Ask this robot for a helping hand

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Subject heading: adaptive human-robot interaction.

Description of novelty: To be useful in a variety of daily tasks, robots must be able to interact physically with humans and infer how to be most helpful. A new theory for interactive robot control allows a robot to learn when to assist or challenge a human during reaching movements.

An unsupervised robot must have two fundamental skills to work closely and safely with a human on a complex task in real time. The robot must be able to recognize human behaviors and respond to them automatically and appropriately. Now researchers at the University of Sussex, Imperial College London, and Nanyang Technological University in Singapore are the first to exploit game theory in designing a physically interactive robot that adapts to changing human behavior, according to a paper published recently in *Nature Machine Intelligence*.

"We have developed an algorithm based on game theory that enables a robot to identify the human's behaviors and then automatically adjust its own behavior to complete a task," said lead author Yanan Li from the University of Sussex, who conducted the work while at Imperial's Department of Bioengineering. The research was funded by the European Commission. This game-theory framework someday could be used for robotics in sport training, injury rehabilitation, or assisted driving.

Current robots can provide rehabilitation assistance by making a task easier for people to complete. But when robots only provide assistance, some people slack off, allowing the robot to do the work, so patients don't advance. The effectiveness of using rehabilitation robots to provide a challenge is also being studied currently. But if the task is too hard, people may not be able to perform the task, and also don't advance. A single robot can be programmed to provide either assistance or a challenge. But a single robot has not been capable of switching back and forth between assisting and challenging without reprogramming.

Li's paper shows how a robot controller can transition between rehabilitation tasks by exploiting game theory to identify a human's strategy. In game theory, multiple players compete or collaborate to complete a task. Each player tries to optimize their performance, while assuming their opponents will also play optimally.

First, the robot controller is programmed to perform a reaching task with a handle. "The robot's motor predicts its reaching motion—how far the handle will move—because it knows how much input to the motor will create that motion," said Li. Next, the robot controller is programmed to track how much force a human applies on the handle to move it. "The robot recognizes that the motion of the handle when the human is trying to move it is different from what the robot does alone. Based on this difference, the robot will know how much of the input is from the human. The robot uses the difference between its own motion and the actual motion during the human-robot interaction to estimate the human's strategy."

The researchers tested the robot controller in simulations and experiments of human-robot physical interactions. In simulations, the robot could adapt when a human's capability changed slowly or when the human made erratic progress. In human experiments, the robot aided healthy individuals by increasing assistance when the user was not strong enough to complete the task. But the robot could also automatically transition from an assistance to a challenge strategy as the human's strength improved.

The game-theory-based system allows the robot to assess where a human's needs are along the spectrum from assistance to resistance and automatically tunes the controller. The controller gains data about how effectively the human-robot interaction is achieving goals. As the robot moves determines the appropriate level of assistance and resistance, it can update the human's progress and estimate how much to increase assistance or resistance.

"This is an important paper," said Lena H. Ting who specializes in the neural control and biomechanics of human movement at the Georgia Institute of Technology's Institute for Robotics and Intelligent Machines. She and Luke Drnach, a graduate student Georgia Tech, published a companion explanatory article about Li's study in the same issue of *Nature Machine Intelligence.* They did not participate in the Li team's work.

The game-theory framework yields theoretic insights that could help the field of physical human-robotic interactions move forward. "In our research, we are studying the principles of how humans move and interact physically with each other in order to understand how assistive robots should best interact with people," said Ting. "We want to understand conscious and unconscious physical cues that occur between people, so that robots can also have this natural, intuitive physical interaction with people. We want robots to get accurate information from people that allow them to modify their own behaviors."

Future studies, noted Ting and Drnach's article, could extend this game-theory framework to include teams of robots helping humans with dangerous or difficult tasks or robots that interact with multiple joints of a human, such as robotic gait trainers and exoskeletons.

Next, the Li team will apply the interactive control behavior to robot-assisted neurorehabilitation at Nanyang Technological University in Singapore, and to shared driving in semi-autonomous vehicles.

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1. Sawers, A., and Ting, L.H. *Journal of Neuroengineering and Rehabilitation.* **11**. 142-155. (2014).
2. Li, Y., Carboni, G., Gonzalez, F., Campolo, D., and Burdet, E. *Nature Machine Intelligence.* **1**. (2018).
3. Jarrassé, N., Charalambous, T., and Burdet, E. *PLOS One*. **7**. e49945. (2012).

4. Colombo, G., Joerg, M., Schreier, R., and Dietz, V. *Journal of Rehabilitation Research and Development*. **37**. 693-700. (2000).
5. Losey, D.P., and O'Malley, M.K. *Transactions on Robotics*. **34.** 126-138. (2018).
6. Krebs, H.I., Hogan, N., Aisen, M.L., and Volpe, B.T. *IEEE Transactions on Rehabilitation Engineering*. **6**. 75-87. (1998)
7. Mihelj, M., Nef, T., and Reiner, R. *Advanced Robotics*. **21**. 843-867. (2007).
8. Smith, B.W., Rowe, J.B., and Reinkensmeyer, D.J. *Journal of Neurophysiology.* **120**. 2107-2120. (2018)
9. Duarte, J.E. and Reinkensmeyer, D.J. *Journal of Neurophysiology*. **113**. 2682-2691. (2015).