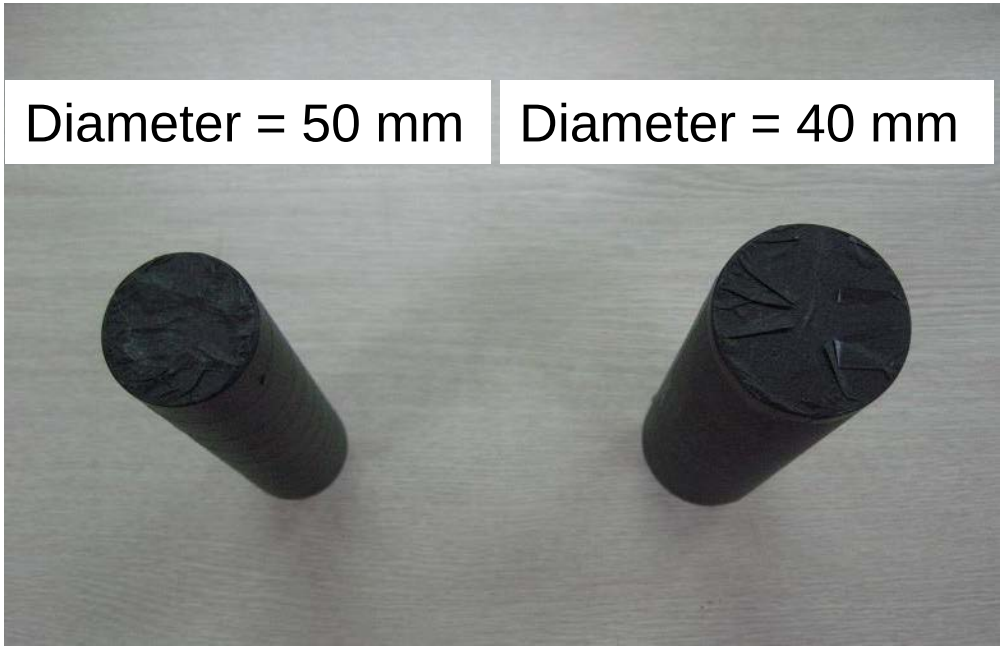
Diameter = 7mm

n = 27

Marker Set

Cylinder Gripping

- Participants were asked to grasp two different cylinders



Cylinder Gripping

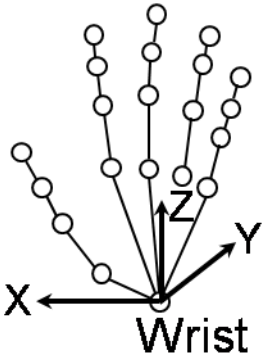
Data Processing

- Transform the captured 3D coordinates in order to be consistent with the 3D coordinate system of the hand model

Construction of a wrist coordinate system

Translation

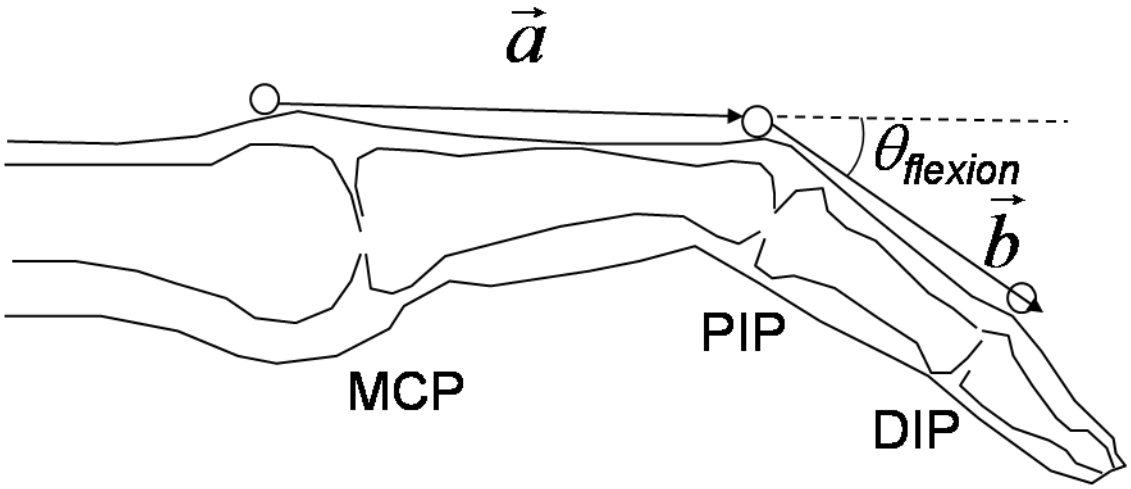
Rotation



4	Frame#	Time	Wirst			Radius		
5			X1	Y1	Z1	X2	Y2	Z2
6	1	0	1348.2	-95.7	655.1	1321.9	-67.9	676.2
7								
8								
9	Translation		0	0	0	-26.2	27.8	21.1

Joint Angle Calculation: 1 DOF

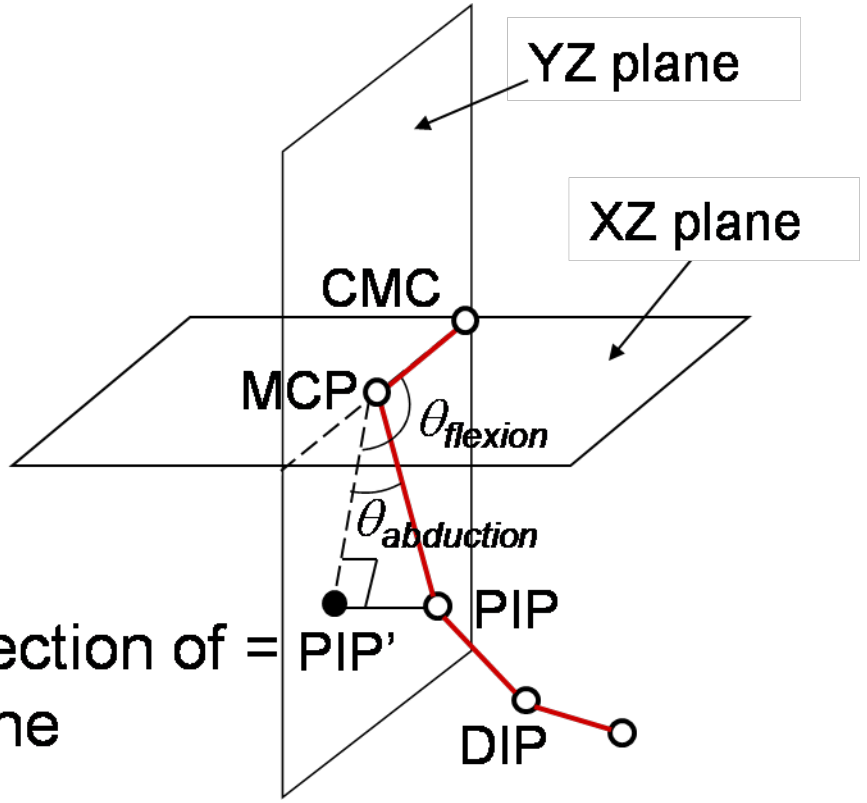
- Example of calculating PIP joint angle



$$\theta_{flexion} = \arccos\left(\frac{\vec{a}\cdot\vec{b}}{|\vec{a}||\vec{b}|}\right)$$

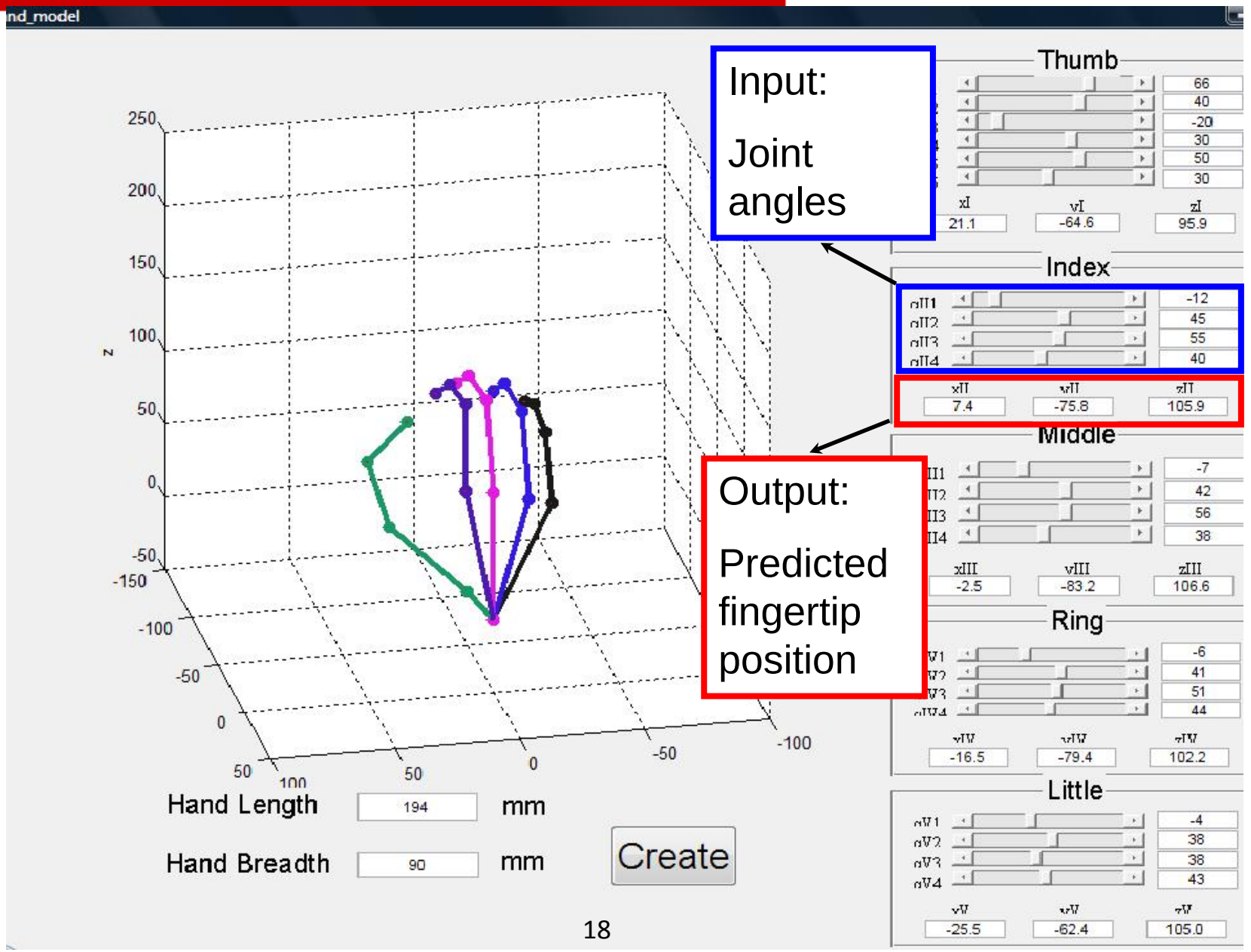
Joint Angle Calculation: 2 DOF

- Example of calculating MCP joint angles



Orthogonal projection of = PIP'
PIP onto YZ plane

Predicted Fingertip Position



Evaluation Criteria

- Prediction Error: Distance between the measured fingertip position (X_M, Y_M, Z_M) and predicted fingertip position (X_P, Y_P, Z_P)

$$\text{Error} = \sqrt{(X_P - X_M)^2 + (Y_P - Y_M)^2 + (Z_P - Z_M)^2}$$

Unit: mm

	Participants	Classification	Index		
2					
3			X	Y	Z
4	P1	Measured	-2.9	-78.2	102.5
5		Predicted	-2.9	-70.1	97.2
6		Prediction error	9.7		

Evaluation Result for the Large Cylinder

- The prediction error is from 10.6 mm to 20.9 mm. The model has less prediction error of fingertip position at longer finger.

Participants	Fingertip position prediction error (mm)			
	Index	Middle	Ring	Little
P1	14.9	11.1	14.0	20.9
P2	11.7	11.3	12.1	20.3
P3	11.2	12.0	12.1	19.1
P4	11.3	10.9	13.2	18.2
P5	13.4	10.6	12.3	10.5
Mean	12.5	11.2	12.7	17.8
S.D.	1.6	0.5	0.8	4.2
Grand mean	13.1			

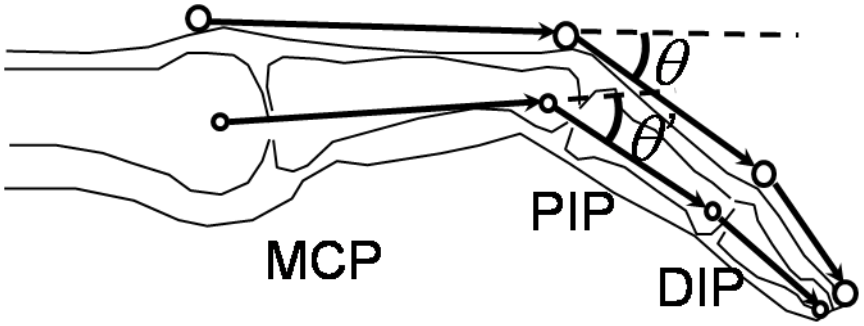
Evaluation Result for the Small Cylinder

- The prediction error is from 10.5 mm to 19.2 mm. The model has less prediction error of fingertip position at longer finger.

Participants	Fingertip position prediction error (mm)			
	Index	Middle	Ring	Little
P1	16.9	16.9	17.7	19.2
P2	11.3	11.2	11.3	19.0
P3	13.7	18.4	12.5	13.1
P4	12.6	11.7	12.3	19.0
P5	12.9	10.5	11.3	13.3
Mean	13.5	13.7	13.0	16.7
SD	2.1	3.6	2.7	3.2
Grand mean	14.2			

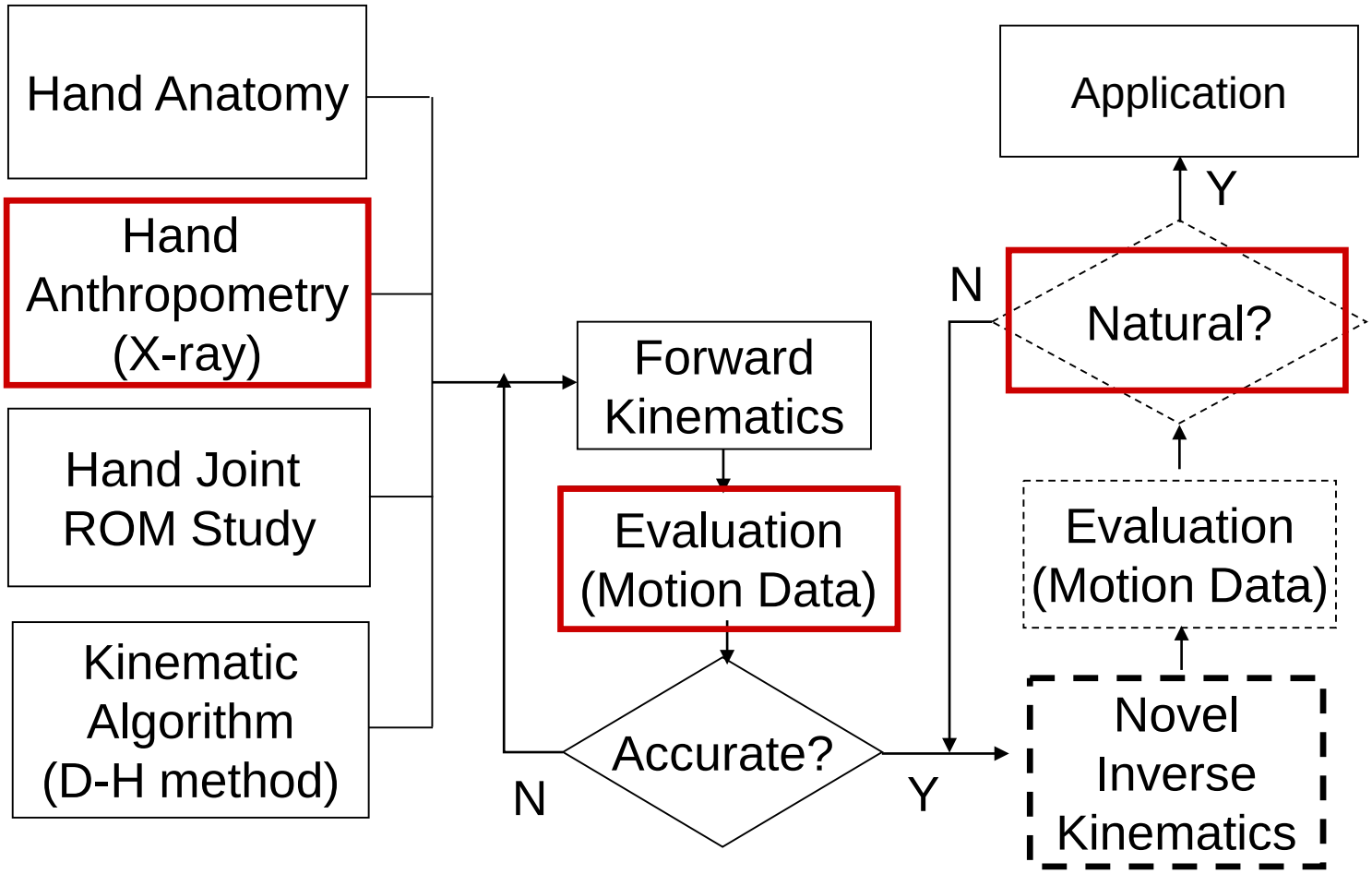
Discussion

- The new hand model has comprehensive degrees of freedom, especially at the CMC and MCP of the thumb and the wrist.
- The Model can predict each bone length of the hand according to an specific individual hand length.
- Sources of the prediction error
  - ✓ Regression of the bone length to the hand length (Small sample size)
  - ✓ Offset between captured coordinates data and bone data



Future Work

- Big Picture of developing a novel inverse kinematic model which can predict natural hand postures



Q & A

Thank you!