

Posture Estimation and Optimization in Ergonomically Intelligent Teleoperation Systems

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WHY ERGONOMICS IS A CONCERN IN TELEOPERATION?

Work-related musculoskeletal disorders:

- The second largest cause of disabilities worldwide
- Main contributor: awkward postures
- Continuous data collection and ergonomic assessment of human posture is tedious



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Teleoperation:

- Remotely control the **follower** robot using a **leader** robot
- An example of physical-HRI
- Teleoperation improves the ergonomics by the ability to design the remote workspace optimally



Da Vinci robot, by Intuitive Surgical

Still high rate of injuries among human teleoperator!

ERGONOMIC RISK ASSESSMENT

RULA risk assessment:

- RULA is the most common posture-dependent risk assessment tool
- Discrete output score \rightarrow not differentiable

ERGONOMICS RULA Employee Assessment Worksheet

Task Name: _____ Date: _____

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position: _____

Step 2: Locate Lower Arm Position: _____

Step 3: Locate Wrist Position: _____

Step 4: Wrist Twist: _____

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position: _____

Step 10: Locate Trunk Position: _____

Step 11: Legs: _____

Table A: Wrist Score

Upper Arm	Lower Arm	Wrist	Wrist Twist	Wrist Twist	Wrist Twist
1	1	2	2	2	3
2	2	2	2	2	3
3	2	3	3	3	3
4	3	3	3	3	4
5	3	3	3	3	4
6	4	4	4	4	5
7	4	4	4	4	5
8	4	4	4	4	5
9	5	5	5	5	6
10	5	5	5	5	6
11	6	6	6	6	7
12	6	6	6	6	7
13	6	6	6	6	7
14	7	7	7	7	8
15	7	7	7	7	8
16	8	8	8	8	9
17	8	8	8	8	9
18	9	9	9	9	9
19	9	9	9	9	9

Table B: Neck, Trunk, Leg Score

Neck	Trunk	Legs	Legs	Legs	Legs
1	2	3	4	5	6
2	3	4	5	6	7
3	4	5	6	7	8
4	5	6	7	8	9
5	6	7	8	9	9
6	7	8	9	9	9
7	8	9	9	9	9
8	9	9	9	9	9
9	9	9	9	9	9
10	9	9	9	9	9
11	9	9	9	9	9
12	9	9	9	9	9
13	9	9	9	9	9
14	9	9	9	9	9
15	9	9	9	9	9
16	9	9	9	9	9
17	9	9	9	9	9
18	9	9	9	9	9
19	9	9	9	9	9
20	9	9	9	9	9

Table C: Neck, Trunk, Leg Score

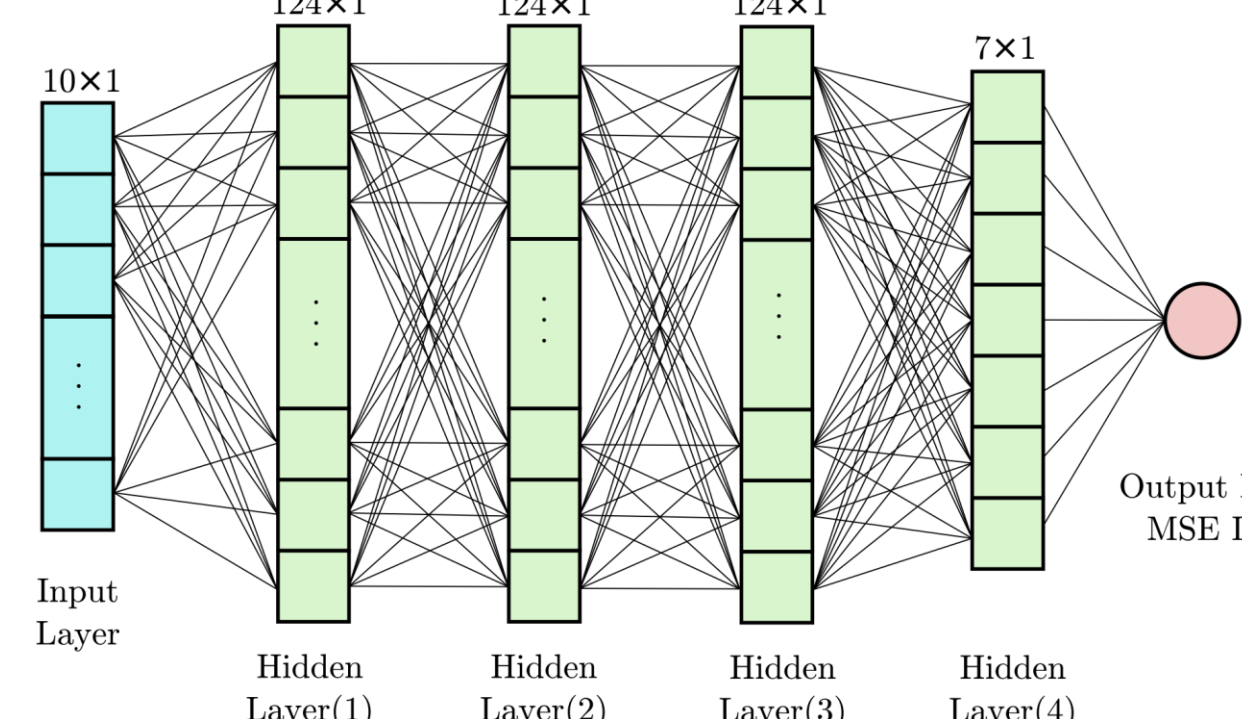
Neck	Trunk	Leg Score
1	2	3
2	3	4
3	4	5
4	5	6
5	6	7
6	7	8
7	8	9
8	9	9
9	9	9
10	9	9
11	9	9
12	9	9
13	9	9
14	9	9
15	9	9
16	9	9
17	9	9
18	9	9
19	9	9
20	9	9

Courtesy of Ergonomics Plus

Learned a continuous & differentiable neural network model for RULA

Learning RULA score:

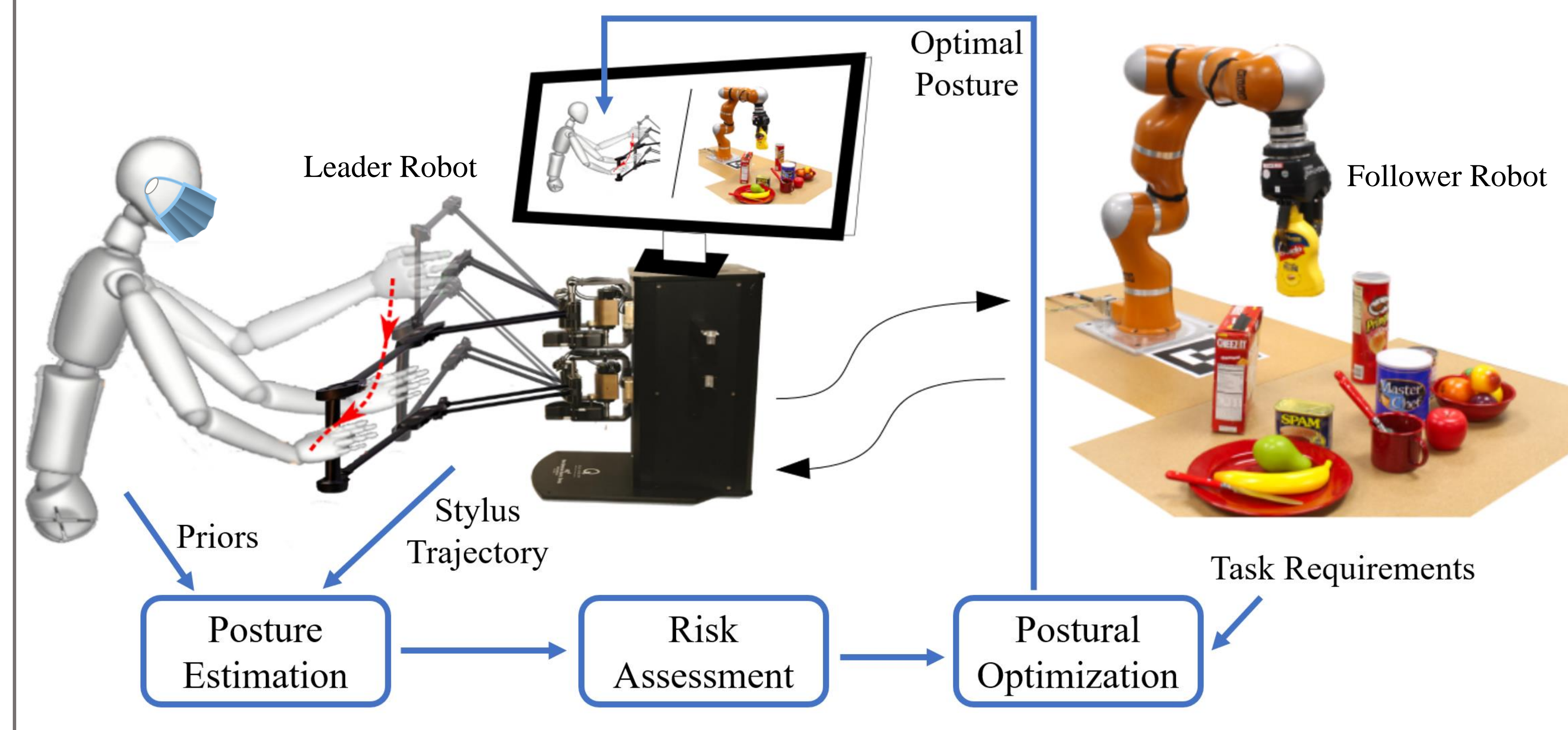
- 5-layer neural networks
- Regression with discrete labels
- 99.7% accuracy



Confusion Matrix for RULA

True Label \ Predicted Label	1	2	3	4	5	6	7
1	100.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0233	99.9534	0.0233	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0310	99.7908	0.1782	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0546	99.7502	0.1639	0.0312	0.0000
5	0.0000	0.0000	0.0546	0.3352	99.3843	0.2260	0.0000
6	0.0000	0.0000	0.0000	0.0389	0.3738	99.5639	0.0234
7	0.0000	0.0000	0.0000	0.0000	0.0000	0.3346	99.6654

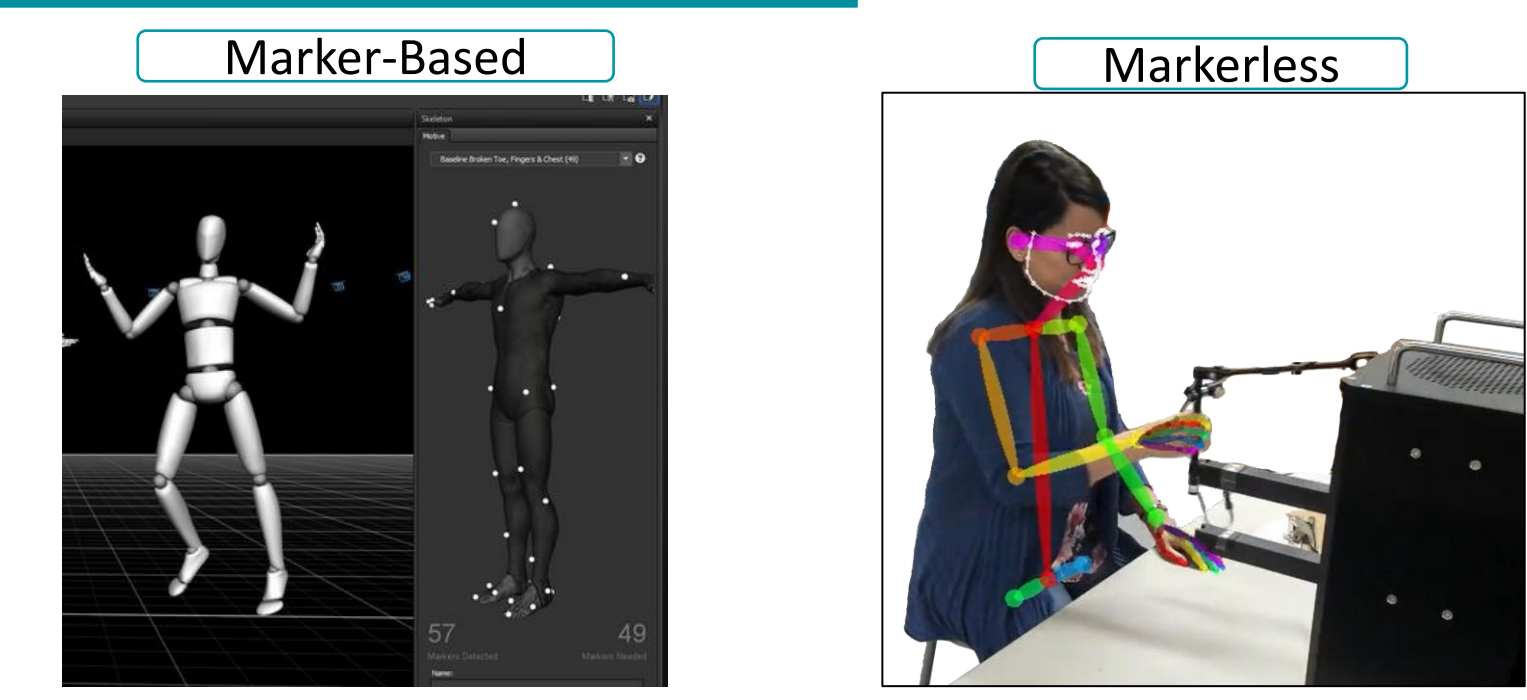
ERGONOMICALLY INTELLIGENT TELEOPERATION SYSTEMS



3D POSTURE ESTIMATION SOLELY FROM THE LEADER ROBOT

Vision-based posture estimation:

- Require extra sensor
- Setup & calibration
- Occlusion
- Sensitive to background light
- Sensitive to cloths
- Attach marker on body



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

Circle Point Analysis

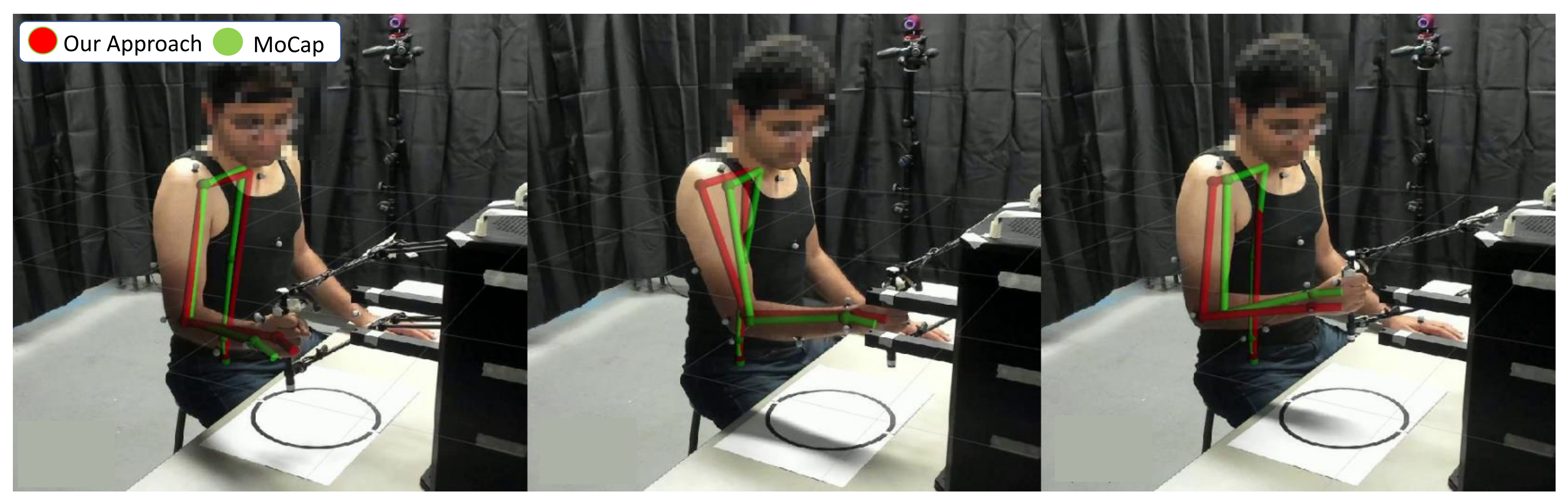
- Circular motion routines while holding the leader robot's stylus
- Estimate the radius of each motion

Partially-Observable Dynamic System

- Particle filter for inference
- Pose-dependant range of motion
- Initialize around neutral posture

Posture estimation results:

- Compared the posture estimation and RULA score from our approach vs. MoCap posture
- Less than 5deg median deviation and less than 15deg upper quartile deviation from Mocap
- %84 accuracy in RULA interpretation compared with Mocap



POSTURE OPTIMIZATION IN TELEOPERATION

Optimal posture:

- Gradient-based solver: Sequential Quadratic Programming
- Gradient-free solver: Cross-Entropy Method

Goal-Constrained Tasks:

$$h^* \mathbf{q}_t^* = \arg \min_{\mathbf{q}_t} \text{RULA}(h^* \mathbf{q}_t)$$

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

Path-Constrained Tasks:

$$h^* \mathbf{r}_{t_c \rightarrow T} = \arg \min_{h^* \mathbf{r}_{t_c \rightarrow T}} \sum_{t=t_c}^T \text{RULA}(h^* \mathbf{q}_t)$$

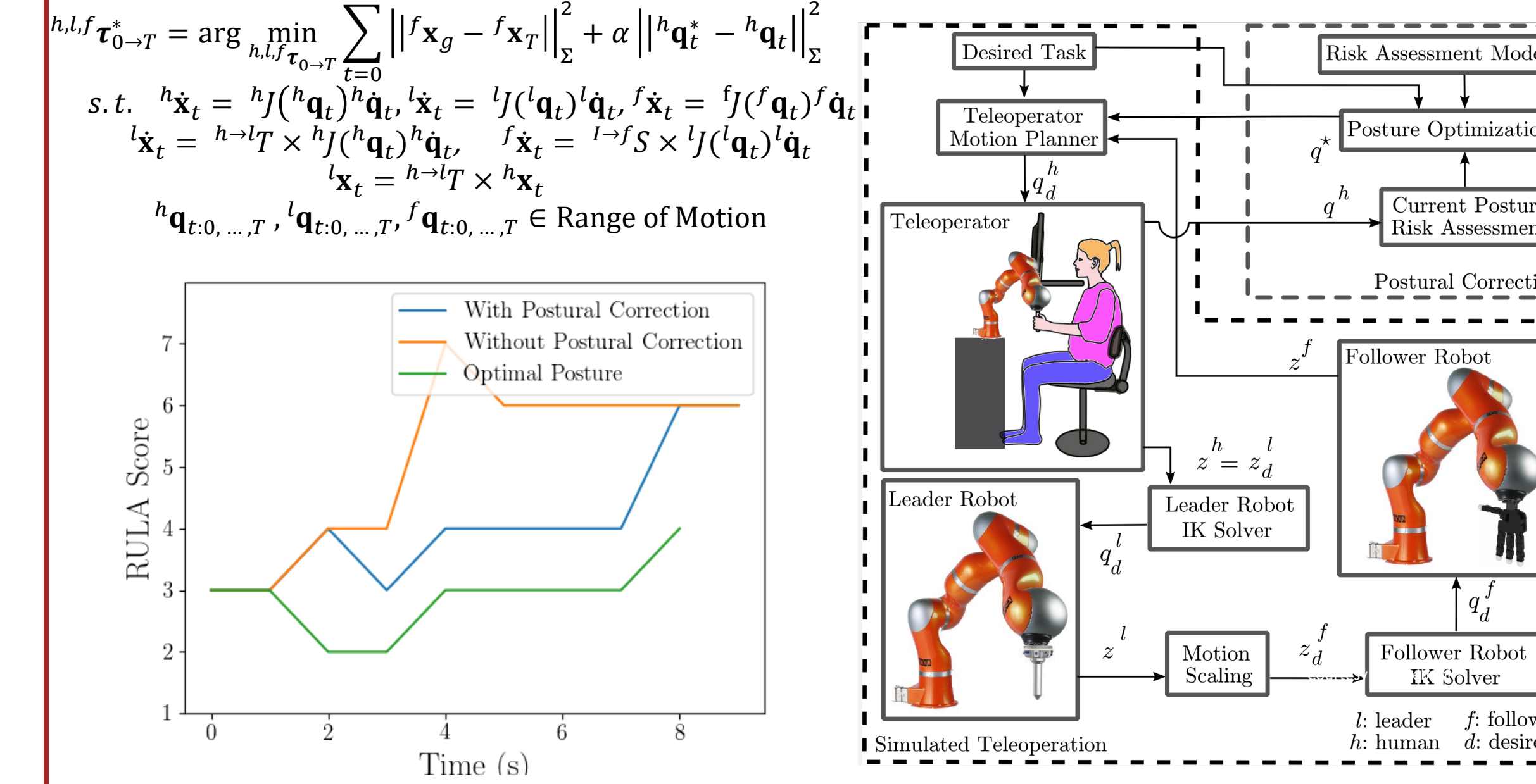
$$s. t. \left\| h^* \tilde{\mathbf{x}}_t - h^* J(h^* \mathbf{q}_t) h^* \mathbf{q}_t \right\|_{\Sigma}^2 < \epsilon \text{ for } \forall t \geq t_c$$

Trajectory-Constrained Tasks:

$$h^* \mathbf{q}_0^* = \arg \min_{h^* \mathbf{q}_0} \sum_{t=0}^T \text{RULA}(h^* \mathbf{q}_t)$$

$$s. t. \left\| h^* \tilde{\mathbf{x}}_t - h^* J(h^* \mathbf{q}_t) h^* \mathbf{q}_t \right\|_{\Sigma}^2 < \epsilon \text{ for } \forall t \geq t_c$$

- Teleoperation simulator:**
- Simulation in Gazebo, including a human teleoperator simulator, and the robots
 - Human teleoperator simulator:
 - Completes the teleoperation tasks
 - Applies the postural correction
 - Optimization planner with replanning



OTHER APPLICATIONS & FUTURE WORK

- Applications:**
- Other p-HRI tasks
 - VR systems using pose of controllers
 - Drivers holding steering wheel
 - Assistive rehabilitations & exoskeletons
- Future work:**
- Conduct a human subject study to evaluate our posture optimization methods
 - Postural correction through motion rate control
 - Compare the effectiveness of visual feedback vs. feedback through the leader robot

REFERENCES

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