Learning to Assess the Cognitive Capacity of Human Partners

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Objectives

Our goal is to build a model for robots so that they can

- learn to assess cognitive capacity of a human partner.
- can act autonomously based on that.
- reduce the human decision burden.
- help improving task performance.

Motivations and Contributions

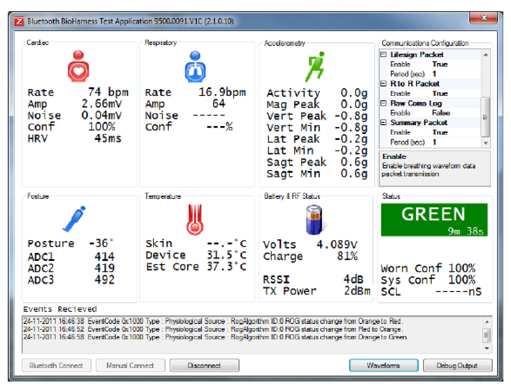
Motivation:

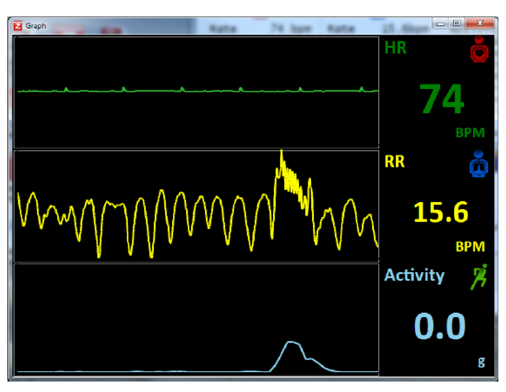
- Overcome inherent communication barrier between human and robot
- Controlling multiple robots becomes impossible: cognitive load, heterogeneous robots
- Complete automation impossible: new task environment
- Robots need to assess cognitive capacity of human-robot team for mutual benefits[1]

Contributions: We produced a robot that can

- Compute a success metric
- Connect observed human behavior to the task success.
- Learned model of human behavior is still useful in tasks when the robot can no longer self-evaluate.

Physiological Metrics





Trivial fundamental metrics[2] of measuring the behavioral indicators (i.e. ECG,EEG) has following drawbacks:

- hard to set up in generic task environments
- a generic method to assess cognitive load should work with simple metric
- can be useful as baseline

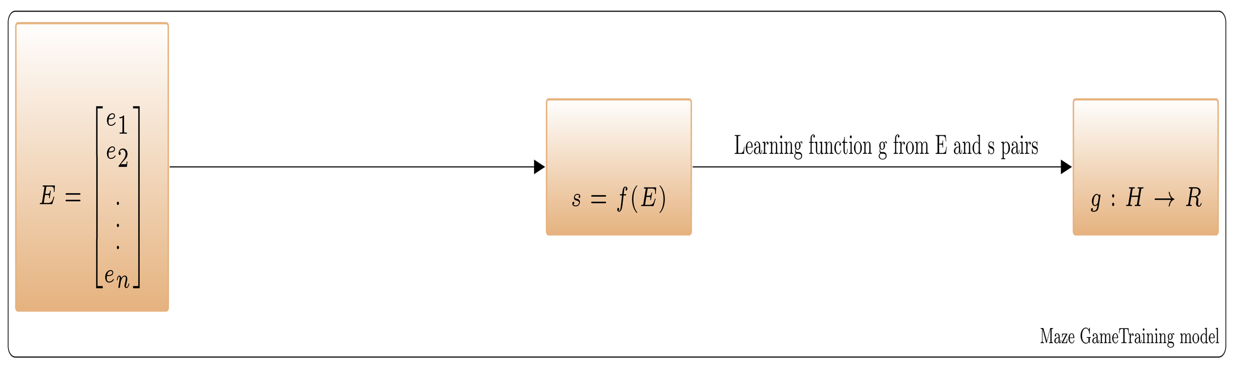
Feature Metrics

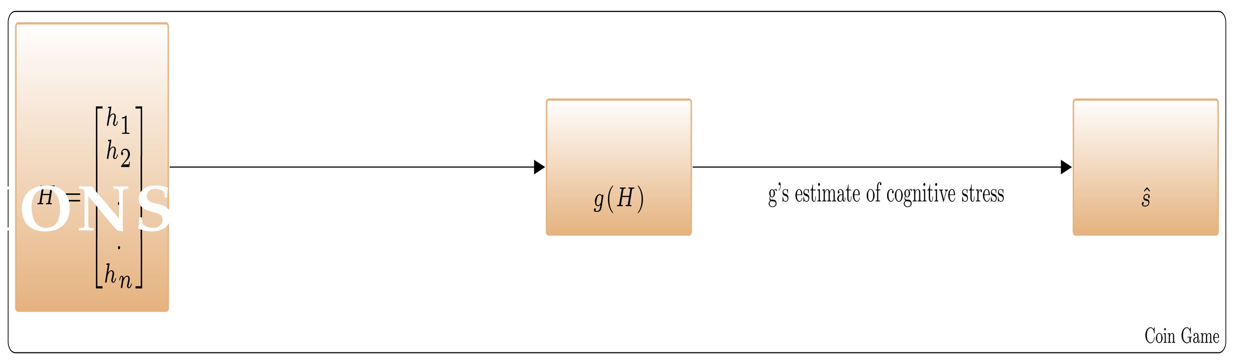
$E = [e_1, \ldots, e_n]$ is measurable environmental features of task success.

$H = [h_1, \ldots, h_n]$ is behavioral metrics which are ecologically valid for a navigation task.

$$E = \begin{bmatrix} e_1 & \text{is} & \text{disparity} \\ e_2 & \text{is} & \text{collision} \\ e_n & \text{is} & \text{time delay} \end{bmatrix} \quad H = \begin{bmatrix} h_1 & \text{is} & \text{decision interval} \\ h_2 & \text{is} & \text{error correction} \\ h_n & \text{is} & \text{franticness} \end{bmatrix}$$

Overview of the Model





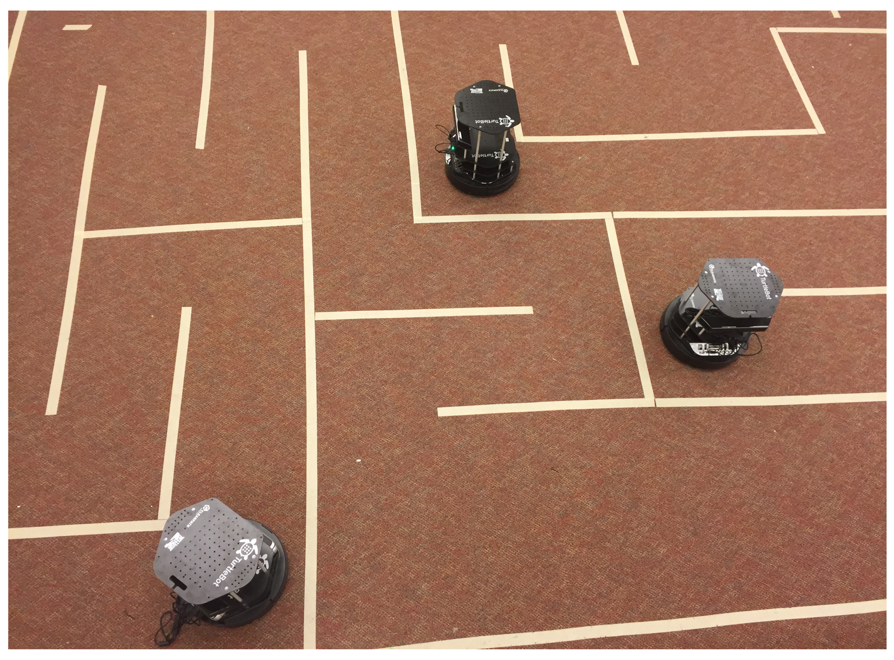


Figure 1: Experimental setup of Maze Game experiment for training model to predict Cognitive Stress

Experiments and Results

Our experiments consisted of two games, maze navigation[3] and coin collection.

Mage Game:

- The task in this game is to complete a maze(Fig.1) by instructing Turtlebot robot
- The game is 2 min. long and collision with walls are negatively rewarded
- The games complexity evolves in succession
- Mage Game was used to collect the metrics in E and calculate the success score s
- The underlying function was modeled using E and s by using Random Forest learner

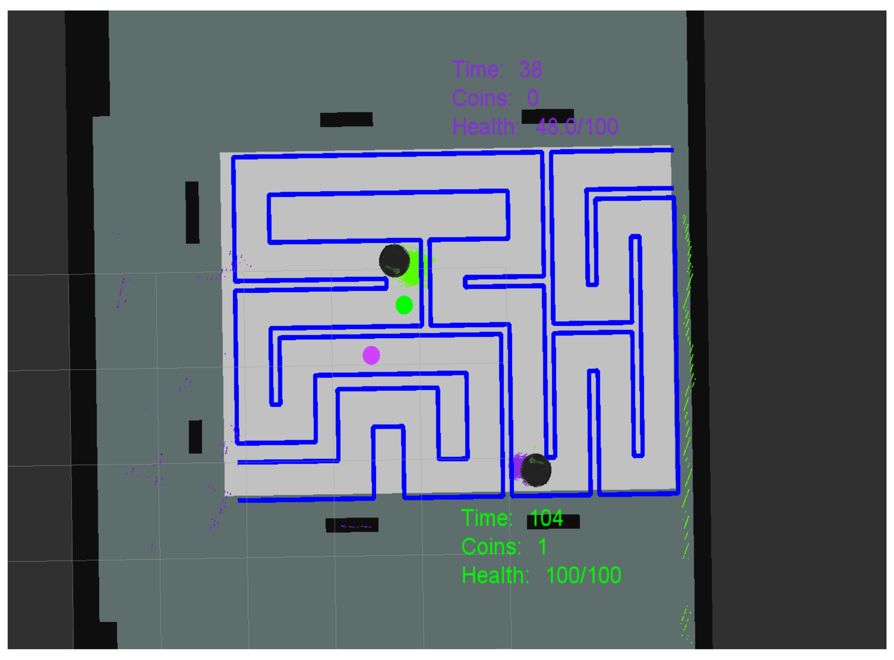


Figure 2: Interface to human operator for Coin game.

Coin Game:

- The goal is to collect 5 coins instead of completing the maze
- The timeout for completion next goal is decremented after each coin collection
- We collected H metrics from the experiment which was input to the model to estimate stress $\hat{s}$
- On detection high stress robot started navigating autonomously

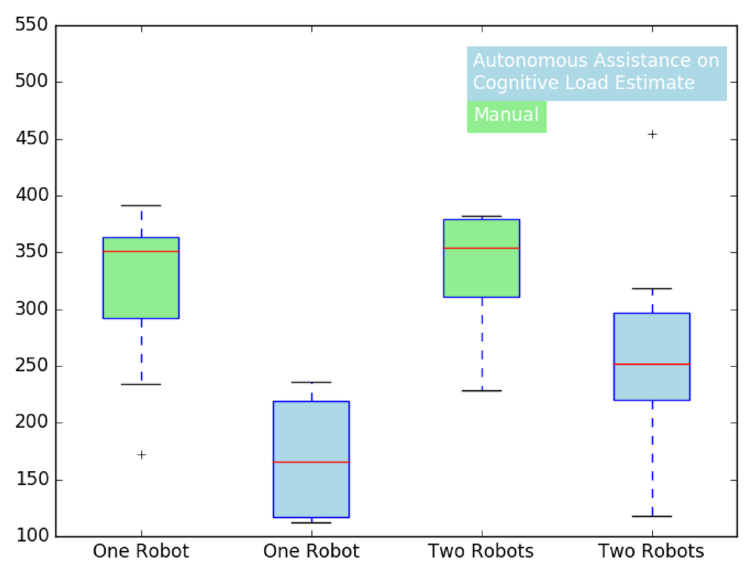


Figure 3: Learned model's contribution to task success: Coin game task penalties in manual vs. autonomous assistance modes across 34 test subjects. $p < 0.05$ in both instances.

Prediction vs Evidence

Result: The robot correctly predicts an operator's cognitive load in Figure 4.

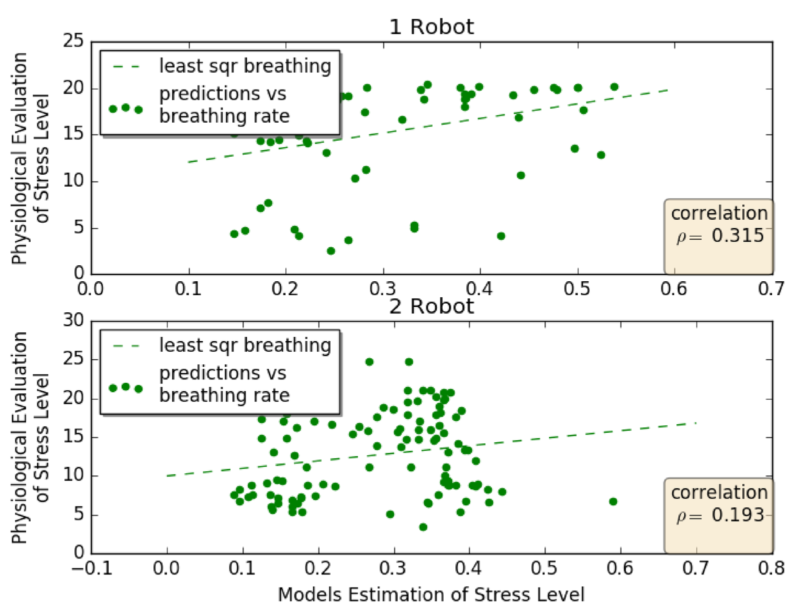


Figure 4: Robot's estimated cognitive stress level modestly correlates with physiological metrics (breathing rate measured with a Bioharness).

References

[1] Jacob W Crandall, Michael Goodrich, Dan R Olsen Jr, Curtis W Nielsen, et al. Validating human-robot interaction schemes in multitasking environments. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans*, 35(4):438–449, 2005.

[2] Dan R Olsen and Michael A Goodrich. Metrics for evaluating human-robot interactions. In *Proceedings of PERMIS*, volume 2003, page 4, 2003.

[3] Christopher Crick, Sarah Osentoski, Graylin Jay, and Odest Chadwicke Jenkins. Human and robot perception in large-scale learning from demonstration. In *Proceedings of the 6th international Conference on Human-Robot Interaction*, pages 339–346. ACM, 2011.