Challenges in Developing a Collaborative Robotic Assistant for Automotive Assembly Lines

Vaibhav V. Unhelkar
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA, USA
unhelkar@mit.edu

Julie A. Shah
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA, USA
julie_a_shah@csail.mit.edu

ABSTRACT

Industrial robots are on the verge of emerging from their cages, and entering the final assembly to work along side humans. Towards this we are developing a collaborative robot capable of assisting humans in the final automotive assembly. Several algorithmic as well as design challenges exist when the robots enter the unpredictable, human-centric and time-critical environment of final assembly. In this work, we briefly discuss a few of these challenges along with developed solutions and proposed methodologies, and their implications for improving human-robot collaboration.

1. INTRODUCTION

Automotive industries have been one of the first to introduce robotics in their manufacturing processes. However, driven by the requirement of high reliability, most of these industrial robots are caged and non-interactive. By operating away from humans, the robot environment is rendered highly predictable allowing for both reliable and human-safe task execution. More recently, due to advancements in robotics, the boundaries for robots in manufacturing are being pushed to introduce them into final assembly.

Kruger [7] provides a detailed survey of robots being used in assembly lines. Several collaborative robots have been developed for work environments [3, 10]; however, till date there have been no mobile robots which work with humans on automotive assembly lines. Our work is aimed at developing a mobile robot which can work along side humans in automotive assembly lines. Here, we highlight the key research challenges faced in developing this system along with obtained solutions and open research questions.

2. RESEARCH CHALLENGES

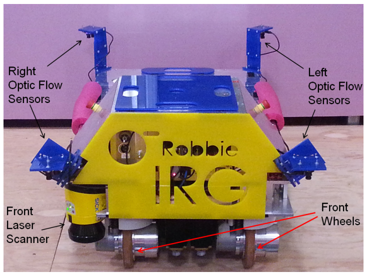

Figure 1: The Rob@Work mobile robotic platform augmented with sensors to navigate assembly lines.

Developing a collaborative robot for time-critical and safety-critical domains, such as final assembly of cars, brings about several multi-disciplinary challenges. Prior to executing any manufacturing task, the robot should have certain prerequisite capabilities. First, the robot should be able to operate safely with due consideration of humans in its surrounding. Next, it should be able to efficiently plan and execute its path in a dynamic and uncertain environment designed for humans. Since, the robot has to operate in automotive assembly lines, which include moving floors, the robot should be able to execute the path on surfaces (and not only obstacles) which are not static. Further, while performing any collaborative tasks the design of robot should be cognizant of human factor issues, such as the robot should be noticeable and be able to convey its intent.

In order to develop this robotic assistant, we use the Rob@Work-3 (Fig. 1) as the base platform [1]. This allows for quick prototyping and testing of algorithms through the use of Robot Operating System (ROS) as its middleware, and includes basic sensing, actuation and safety capabilities.

2.1 Navigating Automotive Assembly Lines

Automotive assembly lines include surfaces that may move, i.e., conveyor belts. Robots typically encounter only static surfaces, such as, in offices, homes and warehouses; however, for the current application the robot needs this additional capability of navigating dynamic surfaces. This requires development of a custom control and sensing system, which ensures smooth operation of robot and enables close proximity collaboration in automotive factories. We designed, implemented and tested a control algorithm and sensing system described in [12], which senses the motion of surfaces using optic flow sensors and controls the robot actuators/wheels for safe operation on moving surfaces.

The developed control and sensing systems require as input localization information (obtained from on-board sensors and map of the environment) and a desired path. Hence, the subsequent challenge for navigating assembly line environments is to sense human motion and design algorithms to plan efficient paths in human-oriented environments.

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Challenges in planning for human-robot co-navigation in dynamic manufacturing environments are discussed in [2]. My current work addresses parts of this problem, which include (i) anticipating human motion, and (ii) conveying robot intent.

2.2 Anticipating Human Motion

Autonomous planning in dynamic environments can benefit if high fidelity, predictive information regarding the future state of the environment is available. For path planning in human-centric environment this amounts to be able to anticipate human motion. In contrast to existing approaches, such as [6, 11], we are aiming to leverage anticipatory indicators of human walking motion identified in controlled, biomechanical studies of human gait to predict human motion [8]. Towards this we designed a study to analyze human walking motion in a motion capture setting, wherein only desired waypoints of the human path were specified. The study provides statistically significant evidence for existence of signals, namely, head orientation and height-normalized velocity, which anticipate human turns one-to-two steps in advance [13]. By using this signals online in a prediction algorithm [9], the robot can probabilistically predict human motion/goals. We believe given the time-critical nature of operations and high clutter, this anticipatory information will yield significant benefits in reducing robot navigation time on the factory floor. Future work will include hardware implementation of the online prediction algorithm, using on-board sensor information and anticipatory turn indicators, in-the-loop with an anytime planner.

2.3 Robot Saliency and Fluency

Along with anticipating the intent of the human associates in its surrounding, literature suggests that for improved collaborative fluency the robot should also be able to communicate its intent [5]. Using the navigation capability we are developing for the robot, fetch-and-deliver will be one of the primary collaborative tasks that the robot can carry out. Since, our robot has a non-anthropomorphic geometry, omni-directional mobility and no in-built communication capability, we first aimed to evaluate its performance in a human-robot collaboration task to identify the need and format of design interventions.

We carried out a human-subject experiment, detailed in [14], which compared Human-Robot (HRI) and Human-Human Interaction (HHI) during delivery phase of fetch-and-deliver tasks. We observed statistically significant differences between human and the robot in the objective measures of fluency [4], as well as in a measure we defined as robot saliency. Interestingly, though the HRI was more salient it was less fluent than the HHI. This suggests participants respect a human collaborator's time more as compared to that of a robot. The study indicates a need for design interventions, especially for the time-critical operations in a factory where the robot idle time should be minimized and HRI be made more fluent. My future work includes design of algorithms and on-board indicators that will help improve the fluency of human-robot interactions.

2.4 Factory Deployment

We have carried out successful initial tests and demonstrations of the robot, using the algorithms described in Section 2.1, on conveyor belts aimed towards factory deployment of the autonomous robot. This brings about issues concerning reliability, usability and maintainability of the robot. Though, not the focus of our research effort this issues are equally important and need to be duly considered.

3. CONCLUSION AND CONTRIBUTIONS

This work provides an overview of challenges, along with corresponding solutions and methodologies, in developing a collaborative robotic assistant for final assembly of cars. We have developed and tested a control and sensing system for the robot, which is being followed up with development of an autonomous navigation system. We have extracted and used anticipatory indicators of human walking motion for prediction of human paths. We believe these indicators can aid robot path planning in dynamic, human-centric environments. Additionally, through human-subject experimentation, we studied the saliency and team fluency of our robotic assistant. Future work will include design of algorithms, motivated by these and similar human factor studies, for improving robot planning performance and human-robot team fluency in HRI scenarios.

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