Estimation of human joint mechanical impedance during a tooling task

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human skills capturing and transfer to robots
Human arm Impedance as an addition to hybrid control

- Experimental assessment
- Cartesian analysis (tool perspective)
- Transfer of skills

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Assessing Human Impedance

Mechanical Impedance of Human Arm

Mechanical impedance refers to the forces generated by a system in response to an imposed motion. When a limb is slightly perturbed during a movement or static posture, it tends to move back to the original trajectory or position. The mechanical impedance is represented by inertia, damping, and stiffness.

Stiffness Estimation:

During Posture

![Diagram of a limb with forces and angles labeled](image1)

\[
[I_{\text{end}}] \begin{bmatrix} \ddot{x} \\ \ddot{y} \end{bmatrix} + [B_{\text{end}}] \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} + [K_{\text{end}}] \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} f_x \\ f_y \end{bmatrix}
\]


During Movement

![Diagram of a limb with forces and angles labeled](image2)

\[
\begin{bmatrix} \delta \tau_s \\ \delta \tau_e \end{bmatrix} = \Delta K_q \begin{bmatrix} \Delta q_s \\ \Delta q_e \end{bmatrix}
\]

Sense of touch (haptics) and its importance for manipulation

desensitized fingers

Johansson, 2005

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In-Line Haptic Sensing

- Motion capture
- Kinematic Measurements
- Dynamic Measurements
- Loadcell
- IMU
- 3D vibration
- In-Line Sensing
- Stiffness Estimation
haptics for industrial robots
The contact force at the task space can be estimated as:

\[ F_e = F - mg \]
Dynamics Estimation of Contact

A wrench $W$ represents the force and torque acting on the tool: $W = [F \ T]^T \in \mathbb{R}^6$

The estimated contact point is given by: $T = r \times F$
Dynamic Measurements

Dynamics Estimation of Contact

Loadcell

\( r \)

\( F \)

\( \omega \)

workpiece

wrench-axis

\( S \)

CP

Loadcell

x-direction [mm]

z-direction [mm]

-10

-15

-20

-25

-30

-35

-40

0

5

10

x-direction [mm]
The estimated contact point (CP) is given by the intersection between the wrench-axis and the surface $S$ of the mounting-bit.
Dynamic Measurements

Geometry of mounting-bit

Once the contact point $\mathbf{r} = [x \ y \ S(x,y)]^T$ is determined, the first order analysis allows measuring two tangent vectors to the surface, and the vector $\mathbf{n}$ normal to the surface.

$$\mathbf{r}_x = \frac{\partial \mathbf{r}}{\partial x} \quad ; \quad \mathbf{r}_y = \frac{\partial \mathbf{r}}{\partial y} \quad ; \quad \mathbf{n} = \frac{\mathbf{r}_x \times \mathbf{r}_y}{||\mathbf{r}_x \times \mathbf{r}_y||}$$

$\{\mathbf{r}_x \ \mathbf{r}_y\}$ gives the tangent plane $\Pi$ at the contact point.
Dynamic Measurements

Geometry of mounting-bit

Splitting the interaction force $F$ into tangent plane $\Pi$ and normal vector $n$

$$F_n = \frac{F \cdot n}{\|n\|} n$$

$$F_{\Pi} = \frac{n \times (F \times n)}{\|n\|^2}$$
Assessing human skills during tooling tasks

- Infra-red Markers
- EMG
- Instrumented tool
- Work-piece

Estimated Stiffness

Estimated Angle

Measured Torque

\[ \hat{k}^{RU} = 5.10 \text{ [Nm/rad]} \]
transferring human skills to robots

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\[
\begin{bmatrix}
T_{RU}^i \\
\end{bmatrix} = T_{avg}^{RU} + \begin{bmatrix}
q_{RU}^i \\
\dot{q}_{RU}^i \\
\end{bmatrix} \begin{bmatrix}
\hat{k} \\
\hat{b} \\
\end{bmatrix}
\]

\[\hat{k} = 10.28 \text{ Nm/rad} \]
\[\hat{b} = 2.02 \text{ Nms/rad} \]

\[
\begin{align*}
\hat{k}^\prime &= 10.34 \text{ Nm/rad} \\
\end{align*}
\]
THANK YOU