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WORKSPACE ANALYSIS AND THE EFFECT OF GEOMETRIC PARAMETERS FOR PARALLEL MECHANISMS OF THE N-UUU CLASS

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1. INTRODUCTION
Hand-Forearm Assembly
- 12 DOF
- 290mm x 70mm x 40mm
- 0.95 kg
iCUB WRIST

2DOF Tendon-Driven Coupled Mechanism
DESIRED CHARACTERISTICS

2 Fully Decoupled DOF
   Independent Yaw and Pitch Motions.

Large Range of Motion
   Over +/- 45 degrees.

Simpler Kinematics
   Easy to model and control.

Compact Design
   Space Constraints on the forearm.

Higher Payload-to-Weight Ratio
   Higher payload-to-weight ratio.
N-UU MECHANISMS

Wu and Carricato; ASME J. Mechanisms and Robotics; 2017
OMNI - WRIST III

Mirror-symmetric architecture, large hemispherical workspace, slender form factor
2. MODELLING & SIMULATION
OUR APPROACH

- **CAD Model**: Create conceptual design of the mechanism using CAD tools.
- **Mechanism Simulation**: Run kinematic simulations spanning the entire actuator range.
- **Extract Measures**: Record and extract platform coordinates and orientation angles throughout the simulation.
- **Contour Plots**: Generate workspace and isotropy contours against the input actuators.
MECHANISM SIMULATION

Full workspace scan of the mechanism.
CONSTANT MAGNITUDE

NORMALIZED CARTESIAN WORKSPACE
3. ANALYSES
WORKSPACE ANALYSES - PLATFORM COORDINATES - GIMBAL

X

Y

Z

2DOF Gimbal X-Coordinate

2DOF Gimbal Y-Coordinate

2DOF Gimbal Z-Coordinate
WORKSPACE ANALYSES - PLATFORM COORDINATES - $\alpha = 30^\circ$
WORKSPACE ANALYSES - PLATFORM COORDINATES - $\alpha = 45^\circ$
WORKSPACE ANALYSES - PLATFORM COORDINATES - \( \alpha = 60^\circ \)
WORKSPACE ANALYSES - EULER ANGLES - $\alpha = 30^\circ$

- **Roll**
- **Yaw**
- **Pitch**
WORKSPACE ANALYSES - EULER ANGLES - $\alpha = 60^\circ$
\[ J = \begin{bmatrix}
\frac{\partial \theta_p}{\partial q_1} & \frac{\partial \theta_p}{\partial q_2} \\
\frac{\partial \theta_y}{\partial q_1} & \frac{\partial \theta_y}{\partial q_2}
\end{bmatrix} \]

\[ \Delta = \frac{M}{\Psi} = \frac{\sqrt[\text{m}]{\text{det}(JJ^T)}}{\text{trace}(JJ^T)/m} \]
CONCLUSIONS

**Spherical**
The magnitude of the platform center w.r.t the base is always constant.

**Asymmetry**
Mechanism behaviour is not symmetric, i.e., the plots are not centered with zero.

**Warping**
Workspace diverges towards the extremes. This effect increases with $\alpha$.

**Parasitic motion**
Platform possesses undesired *Roll* motion.

**Coupling**
Pitch and yaw motions of the platform are dependent of each other.

**Anisotropy**
Mechanism is not fully isotropic throughout the workspace. Anisotropy increases with $\alpha$. 
OPENING

Post-Doc on “The design of better iCub Hands”

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Any questions?

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FIN.
ANALYTICAL MODEL

» Limb A
\[ A = A_1(\theta_1)A_2(\theta_2)A_3(\theta_3)A_4(\theta_4) \]

» Limb B
\[ B = B_5(\theta_5)B_6(\theta_6)B_7(\theta_7)B_8(\theta_8) \]

» Platform C
\[ C = T_{XYZ}(x, y, z)R_Z(\alpha)R_Y(\beta)R_X(\gamma) \]

» Closed-Form
\[ A = B = C \]
ERROR COMPARISON BETWEEN CAD SIMULATION AND ANALYTICAL COMPUTATIONS
4.

GAMMA CASE PLOTS
WORKSPACE ANALYSES - X COORDINATE [GAMMA CASE]

Gimbal

\[ \gamma = 120^\circ \]

\[ \gamma = 90^\circ \]
WORKSPACE ANALYSES - Y COORDINATE [GAMMA CASE]

Gimbal

\( \gamma = 120^\circ \)

\( \gamma = 90^\circ \)
WORKSPACE ANALYSES - Z COORDINATE [GAMMA CASE]

Gimbal

\( \gamma = 120^\circ \)

\( \gamma = 90^\circ \)
Gimbal

$\gamma = 120^\circ$

$\gamma = 90^\circ$
WORKSPACE ANALYSES - YAW [GAMMA CASE]

Gimbal

$\gamma = 120^\circ$

$\gamma = 90^\circ$
WORKSPACE ANALYSES - PITCH [GAMMA CASE]

Gimbal

\( \gamma = 120^\circ \)  
\( \gamma = 90^\circ \)
ISOTROPY ANALYSIS [GAMMA CASE]

Gimbal

$\gamma = 120^\circ$

$\gamma = 90^\circ$