Human-Robot Mutual Adaptation

Waleed Mustafa

University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics
Technical Aspects of Multimodal Systems

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Outline

Motivation

- Robots are destined to be everywhere [6]
- Robot Humans do collaborative tasks
- In Human teams, *mutual* adaptation increase performance [3]
- Maybe human robot teams benefit from mutual adaptation

Example: Table Carrying Task

(a)

(b)

Courtesy of [4]

- Human and Robot have the common task to get a table out of room
- Two strategies possible:
  - Goal A: Robot facing the door and human facing away
  - Goal B: Robot facing away and human facing door
- Robot prefers Goal A because sensors of his front are stronger
- Human may prefer Goal B

- Two possible handling:
  - Either Robot insist on his strategy: human trust lost! [1]
  - Or Robot adapt to Human: performance is lost!
- The trade-off between **Performance** and **Trust**
- Different humans have different adaptability

Introducing the model

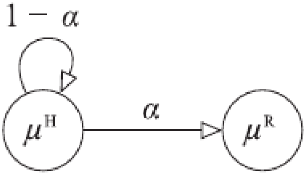
- Nikolaidis et al. proposed to model human adaptation behaviour
- The model of Human is a finite-state stochastic controller
- The Human has a number of collaboration modes
- The human chooses among them based on historical interactions and his adaptability
- The model of human behaviour is embedded in the robot decision process

Bounded-Memory Adaptation Model (BAM)

- Human policy π^H is modeled as PFA
- The set of states are $Q : X^{\text{world}} \times H_t$
  - X^{world} is the set of possible world states,
  - and H_t is the set of possible histories
  - The Human model has Bounded-Memory (i.e., forgets history beyond (t-k)th step)

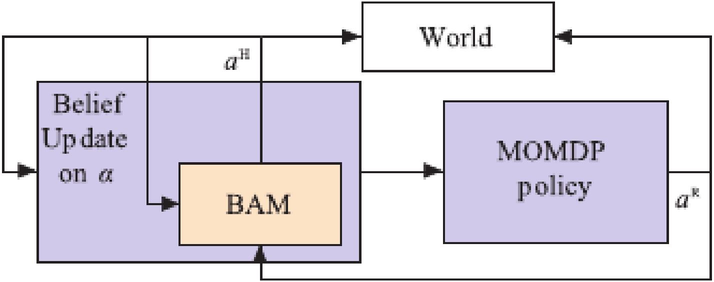
Bounded-Memory Adaptation Model (BAM) (cont.)

- After human action a^H and robot action a^R,
  - A human chooses to stay with his mode u^H with probability $1 - \alpha$ or,
  - changes to the robots mode u^R with probability α



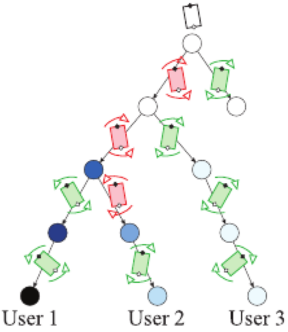
Courtesy of [4]

- The robot follow a Mixed Observable Markov Decision Model (MOMDP) [5]
- State Variables X, Y, where X is observable task steps and robot-human modal policies, Y unobservable human adaptability α
- π^H is the human stochastic policy
- The robot takes actions to maximize expected reward (with considering human actions)



Courtesy of [4]

The model in action



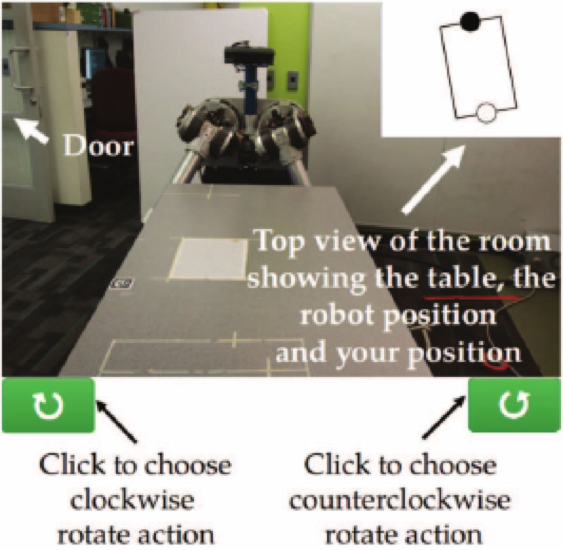
Courtesy of [4]

Hypothesis to be tested [4]

- H1: Fixed vs. Mutual adaptation:
  - Trust-worthiness?
  - Team Performance?
- H2: Mutual Adaptation vs. Cross-training:
  - Human follows robot preference?
- H3: Mutual Adaptation vs. Cross-training:
  - Perceived teammate performance?

Experimental Setup

- Three conditions:
  - Fixed session: A robot executes fixed policy regardless of human preference
  - Mutual adaptation: The robot executes the policy inferred from the presented model
  - Cross-Training: The robot executes a policy that highly adaptable to human reference
- Human experiment on a video simulation



Courtesy of [4]

Experimental Setup (cont'd)

- Participants answer a questionnaire
  - five-point Likert scale
  - Questions taken mostly from Hoffman [2]
- Subject allocation:
  - Amazon's Mechanical Turk
  - 18-65 years old
  - Trap questions to exclude non-serious participants

Q1: "HERB is trustworthy."
Q2: "I trusted HERB to do the right thing at the right time."
Q3: "HERB is intelligent."
Q4: "HERB perceived accurately what my goals are."
Q5: "HERB did not understand how I wanted to do the task."
Q6: "HERB and I worked towards mutually agreed upon goals."
Q7: "I was satisfied with HERB and my performance."
Q8: "HERB and I collaborated well together."
Q9: "HERB made me change my mind during the task."
Q10: "HERB's actions were reasonable."

Courtesy of [4]

Results

- H1: Fixed vs. Mutual adaptation (Two-tailed Mann-Whitney test):
  - Mutual-Adaptation is trust-worthy ($p = 0.048$)
  - No statistically significant data for team performance or human satisfaction
- H2: Mutual Adaptation vs. Cross-training:
  - 57% adapted to the robot in Mutual-adaptation mode
  - 26% adapted to the robot in Cross-Training
  - χ^2-test ($p = 0.036$)
- H3: Mutual Adaptation vs. Cross-training:
  - Robot performance as team-mate not worse than cross-training
  - One tailed unpaired t-test ($p < 0.05$) in all categories

	Cross-Training	Bounded-Memory Adaptation
Policies	Learned through interaction and role-switch	Selected from given Model policies
Human Adaptation model	Implicitly modeled	Explicitly Modeled
Push Human to adaptation	Low	High

Conclusion

- Adaptation in Human teams lead to better performance
- We presented an approach to reach coadaptation between Humans and Robots
- Experiment on Human participants showed that it is indeed the case that coadaptation lead to better performance and trust in human-robot teams

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[2] G. Hoffman. Evaluating fluency in human-robot collaboration. In *International conference on human-robot interaction (HRI), workshop on human robot collaboration*, volume 381, pages 1–8, 2013.

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