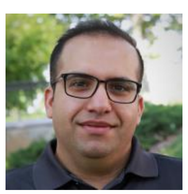
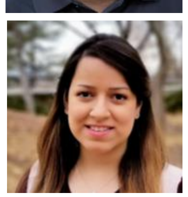
PIONEERS WORKSHOP 2021

ROBOTICS CENTER
THE UNIVERSITY OF UTAH

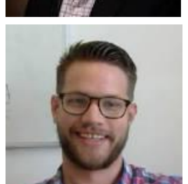
LL4MA LAB
THE UNIVERSITY OF UTAH

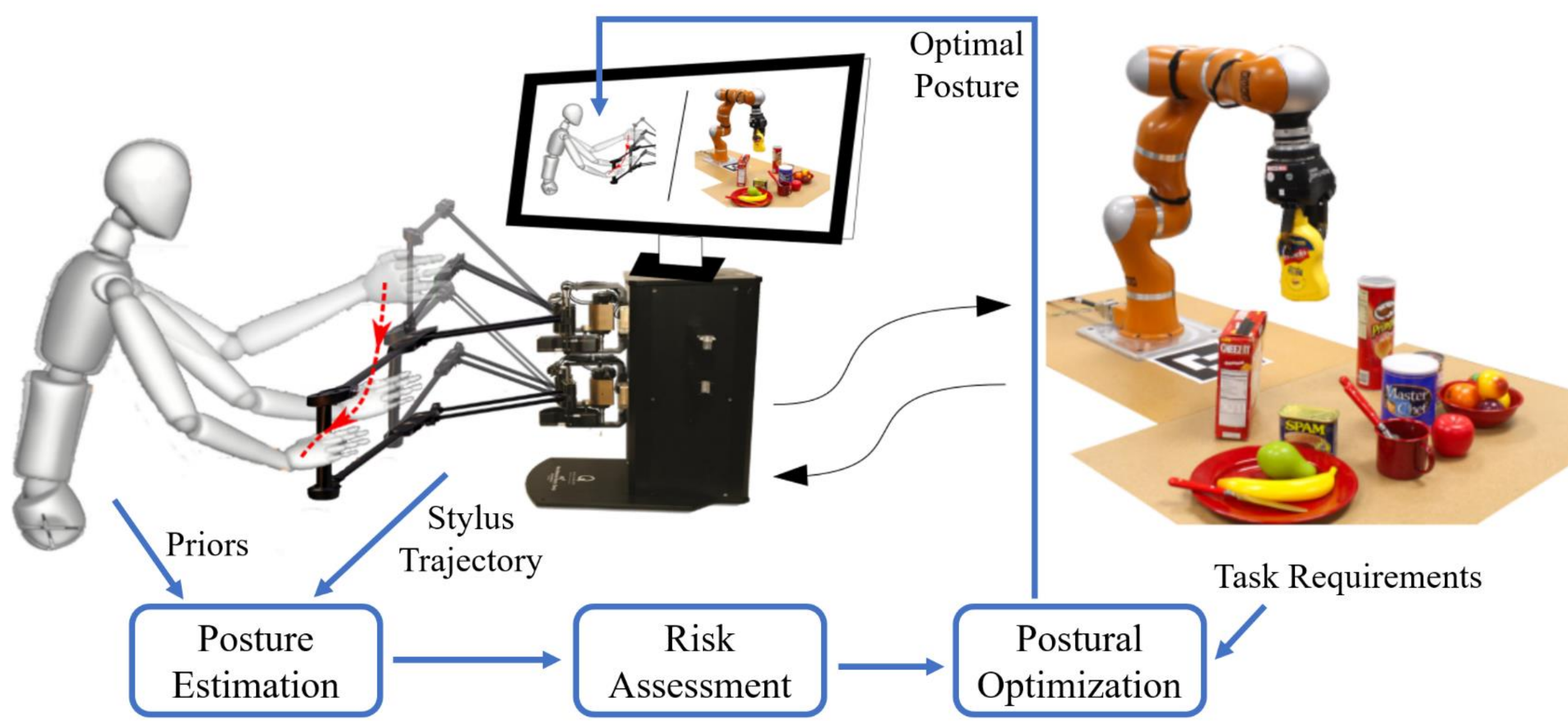
Posture Estimation and Optimization for Ergonomically Intelligence Teleoperation Systems


Amir Yazdani


Roya Sabbagh Novin


Andrew Merryweather


Tucker Hermans

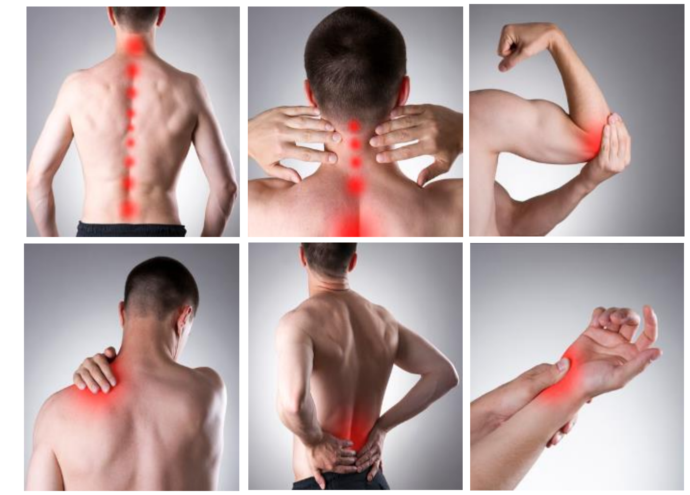


March 8, 2021

Work-Related Injuries in Teleoperation

Work-related musculoskeletal disorders:

- The 2nd largest cause of disabilities worldwide (Vos et al. 2015)
- Main contributor: awkward postures



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A Solution: Teleoperation

- Remotely control the <u>follower</u> robot using a <u>leader</u> robot
- An example of physical-HRI
- Benefit: Design the remote workspace optimally w.r.t. ergonomics

Da Vinci robot, by Intuitive Surgical

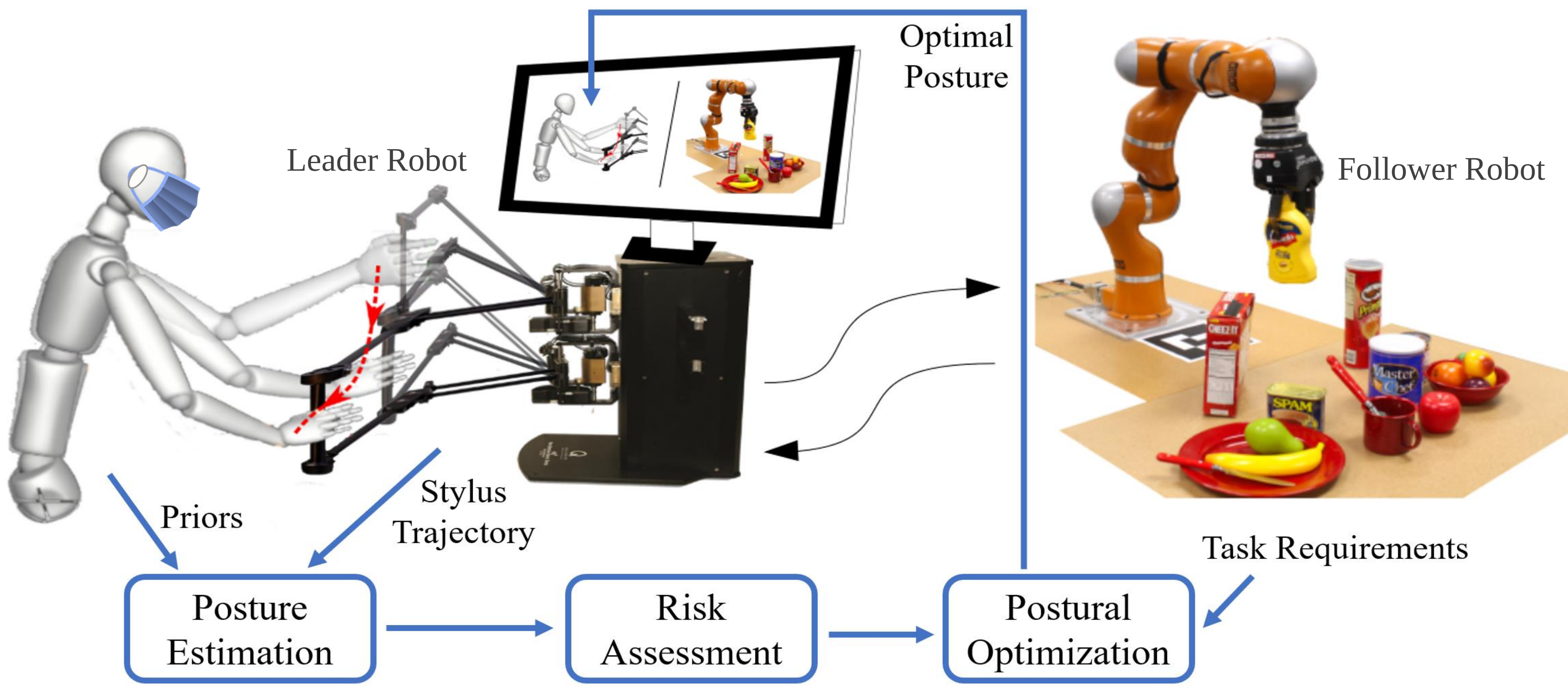
Still high rate of injuries among human teleoperator!

(Peternel et al. 2020, Yu et al. 2014)

Sarcos Guardian GT

Ergonomically Intelligent Teleoperation Systems

Our Solution

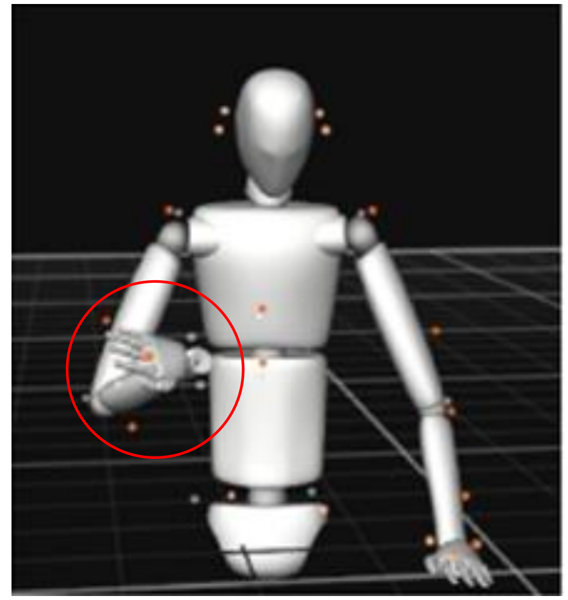


3D Posture Estimation Solely From the Leader Robot

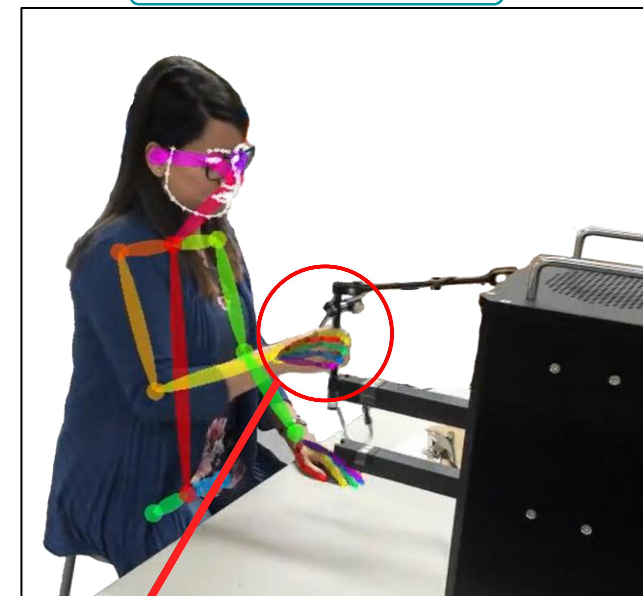
Vison-based posture estimation:

- Require extra sensor
- Tedious setup & calibration
- Occlusion
- Sensitive to background light
- Sensitive to cloths
- Attach markers on body

Marker-Based

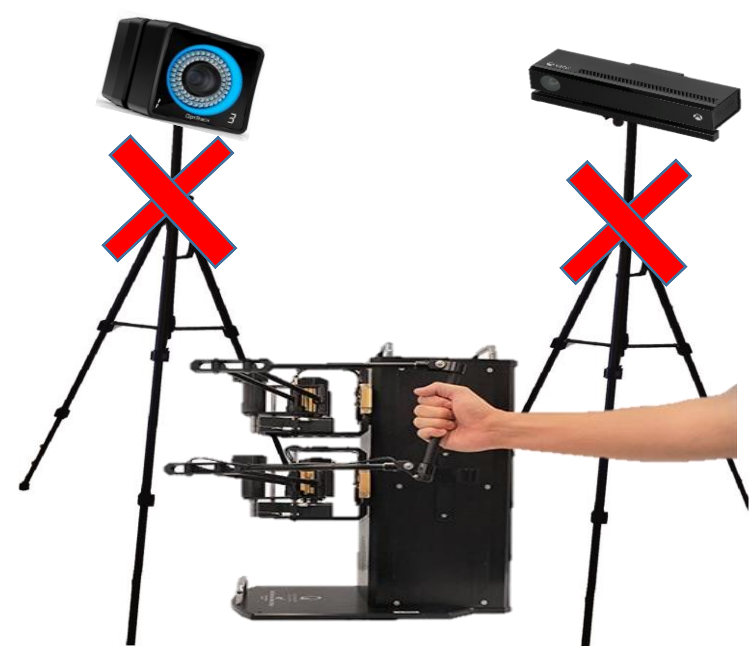


Markerless

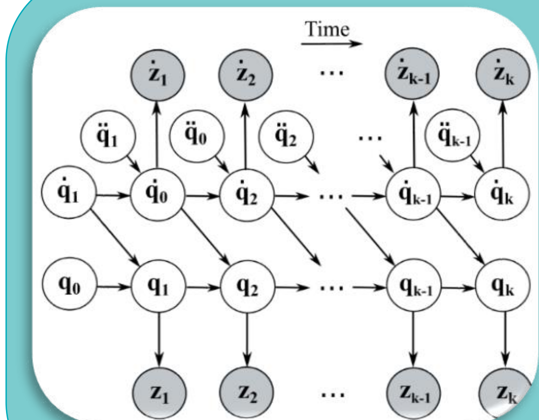


Physical Interaction

Use the leader robot as the only sensor for 3D posture estimation



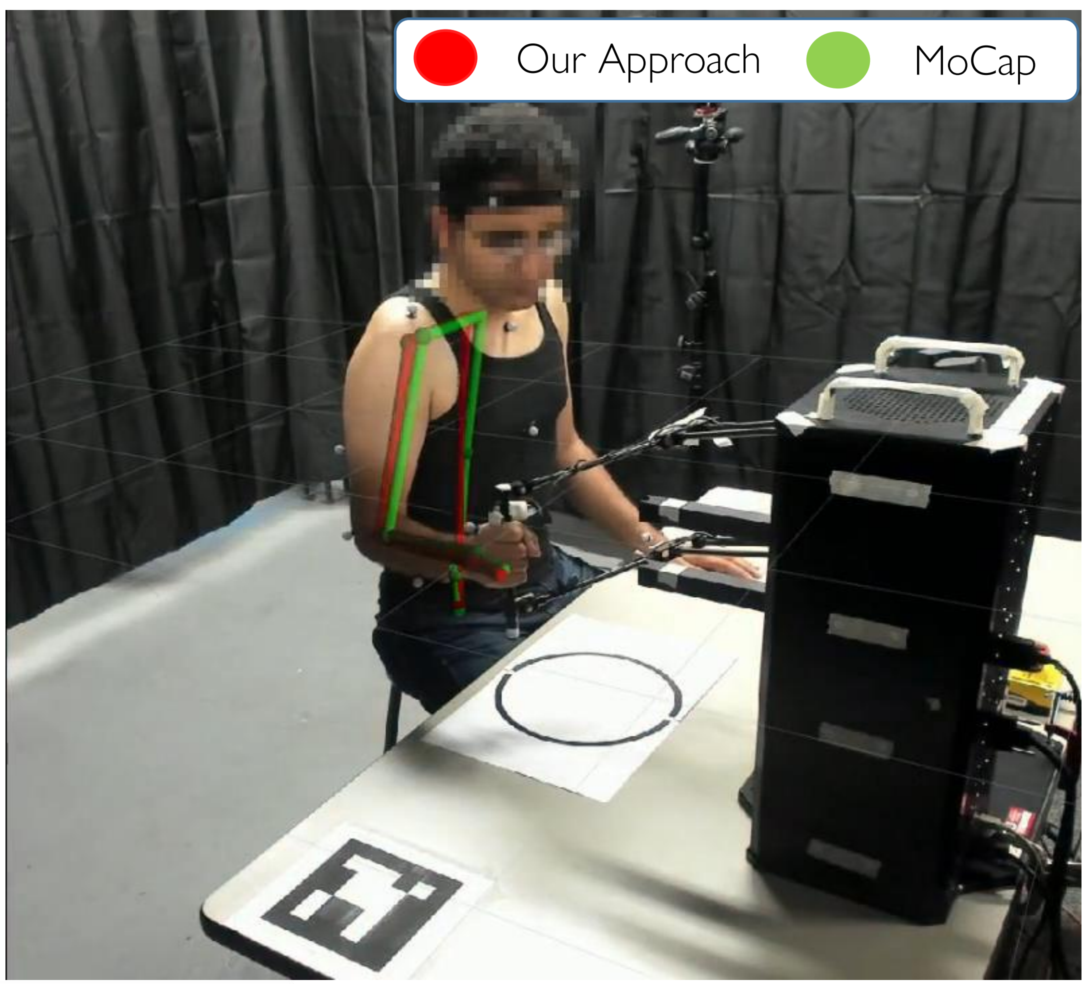
3D Posture Estimation Solely From the Leader Robot



Joint Angles Estimation

Partially-Observable Dynamic System

- Particle filter for inference
- Learned model for pose-dependant range of motion (Jiang et al, 2018)



Human subject study

- 8 participants
- 4 tasks, 2 trials each

5 deg
Median Deviation

15 deg
Upper Quartile Deviation

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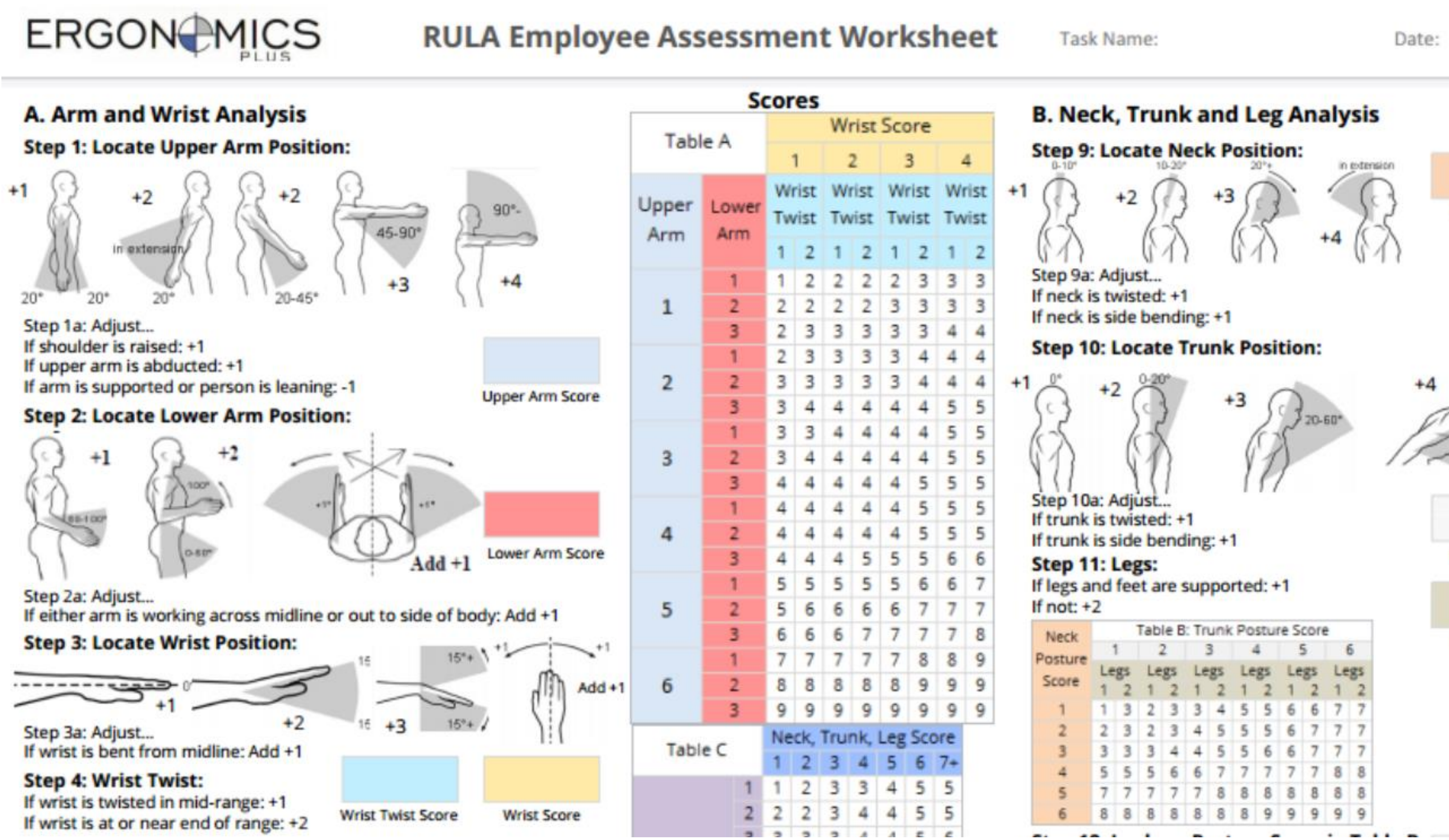
Ergonomic Risk Assessment

Rapid Upper Limb Assessment (RULA):

- The most common posture-dependent risk assessment tool
- Discrete output score (1-7) ⟶ not differentiable

84%
Accuracy in RULA Risk Assessment



ERGONOMICS PLUS

RULA Employee Assessment Worksheet

Task Name:

Date:

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 2: Locate Lower Arm Position:

Lower Arm Score

Step 2a: Adjust...
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

Step 3a: Adjust...
If wrist is bent from midline: Add +1

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Wrist Score

Scores

Table A		Wrist Score 1		Wrist Score 2		Wrist Score 3		Wrist Score 4	
Upper Arm	Lower Arm	Wrist Twist 1	Wrist Twist 2	Wrist Twist 1	Wrist Twist 2	Wrist Twist 1	Wrist Twist 2	Wrist Twist 1	Wrist Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C		Neck, Trunk, Leg Score 1	2	3	4	5	6	7+
	1	1	2	3	3	4	5	5
	2	2	2	3	4	4	5	5

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

Neck Score

Step 9a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 10: Locate Trunk Position:

Trunk Score

Step 10a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

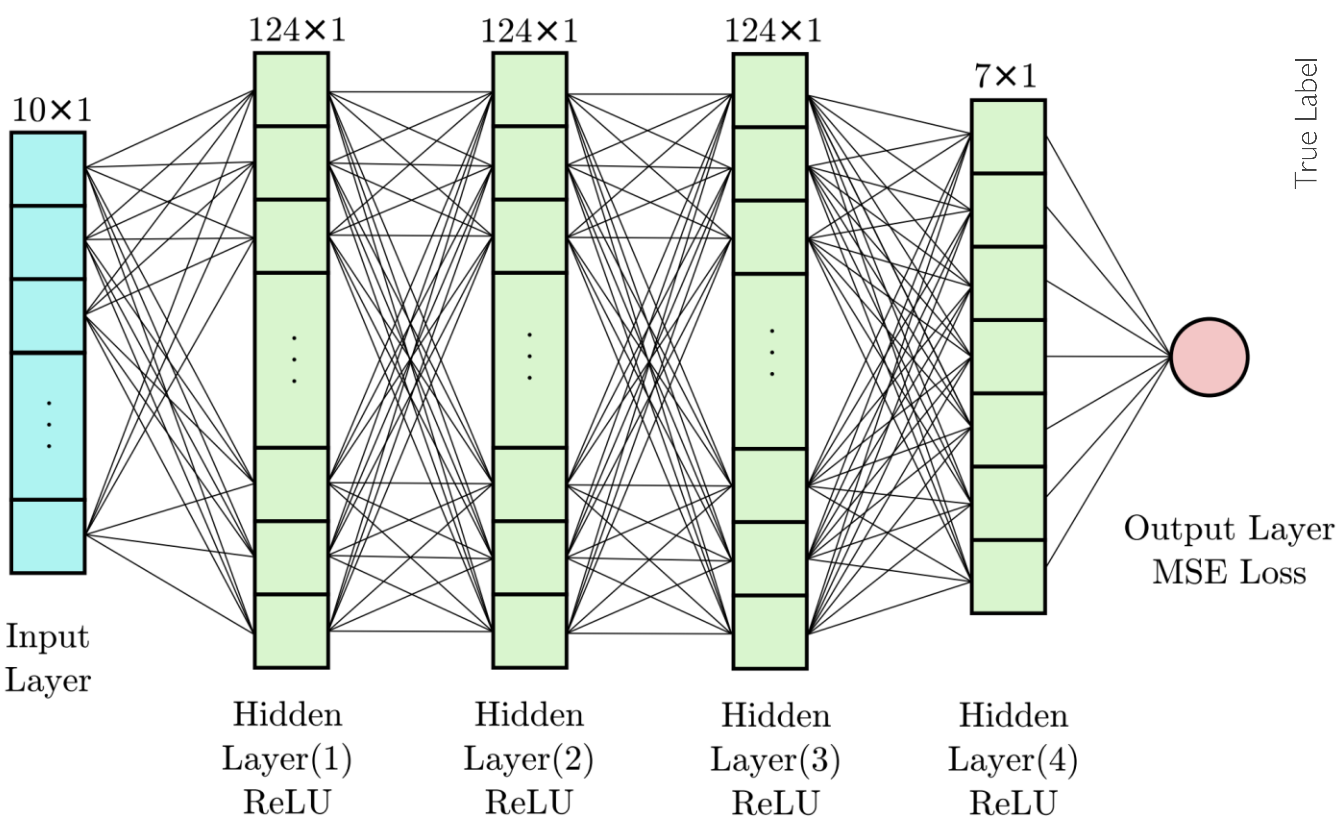
Neck Posture Score	Table B: Trunk Posture Score 1		2		3		4		5		6	
	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2	Legs 1	Legs 2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

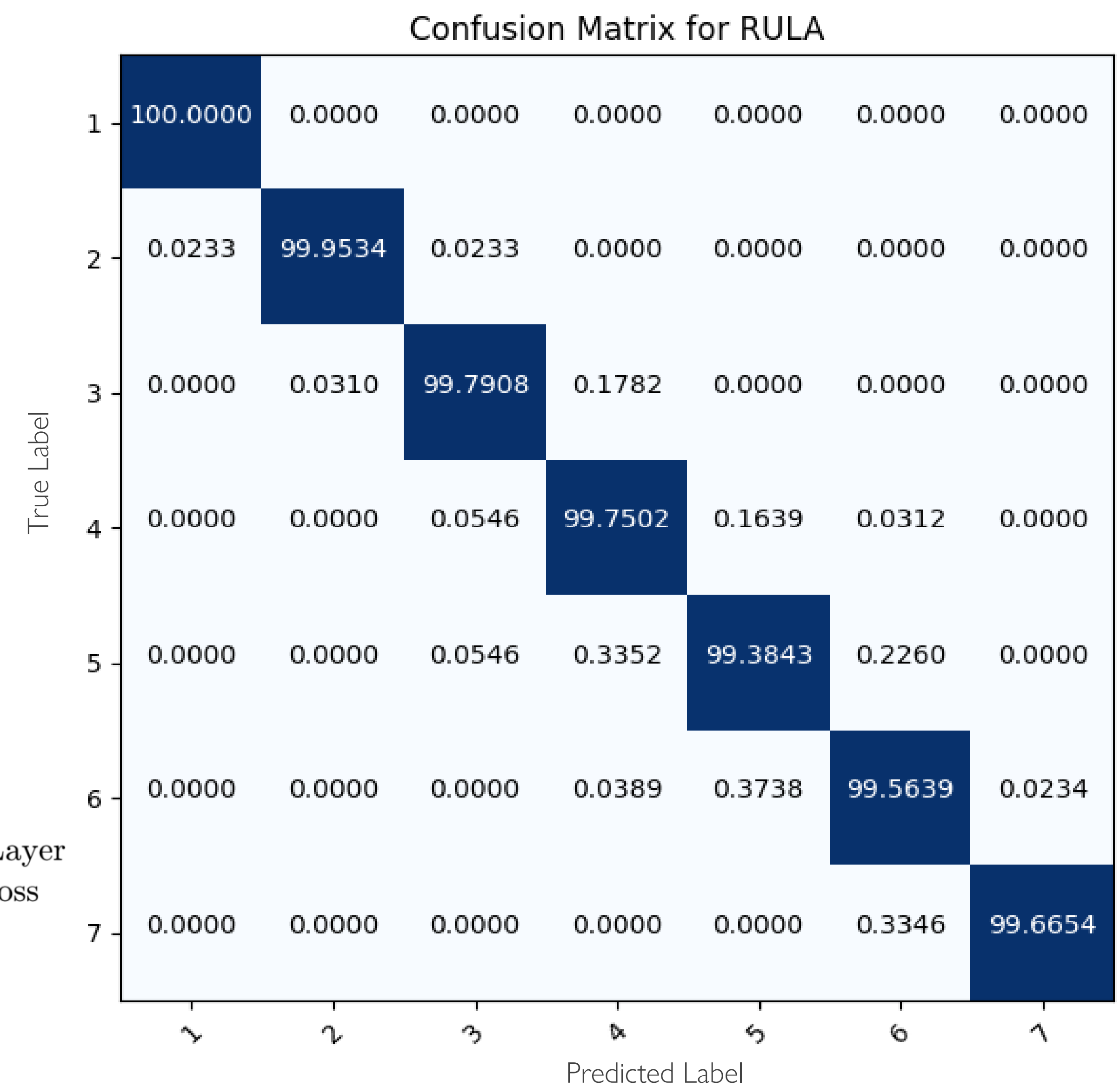
Ergonomic Risk Assessment

Learned a continuous & differentiable neural network model for RULA

Learning RULA score:

- 5-layer neural networks
- Regression with discrete labels
- 99.7% accuracy





Posture Optimization In Teleoperation

Teleoperation Tasks

Goal-Constrained Tasks

Path-Constrained Tasks

Trajectory-Constrained Tasks

Postural Correction

Online Posture Correction

$$ {}^h\mathbf{q}^*_{t_c} = \arg\min_{{}^h\mathbf{q}_t} \ \mathrm{RULA}({}^h\mathbf{q}_{t_c}) $$
$$ s.t. \ \left\| {}^h\mathbf{x}_{t_c} - \Phi({}^h\mathbf{q}_{t_c}) \right\|^2_{\Sigma} < \epsilon $$

Posture Correction through Interface Reconfiguration

$$ {}^h\boldsymbol{\tau}^*_{t_c \to T} = \arg\min_{{}^h\boldsymbol{\tau}_{t_c \to T}} \sum_{t=t_c}^{T} \mathrm{RULA}({}^h\mathbf{q}_t) $$
$$ s.t. \ \left\| {}^h\tilde{\dot{\mathbf{x}}}_t - {}^hJ({}^h\mathbf{q}_t)\,{}^h\dot{\mathbf{q}}_t \right\|^2_{\Sigma} < \epsilon \ \text{ for } \forall t \geq t_c $$

Initial Posture Correction

$$ {}^h\mathbf{q}^*_0 = \arg\min_{{}^h\mathbf{q}_0} \sum_{t=0}^{T} \mathrm{RULA}({}^h\mathbf{q}_t) $$
$$ s.t. \ \left\| {}^h\tilde{\dot{\mathbf{x}}}_t - {}^hJ({}^h\mathbf{q}_t)\,{}^h\dot{\mathbf{q}}_t \right\|^2_{\Sigma} < \epsilon \ \text{ for } \forall t \geq t_c $$

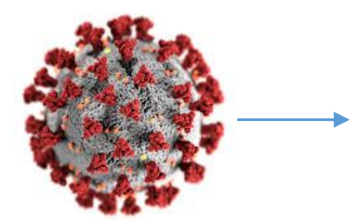
Optimal posture:

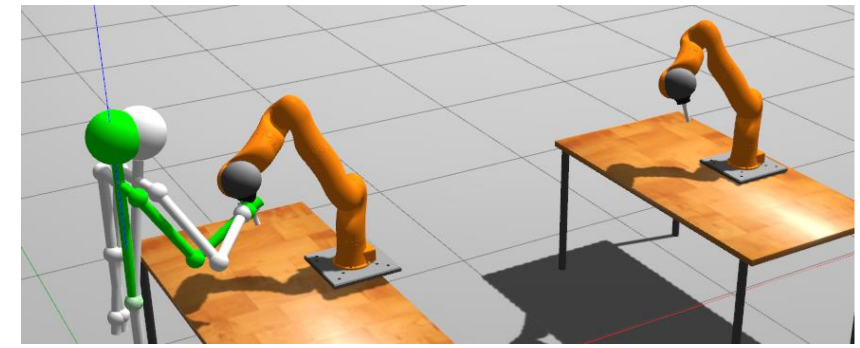
- Gradient-based solver: Sequential Quadratic Programming ← Learned RULA
- Gradient-free solver: Cross-Entropy Method ← Normal RULA

Posture Optimization In Teleoperation

Teleoperation simulator:

- Simulation in Gazebo, including a human teleoperator simulator, and the robots
- Human teleoperator simulator:
  - Completes the teleoperation tasks
  - Applies the correction probabilistically
  - Optimization-based replanning algorithm





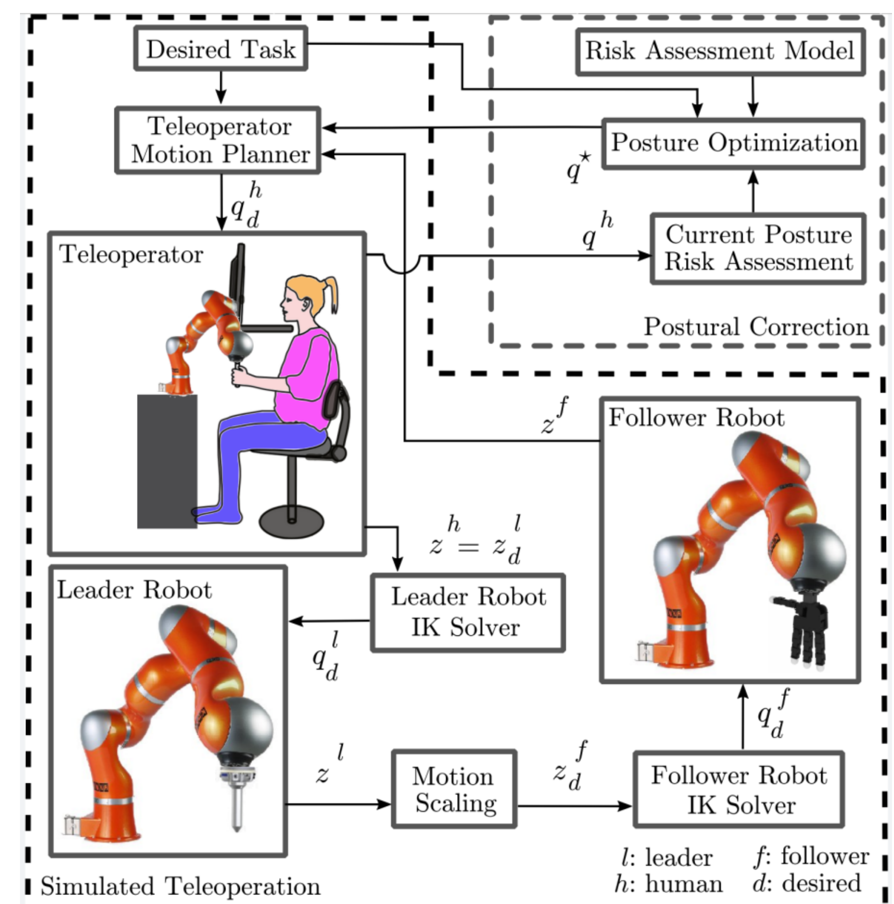
$$^{h,l,f}\boldsymbol{\tau}^{*}_{0\to T} = \arg \min_{^{h,l,f}\boldsymbol{\tau}_{0\to T}} \sum_{t=0}^{T} \left\| {}^{f}\mathbf{x}_{g} - {}^{f}\mathbf{x}_{T} \right\|_{\Sigma}^{2} + \alpha \left\| {}^{h}\mathbf{q}^{*}_{t} - {}^{h}\mathbf{q}_{t} \right\|_{\Sigma}^{2}$$

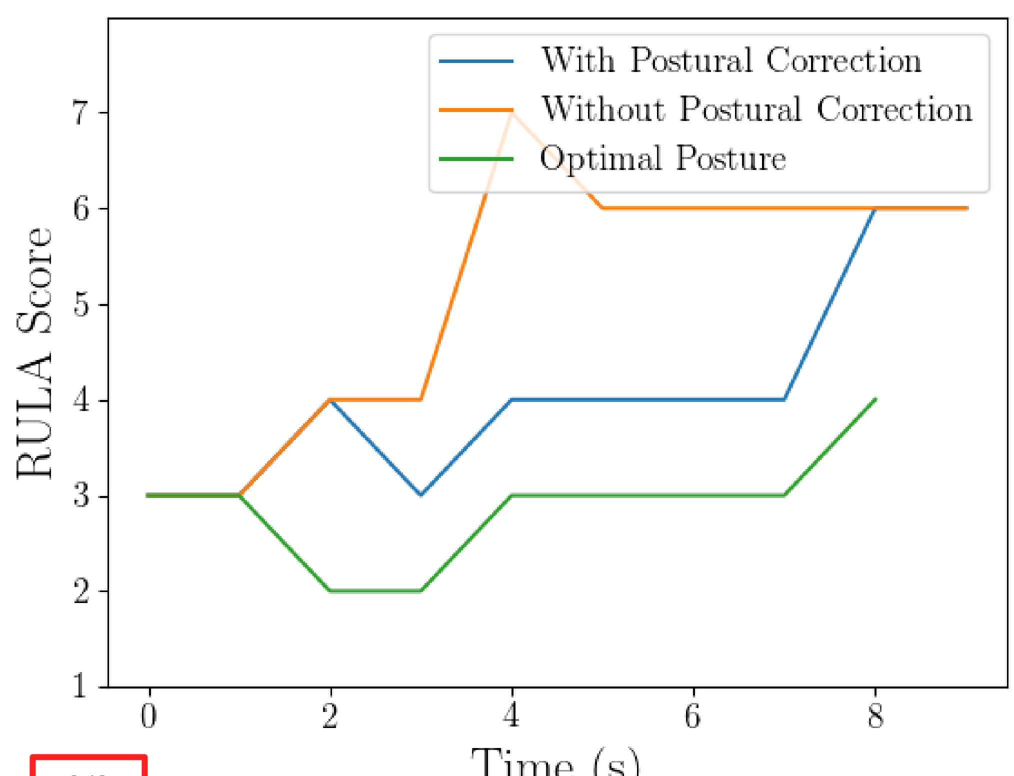
$$s.t. \quad {}^{h}\dot{\mathbf{x}}_t = {}^{h}J({}^{h}\mathbf{q}_t)\,{}^{h}\dot{\mathbf{q}}_t,\ {}^{l}\dot{\mathbf{x}}_t = {}^{l}J({}^{l}\mathbf{q}_t)\,{}^{l}\dot{\mathbf{q}}_t,\ {}^{f}\dot{\mathbf{x}}_t = {}^{f}J({}^{f}\mathbf{q}_t)\,{}^{f}\dot{\mathbf{q}}_t$$

$${}^{l}\dot{\mathbf{x}}_t = {}^{h\to l}T \times {}^{h}J({}^{h}\mathbf{q}_t)\,{}^{h}\dot{\mathbf{q}}_t, \qquad {}^{f}\dot{\mathbf{x}}_t = {}^{l\to f}S \times {}^{l}J({}^{l}\mathbf{q}_t)\,{}^{l}\dot{\mathbf{q}}_t$$

$${}^{l}\mathbf{x}_t = {}^{h\to l}T \times {}^{h}\mathbf{x}_t$$

$${}^{h}\mathbf{q}_{t:0,\dots,T},\ {}^{l}\mathbf{q}_{t:0,\dots,T},\ {}^{f}\mathbf{q}_{t:0,\dots,T} \in \text{Range of Motion}$$

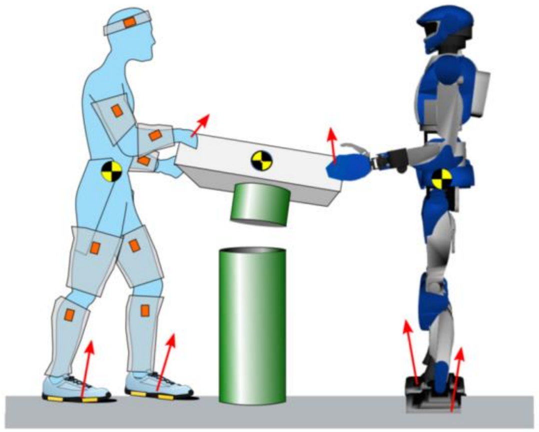




Other Applications and Future Work

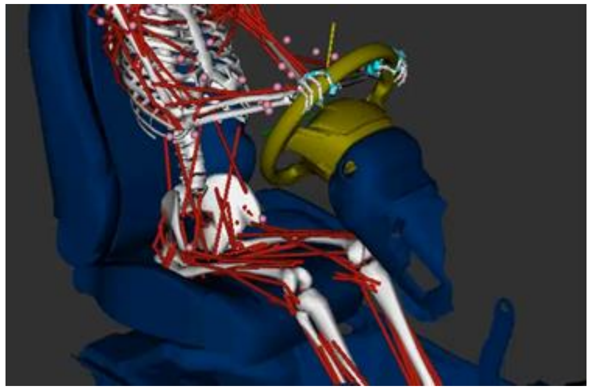
Applications:

- Other p-HRI tasks
- VR systems using pose of controllers
- Drivers holding steering wheel
- Assistive rehabilitations & exoskeletons



Otani et al. 2018

Courtesy of Facebook



Courtesy of Honda Research Inst.

Future work:

- Postural correction through motion rate control and visual feedback
- Conduct a human subject study
  - evaluate our posture optimization methods
  - compare the effectiveness of correction feedbacks
- Multi-modal posture estimation (our approach + OpenPose in GTSAM)

Courtesy of OT Potential

SCAN ME

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