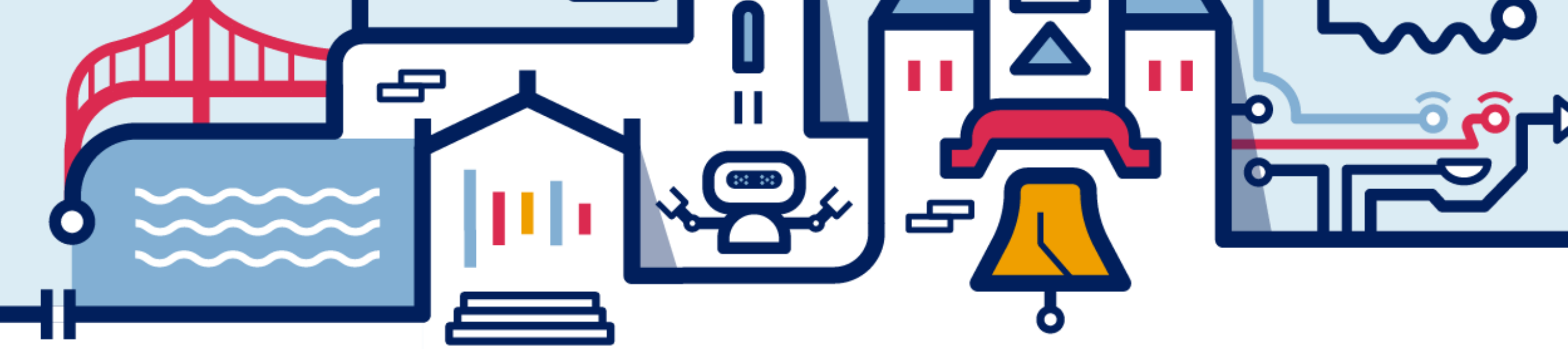


Adaptive Impedance Controller for Human-Robot Arbitration based on Cooperative Differential Game Theory

Paolo Franceschi[1,2], Nicola Pedrocchi[1] , Manuel Beschi[2]

[1] CNR-STIIMA, via Alfonso Corti 12, 20148, Milano, Italy
2 University of Brescia, Via Branze, 38, 25123, Brescia, Italy

ICRA 2022
IEEE International Conference on Robotics and Automation

UNIVERSITÀ DEGLI STUDI DI BRESCIA

STIIMA
Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato
Consiglio Nazionale delle Ricerche

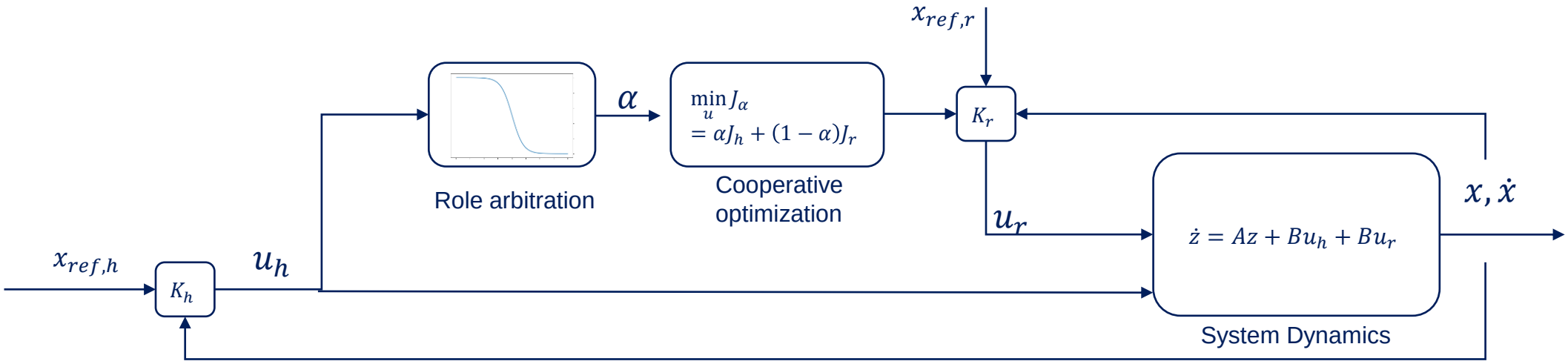
Motivation and goal

Motivation: Humans and robots have complementary capabilities that should be combined to improve both working conditions and quality of results

Goal: develop a methodology that allows shared autonomy and role arbitration between a human and a robot

Method

Cooperative Differential Game: Pareto optima are usually better than Nash equilibria, naturally allowing "agreement" between players



Method

$$\dot{x} = Ax + B_h u_h + B_r u_r$$

System dynamics

Remark: linear model for the human are useful approximation of the more complex human behavior

$$J_h = \int_0^\infty \{x^T Q_h x + u_h^T R_h u_h\}\, dt$$

Human cost function

$$J_r = \int_0^\infty \{x^T Q_r x + u_r^T R_r u_r\}\, dt$$

Robot cost function

$$J(\alpha) = \alpha J_h + (1-\alpha) J_r = \int_0^\infty \{x^T Q(\alpha) x + u^T R(\alpha) u\}\, dt$$

Cooperative cost function

α: weighting factor. Selects the solution among the ones lying on the Pareto frontiers. The choice of α is the so-called Bargaining Theory

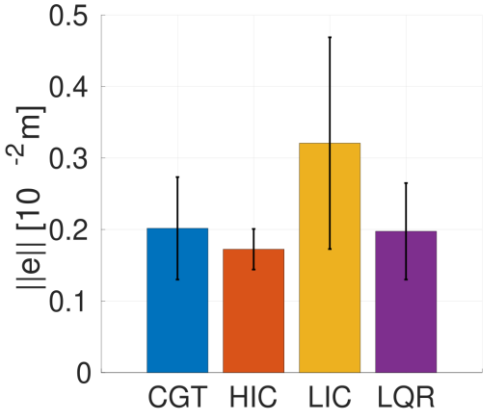
Method

- **Role Arbitration:** the mechanism that assigns control of the task to either the human or the robot
- **Bargaining solution**: the parameter α is made variable according to the human will to lead the action
- **Results**: a Variable Impedance controller, which varies stiffness and damping parameters due to the adaptation of the robot's role of leader/follower according to human intentions.

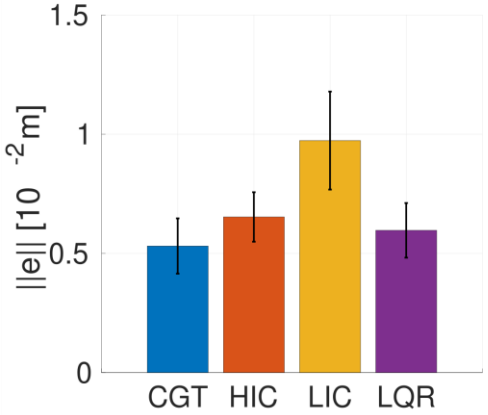
Experiments

Human and robot have to follow two partially overlapping trajectories. The robot does not know the human trajectory. When the human applies a force, the robot behaves as a follower, otherwise as leader

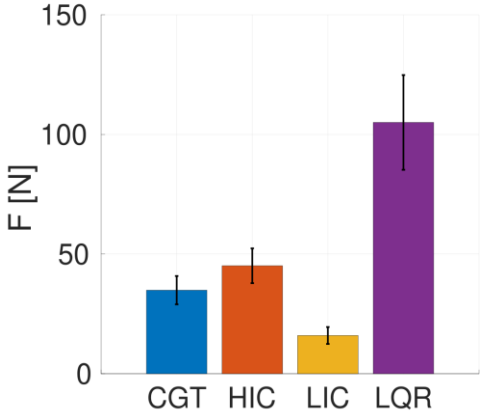
Results



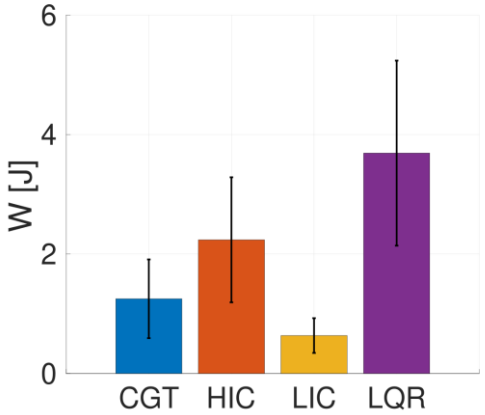
Path tracking error



Trajectory trac error

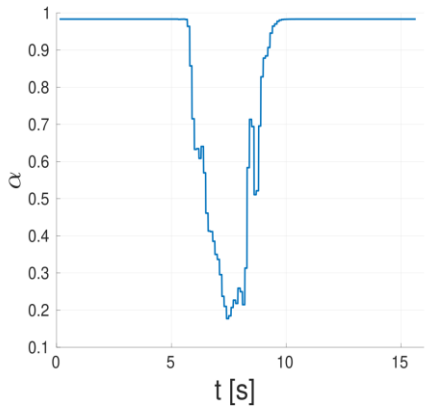


Exchanged force

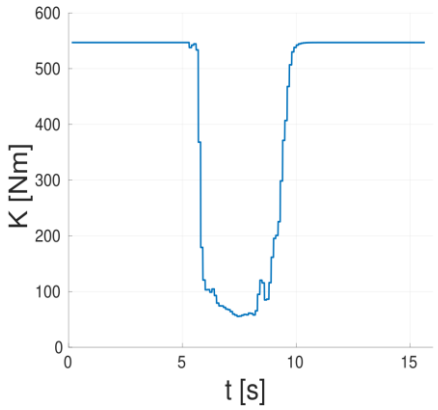


Mechanical work

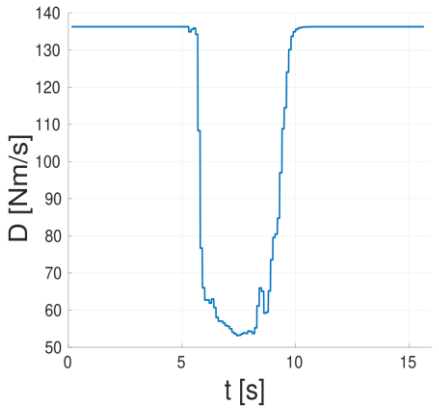
Results



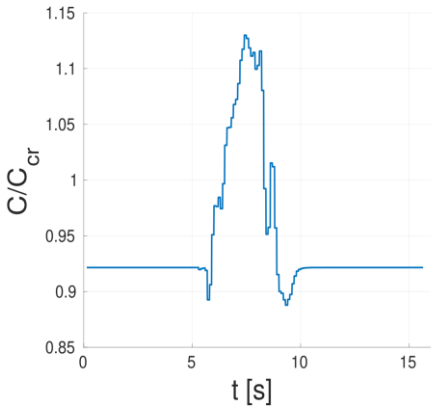
α



Variable stiffness



Variable damping



Variable critical damping

Thank you for your attention

p.franceschi@unibs.it, paolo.franceschi@cnr.stiima.it