



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

M. Felix Orlando

DEPARTMENT OF ELECTRICAL ENGINEERING

Manipulability Analysis of Human Fingers in Cooperative Rotational Motion

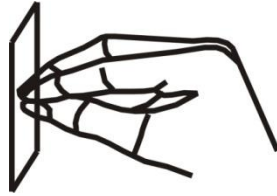


Outline

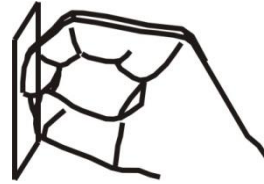
1. Introduction
2. Cooperative 3D Rotational Motion Investigation
3. Conclusions



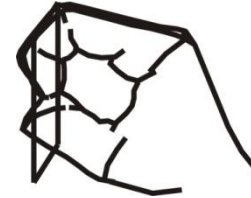
Three planes and postures considered for coordinated finger motions in object rotation



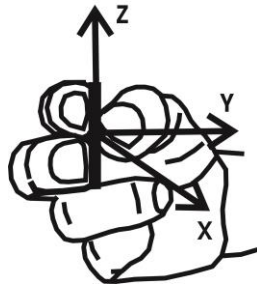
(a) Extended plane (ETP)



(b) Intermediate plane (ITP)



(c) Flexed plane (FXP)



(d) Central rotation posture



(e) Right rotation posture

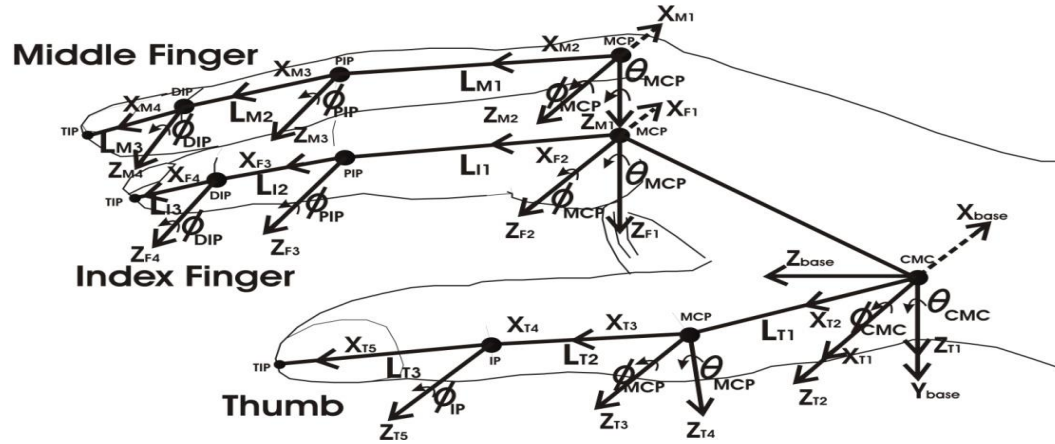


(f) Left rotation posture

Methods

Link models of the thumb, index and middle finger

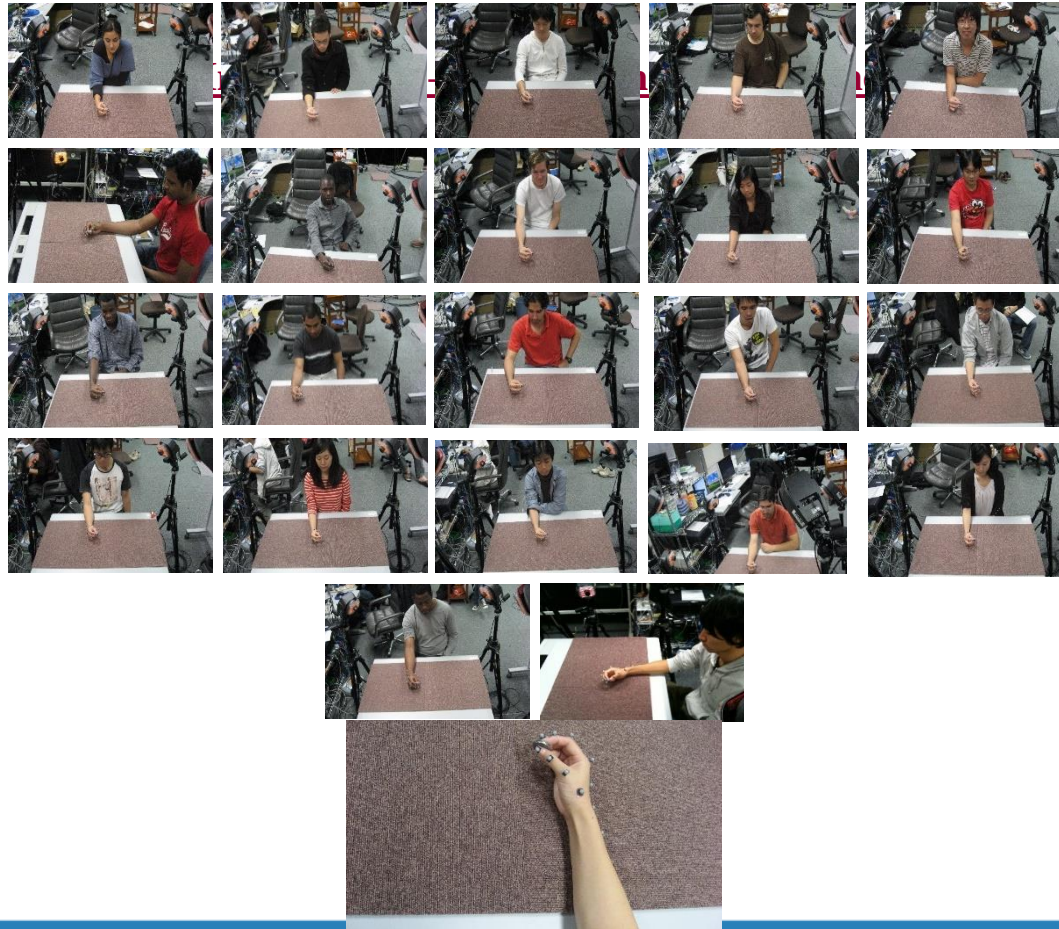
● Joint



$$I_{TIP} = I_{MCP} + {}^{MCP}_{PIP}R[I_{PIPwrtMCP} + {}^{PIP}_{DIP}R \bullet I_{DIPwrtPIP} + {}^{DIP}_{TIP}R \bullet I_{TIPwrtDIP}]$$

$$M_{TIP} = M_{MCP} + {}^{MCP}_{PIP}R[M_{PIPwrtMCP} + {}^{PIP}_{DIP}R \bullet M_{DIPwrtPIP} + {}^{DIP}_{TIP}R \bullet M_{TIPwrtDIP}]$$

$$T_{TIP} = {}^{CMC}_{MCP}R[T_{MCP} + {}^{MCP}_{IP}R \bullet T_{IPwrtMCP} + {}^{IP}_{TIP}R \bullet T_{TIPwrtIP}]$$



Methods (cont'd)

- A total of 15 Auto reflective markers
- Size = 6mm diameter
- MAC 3D Motion Capture System



A subject with auto reflective markers
attached to the finger joints

Methods (cont'd):

Manipulability Ellipsoid

Finger Tip Velocity is $\dot{\mathbf{I}}_{Tip} = \mathbf{J}_I \dot{\mathbf{q}}_I$

such that,

$$\dot{\mathbf{I}}_{Tip} = [\dot{x}_I, \dot{y}_I, \dot{z}_I]^T,$$

$$\dot{\mathbf{q}}_I = [\dot{\phi}_{MCP_AA_I}, \dot{\phi}_{MCP_FE_I}, \dot{\phi}_{PIP_I}, \dot{\phi}_{DIP_I}]^T$$

\mathbf{J}_I is the Jacobian Matrix of size 3 x 4;

The set of all finger tip velocities which are realizable by its joint velocities such that the Euclidean norm of joint velocity is unity, i.e.,

$$\|\dot{\mathbf{q}}_I\| = \sqrt{(\dot{\phi}_{MCP_AA_I})^2 + (\dot{\phi}_{MCP_FE_I})^2 + (\dot{\phi}_{PIP_I})^2 + (\dot{\phi}_{DIP_I})^2} \leq 1$$

which is equivalent to $\dot{\mathbf{I}}_{TIP}^T (\mathbf{J}_I^+)^T \mathbf{J}_I^+ \dot{\mathbf{I}}_{TIP} \leq 1$



Methods (cont'd):
Three manipulability Criteria

- Calculated based on the singular value decomposition of the Jacobian matrix J_I of each digit.

$$J_I = R \Sigma S^T$$

R and S are orthogonal matrices and Σ is a 3 x 4 matrix given by

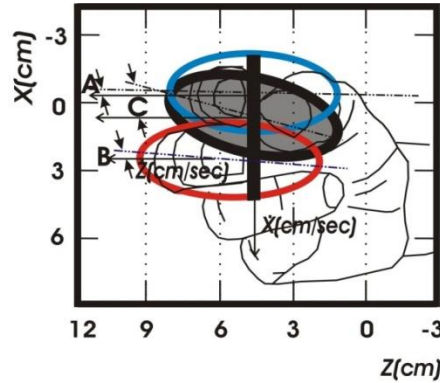
$$\Sigma = \begin{bmatrix} \sigma_1 & 0 & 0 & 0 \\ 0 & \sigma_2 & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 \end{bmatrix}, \sigma_1 \geq \sigma_2 \geq \sigma_3 \geq 0$$

- Manipulability Measure $w = \sqrt{|J_I J_I^T|}$
- Major axis direction angle measurement is based on the weak sense and is used to investigate the posture of the ellipsoid.
- Ratio of the minimum/maximum radii of the ellipsoid represents its shape, σ_3/σ_1



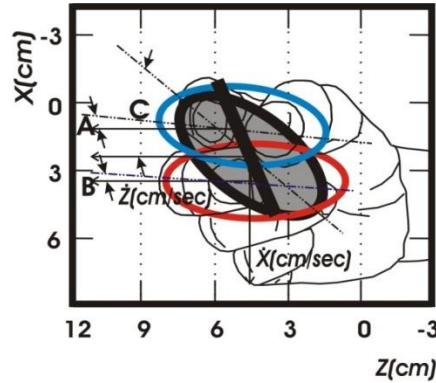
Results

Manipulability Ellipsoids in the ETP plane



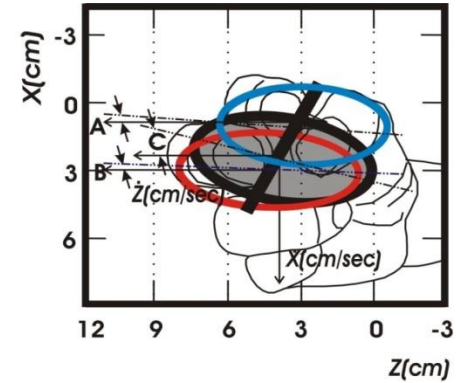
(A) Extended Rotation Posture CR
(Front View)

A=3 deg, B=4 deg,
C=29 deg



(B) Extended Rotation Posture RR
(Front View)

A=5 deg, B=6 deg,
C=42 deg



(C) Extended Rotation Posture LR
(Front View)

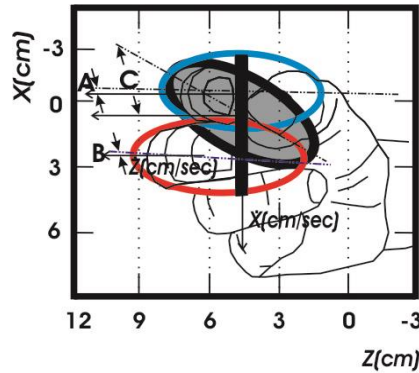
A=2 deg, B=4 deg,
C=22 deg

— : Manipulability Ellipsoid of Tip of Index Finger
— : Manipulability Ellipsoid of Tip of Middle Finger
— : Manipulability Ellipsoid of Tip of Thumb
— : Object

A : Major Axis Direction Angle of Manipulability Ellipsoid of Index Finger
B : Major Axis Direction Angle of Manipulability Ellipsoid of Middle Finger
C : Major Axis Direction Angle of Manipulability Ellipsoid of Thumb

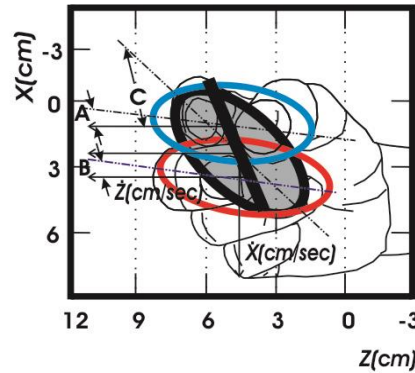
Results

Manipulability Ellipsoids in the ITP plane



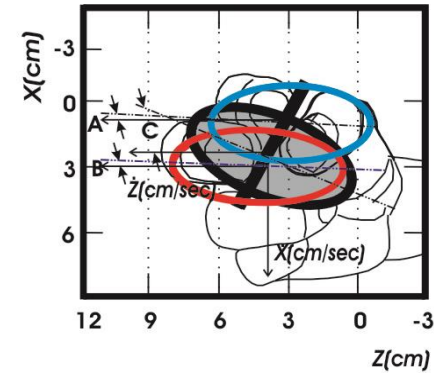
(A) Intermediate Rotation Posture CR
(Front View)

A=6 deg, B=1 deg,
C=35 deg



(B) Intermediate Rotation Posture RR
(Front View)

A=6 deg, B=8 deg,
C=55 deg



(C) Intermediate Rotation Posture LR
(Front View)

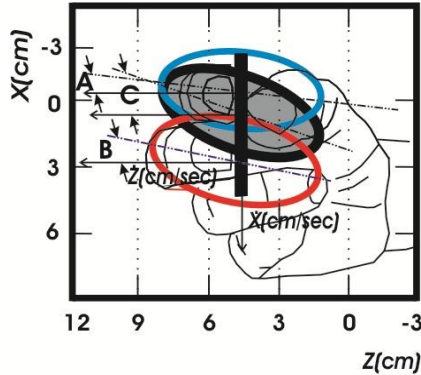
A=2 deg, B=2 deg,
C=29 deg

— : Manipulability Ellipsoid of Tip of Index Finger
— : Manipulability Ellipsoid of Tip of Middle Finger
— : Manipulability Ellipsoid of Tip of Thumb
— : Object

A : Major Axis Direction Angle of Manipulability Ellipsoid of Index Finger
B : Major Axis Direction Angle of Manipulability Ellipsoid of Middle Finger
C : Major Axis Direction Angle of Manipulability Ellipsoid of Thumb

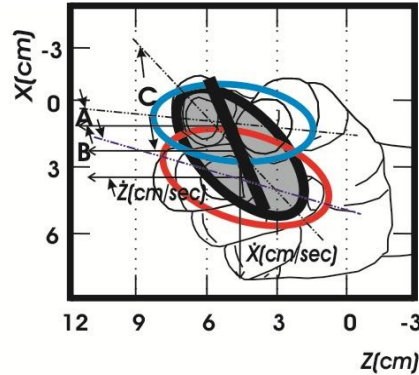
Results

Manipulability Ellipsoids in the FXP plane



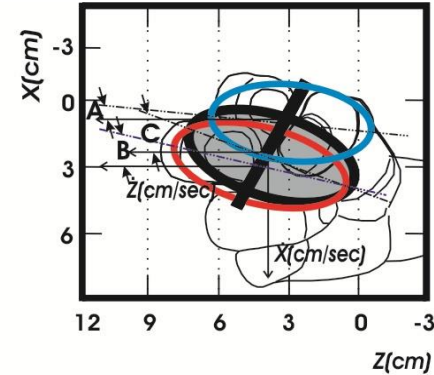
(A) Flexed Rotation Posture CR
(Front View)

A=9 deg, B=12 deg,
C=45 deg



(B) Flexed Rotation Posture RR
(Front View)

A=8 deg, B=15 deg,
C=58 deg



(C) Flexed Rotation Posture LR
(Front View)

A=10 deg, B=18 deg,
C=43 deg

— :Manipulability Ellipsoid of Tip of Index Finger
— :Manipulability Ellipsoid of Tip of Middle Finger
— :Manipulability Ellipsoid of Tip of Thumb
— :Object

A : Major Axis Direction Angle of Manipulability Ellipsoid of Index Finger
B : Major Axis Direction Angle of Manipulability Ellipsoid of Middle Finger
C : Major Axis Direction Angle of Manipulability Ellipsoid of Thumb

Table 1: Criteria differences in Motion I of the three fingers in all the planes

Variation in Criteria	Motion I								
	ETP			ITP			FXP		
Major Axis Direction Angle (deg)	Thumb	Index	Middle	Thumb	Index	Middle	Thumb	Index	Middle
	20.00 (3.50)	4.00 (1.00)	5.00 (2.00)	20.00 (3.00)	2.00 (1.00)	5.00 (2.00)	13.00 (2.00)	4.00 (1.00)	2.00 (1.00)
Minimum/Maximum Radii	0.10 (0.02)	0.02 (0.01)	0.10 (0.01)	0.18 (0.02)	0.03 (0.01)	0.10 (0.02)	0.13 (0.02)	0.08 (0.02)	0.09 (0.02)
Ellipsoid Volume	0.13 (0.05)	0.05 (0.01)	0.20 (0.01)	0.12 (0.02)	0.02 (0.01)	0.13 (0.01)	0.10 (0.04)	0.06 (0.03)	0.05 (0.06)

Table 2: Criteria differences in Motion II of the three fingers in all the planes

Variation in Criteria	Motion II								
	ETP			ITP			FXP		
	Thumb	Index	Middle	Thumb	Index	Middle	Thumb	Index	Middle
Major Axis Direction Angle (deg)	19.00 (3.0)	3.00 (1.00)	8.00 (1.00)	22.00 (4.00)	3.00 (1.0)	4.00 (1.0)	14.00 (1.00)	5.00 (1.0)	5.00 (1.00)
Minimum/Maximum Radii	0.09 (0.03)	0.08 (0.01)	0.17 (0.02)	0.18 (0.02)	0.07 (0.03)	0.14 (0.04)	0.13 (0.02)	0.10 (0.01)	0.18 (0.02)
Ellipsoid Volume	0.18 (0.05)	0.14 (0.03)	0.25 (0.04)	0.14 (0.01)	0.13 (0.03)	0.23 (0.01)	0.11 (0.02)	0.08 (0.02)	0.20 (0.01)

Table 3: Average distance travelled by the three digits in Motion I in all the three planes

Digit	Motion I in mm (SD)		
	ETP	ITP	FXP
Thumb	5.74 (0.96)	5.77 (1.01)	3.68 (0.77)
Index Finger	4.17(0.98)	4.40 (0.96)	3.44 (0.96)
Middle Finger	6.76(1.09)	6.67 (1.03)	6.68 (1.02)

Table 4: Average distance travelled by the three digits in Motion II in all the three planes

Digit	Motion II in mm (SD)		
	ETP	ITP	FXP
Thumb	10.82 (1.27)	10.87 (1.25)	8.48 (1.57)
Index Finger	7.77 (1.34)	7.63 (1.16)	6.13 (0.73)
Middle Finger	12.04 (1.99)	11.61 (1.68)	11.00 (1.17)

Discussion

❖ Weak Sense

❖ Strong Sense



Concluding Remarks

- ❖ In this piece of investigation, experiments using a 3D motion capture system involving thumb, index and middle finger are performed.
- ❖ Joint angle variations are studied for cooperative object rotation motions.
- ❖ Analysis of results reveal that the thumb and middle finger actively control the rotation of small objects which are passively supported by the index finger.
- ❖ The findings of this study is important in the design of the three finger exoskeleton for rehabilitation purposes.

Thank You!

