A Game-Theoretic Approach for Adaptive Action Selection in Close Proximity Human-Robot-Collaboration

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Motivation

Autonomous Robots in Human-Robot Collaboration (HRC)

Given high-level actions [Nau+ 2004] e.g.

- pick(robot, object1)
- pick(robot, object2)
- pick(human, object1)
- pick(human, object3)

Adapt high-level action-selection to

- Minimize agents' effort
- Maximize team-efficiency
- Guarantee Safety for Human

Exemplary
Human-Robot Scenario

Contribution of this Work

HRC Approaches

State of the art: Adapt to human action without reflecting human adaptivity [Mainprice+ 2013; Hawkins+ 2014; Maeda+ 2014; Gombolay+ 2015]

Contribution: Evaluation of the complete action-space for all involved agents using **normal form games**

HRC and Game Theory

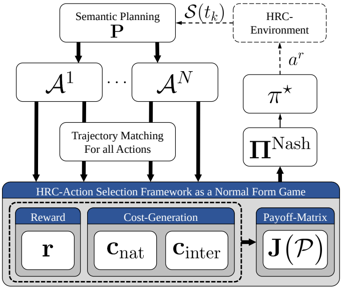
State of the art: Application limited to differential game theory or simulations [Jarrassé+ 2012; Li+ 2015; Bahram+ 2015; Turnwald+ 2016]

Contribution: discrete online action selection in real HRC

General Approach

Iterative Decision Process as a **Normal Form Game**

- Direct mapping of high-level action and estimated trajectory
- Interaction heuristics rather than purely data-driven models



Schematic Framework

Applied Interaction Heuristics

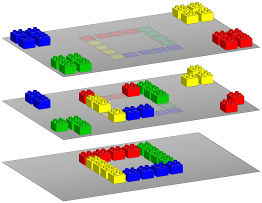
- Task dependent reward r_k
- Native cost c_k^{nat}
- Interactive cost c_k^{inter}

$$J_k(\boldsymbol{\pi}) = r_k - c_k^{\text{nat}}(a_k) - c_k^{\text{inter}}(\boldsymbol{\pi}), \text{ with } a_k \in \boldsymbol{\pi}$$

Experimental Evaluation

Baseline comparison to a fixed action policy

- Cooperative pick- and place assembly
- $n = 30$ participants



Claimed Hypothesis

The robot's action-selection ...

H1 will be preferred by the participants ...
H2 increase the safety aspects ...
H3 decrease the overall efficiency ...

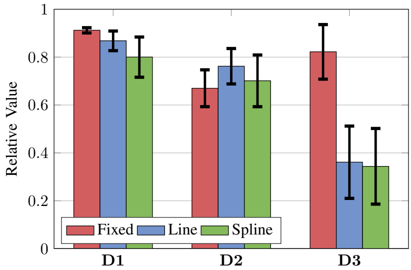
... compared to a non-reactive strategy.

Experimental Measurements

- Subjective questionnaire (**H1**)
- Potential field safety layer (**H2**)
- Overall completion time (**H3**)

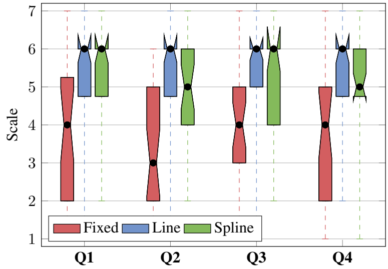
Experimental Results

D1 *Normalized overall assembly time.*
D2 *Normalized human idle time.*
D3 *Normalized repellent force.*



Empirical Measurement Data

How would you grade the ...
Q1 *... collaboration with the robot?*
Q2 *... robot as a helpful co-worker?*
Q3 *... motion reaction of the robot?*
Q4 *... action selection of the robot?*



Questionnaire Evaluation

D1: confirming **H2**
D3: confirming **H3**

confirming **H1**

Summary

Conclusion

- Design of a **normal form game** decision framework
- **Online application** of proposed framework
- Confirmed three hypothesis in extensive user-study
  - **H1** increased subjective acceptance
  - **H2** increased human safety
  - **H3** improved team-efficiency

Future Work

- Extension to multi-agent systems
- Comparison with latest state-of-the-art on complex scenarios

Extensions at Booth #4

- Representative video from experiment recordings
- Further insight on framework and experimental details
- Question, answers and open discussion

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