



# Toward Safe and Efficient HRI in Industrial Settings via Distance-Based Speed Limiting and Motion-Level Adaptation

*Przemyslaw (Pem) Lasota*

*Julie A. Shah*

*Massachusetts Institute of Technology  
Department of Aeronautics and Astronautics*

# Defining Safety in Human-Robot Interaction

## Safe HRI

### Physical

- No unwanted contact
- Required contact must not cause pain/injury

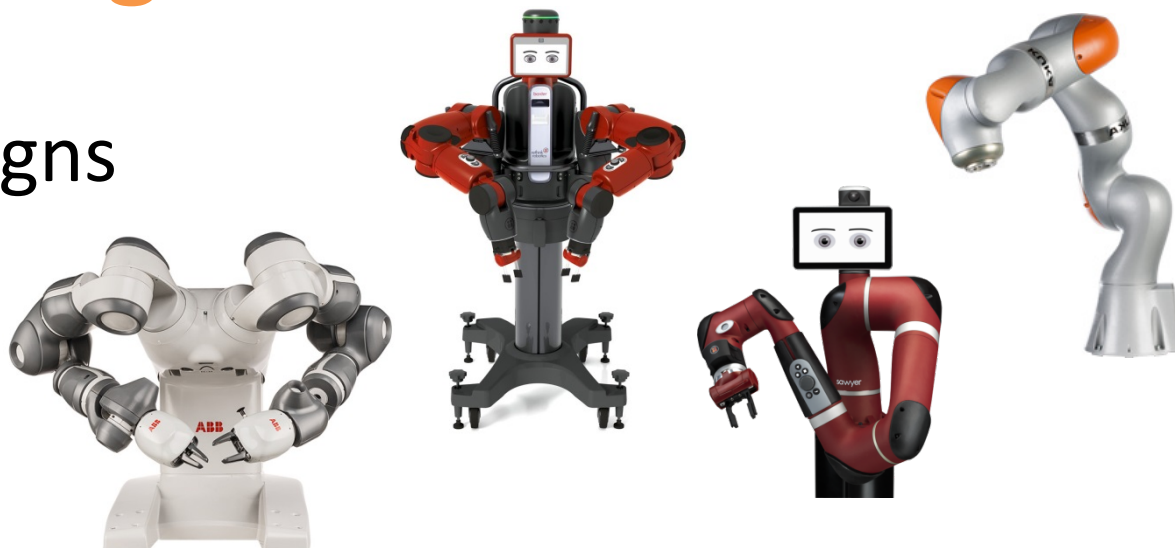
### Psychological

- Interaction must not cause excessive stress or discomfort

# Safety by Design?

## New Robot Designs

- Lightweight
- Compliant
- Redundant DOFs
- On-board sensing



## What about **currently deployed** industrial robots?

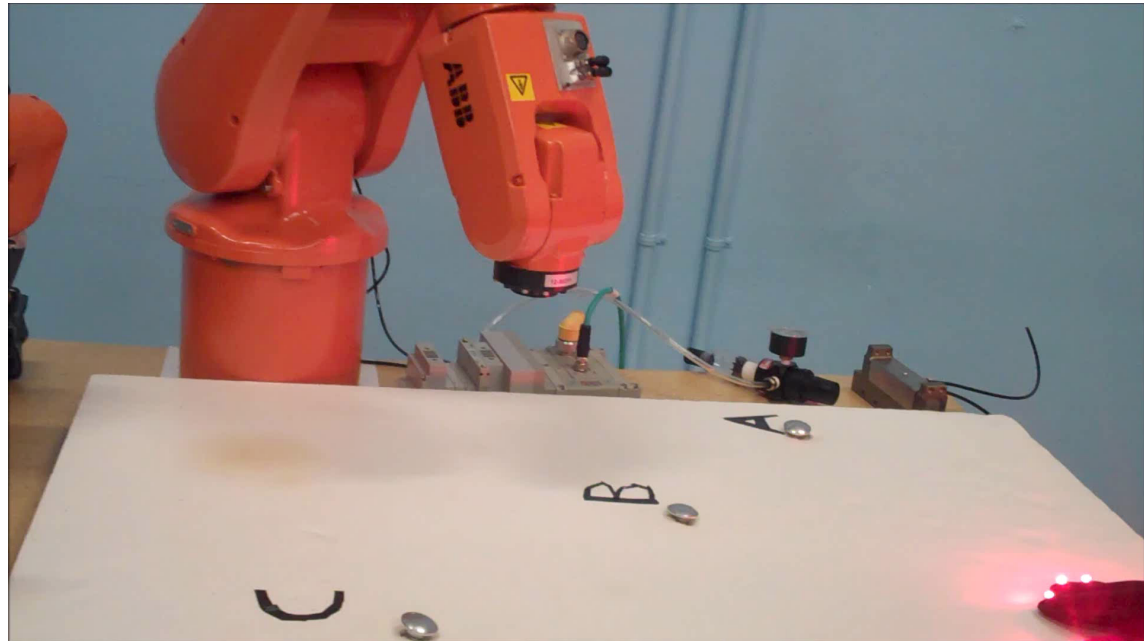
- Estimated 1.3-1.6 million worldwide<sup>++</sup>



<sup>++</sup> “World Robotics Industrial Robots 2014 (Executive Summary)”  
International Federation of Robotics (IFR) Report, September 2014

# Safety System for Current Industrial Robots

- Distance-based speed limiting
- Utilize accurate human position and robot configuration data
- Virtual representation of workspace updated in real time (6ms)



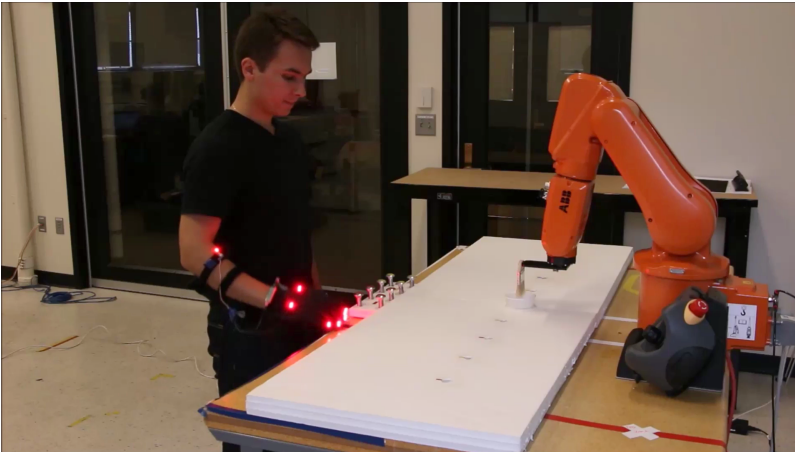
Lasota, P. A., G. F. Rossano, and J. A. Shah, "Toward Safe Close-Proximity Human-Robot Interaction with Standard Industrial Robots", The 10th IEEE International Conference on Automation Science and Engineering (CASE), 08/2014.

While this system can maintain physical safety, it does not address psychological safety.

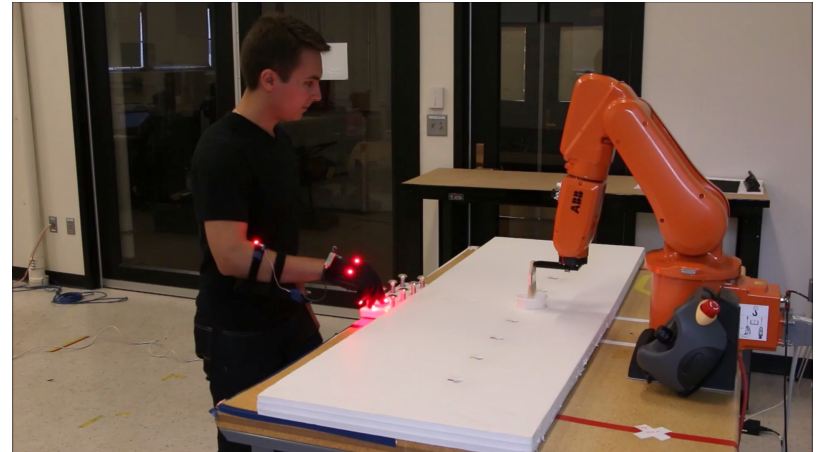
# Analyzing Effects of Motion Level Adaptation on HRI

- Human-subject experiment
  - N=20
- Two conditions:

Standard



Human-Aware



Lasota, P. A., and J. A. Shah, "Analyzing the Effects of Human-Aware Motion Planning on Close-Proximity Human-Robot Collaboration", Human Factors: The Journal of the Human Factors and Ergonomics Society [2014 Human Factors Prize Finalist], vol. 57, issue 1, pp. 21-33, 02/2015.

# Benefits of Motion Adaptation

## Questionnaires:

### **Improved psychological safety:**

- Higher perceived safety and comfort
- Higher satisfaction with robot as co-worker

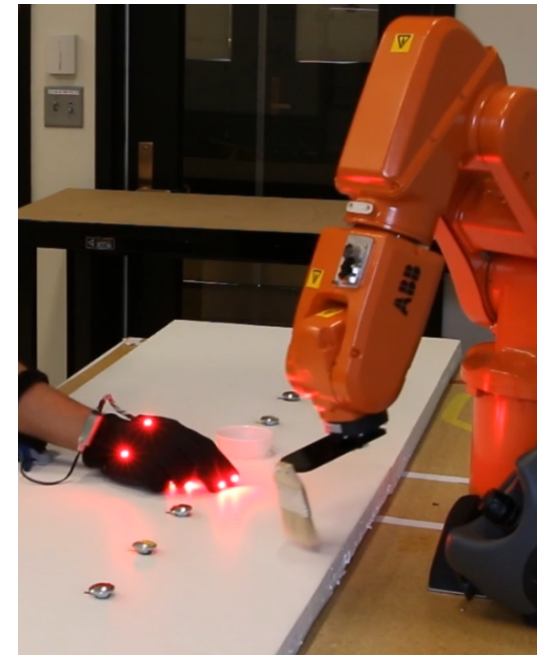
## Team Fluency Metrics:

### **Increased efficiency:**

- Task execution: 6% faster
- Concurrent motion: 20% more
- Separation distance: 15% higher
- Robot idle time: 17% less
- Human idle time: 3% less

# Key Findings and Implications

- Simultaneous improvement in safety and efficiency
- Motivation for use and development of motion-level adaptation
- Addresses both physical and psychological safety





# Acknowledgements

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