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Analyzing the Effects of Human-Aware Motion Planning on Close-Proximity Human–Robot Collaboration

Przemyslaw A. Lasota and **Julie A. Shah**, Massachusetts Institute of Technology, Cambridge, Massachusetts

Objective: The objective of this work was to examine human response to motion-level robot adaptation to determine its effect on team fluency, human satisfaction, and perceived safety and comfort.

Background: The evaluation of human response to adaptive robotic assistants has been limited, particularly in the realm of motion-level adaptation. The lack of true human-in-the-loop evaluation has made it impossible to determine whether such adaptation would lead to efficient and satisfying human–robot interaction.

Method: We conducted an experiment in which participants worked with a robot to perform a collaborative task. Participants worked with an adaptive robot incorporating human-aware motion planning and with a baseline robot using shortest-path motions. Team fluency was evaluated through a set of quantitative metrics, and human satisfaction and perceived safety and comfort were evaluated through questionnaires.

Results: When working with the adaptive robot, participants completed the task 5.57% faster, with 19.9% more concurrent motion, 2.96% less human idle time, 17.3% less robot idle time, and a 15.1% greater separation distance. Questionnaire responses indicated that participants felt safer and more comfortable when working with an adaptive robot and were more satisfied with it as a teammate than with the standard robot.

Conclusion: People respond well to motion-level robot adaptation, and significant benefits can be achieved from its use in terms of both human–robot team fluency and human worker satisfaction.

Application: Our conclusion supports the development of technologies that could be used to implement human-aware motion planning in collaborative robots and the use of this technique for close-proximity human–robot collaboration.

Keywords: human–robot interaction, motion-level adaptation, team fluency, human satisfaction

Address correspondence to Przemyslaw A. Lasota, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139, USA; e-mail: plasota@mit.edu.

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INTRODUCTION

In many domains today, robots are often deployed in complete isolation from humans. Although the physical separation of people and robots can be an effective strategy for some applications, a lack of human–robot integration prevents robots from being used in domains that stand to benefit from robotic assistance. The final assembly of aircraft and automobiles, for example, is still mostly a manual operation, involving minimal use of automation (D. Amirehteshami, Boeing Research and Technology, personal communication, July 2011; S. Bartscher, Innovation Product Division, BMW Group, personal communication, February 2012). Although the capabilities of robotic systems continue to expand, many tasks in domains such as these require a level of judgment, dexterity, and flexible decision making that surpasses the abilities of current robots, causing tasks to become human dominated. However, there are also many non-value-added tasks within these domains that could be performed by robotic assistants. Allowing robots to collaborate with people in shared workspaces and to perform such tasks has the potential to increase productivity and efficiency, providing a strong incentive for the development of technologies that foster this collaboration.

A significant amount of research has been conducted in recent years in support of this goal, across a variety of complementary domains. The first step toward creating robots that can successfully collaborate with people is allowing the robots to navigate a shared workspace, which requires the development of specialized path-planning algorithms and frameworks designed with the human element in mind (Bellotto, 2012; Chung & Huang; 2010; Kitade, Satake, Kanda, & Imai, 2013; Kruse, Kirsch, Sisbot, & Alami, 2010; Trautman & Krause, 2010; Ziebart et al.,