End User Interfaces for Human-Robot Collaboration

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ABSTRACT

Collaborative robots (cobots) are increasingly utilized within the manufacturing industry. However, despite the promise of collaboration and easier programming when compared to traditional industrial robots, cobots introduce new interaction paradigms that require more thought about the environment and distribution of tasks to fully realize their collaboration capabilities. Due to these additional requirements, these collaboration capabilities are underutilized in current manufacturing. Therefore, to make cobots more accessible and easy to use, new systems need to be developed that support users during interaction. In this research, we propose a set of tools that target cobot use for multiple groups of individuals that use them, to better support users and simplify cobot collaboration.

CCS CONCEPTS

• **Human-centered computing** → **Collaborative interaction**; • **Computer systems organization** → *Robotics*.

KEYWORDS

Collaborative Robots, Human-Robot Collaboration

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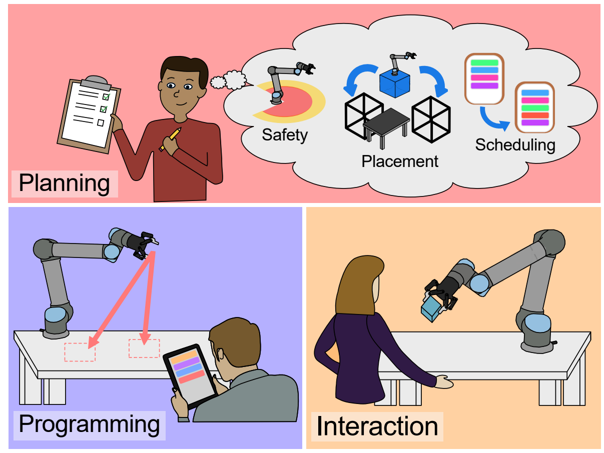

Figure 1: Three ways users interact with cobots: *Planning,* where users think about the cobot interaction and environmental setup; *Programming,* where users make the cobot operational; *Interaction,* where users collaborate with a cobot.

1 INTRODUCTION

Cobots, marketed for their safety and easy-to-use programming capabilities, are increasingly being utilized within manufacturing. However, their increasing usage has introduced many users to new and unfamiliar interaction paradigms when compared to the use of traditional industrial robots. Due to this unfamiliarity, additional training is required for users to better understand how to integrate cobots into their processes and utilize all of their collaborative potential. This unfamiliarity and difficulty are some of the factors that have led to a growing "skills gap" in the industry [6, 9, 16]. This skills gap has resulted in cobots being mainly utilized as a cost-effective form of automation [11, 20] rather than collaborative technologies that can work side by side with people.

As a motivating example of these issues, in our prior work, we collaborated with a small-to-medium enterprise (SME), allowing us to play the role of robot integrator and develop a collaborative manufacturing process that the SME can operationalize. Through that study, we found that our SME collaborators did not have personnel with experience in programming cobots, had no specific knowledge of how they wanted to interact with the cobot, nor knew how to structure their existing manufacturing process to utilize the cobot's collaboration capabilities effectively. Not considering these factors and others, such as operational safety and placement of the cobot [2, 8, 10], can result in the use of cobots as automation. However, this process of thinking about collaborative interactions permeates the entire integration process, including the *planning* stage where users identify tasks the cobot will engage in and how it collaborates with a person on those tasks,*programming* it for effective collaboration, and the *interaction* stage where users will collaborate with it (Figure 1). While recent work has begun to investigate solutions for areas of these stages, such as automatically constructing task plans [5] or communicating robot intent during interaction [1, 13], new interfaces are required to support user knowledge about cobots and their decision-making about how to effectively use them.

In this research, we aim to address the difficulties of using and reasoning about cobots for different end users at different stages of cobot usage, namely the planning, programming, and interaction stages. We plan to engage with SME workers at each stage to understand their needs and identify the areas where the use of cobots is perceived as being difficult or where their knowledge can be better supported. This understanding will be used to develop systems and

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interfaces that support users as they use cobots at each stage. This work seeks to address the following research question:

> How can we support end users as they interact with cobots during the (**RQ1**) planning, (**RQ2**) programming, and (**RQ3**) interaction stages?

2 PLANNING

In the *planning* stage, we seek to answer **RQ1** by first understanding the process for planning cobot integration and then providing end-users with a means for facilitating that process.

Planning Collaborations – Prior work. In our previous work [19], we have worked to understand the steps required to successfully plan for cobots to be integrated into a manufacturing process. That work identified the steps needed to integrate cobots into an existing process and the concrete things that need to be accomplished to increase the manufacturer's understanding and ensure a successful collaborative application of the cobot. In this work, we collaborated with a local SME to understand their existing processes, identify potential areas for cobot integration, develop simulations of their environment and the collaboration taking place, and then discuss with them the implications of the possible integrations and how each one performs. In this process, we built an understanding of their needs and usage of cobots, allowing us to identify what and where support is needed in the process so that we can answer **RQ1**.

Planning UI – Ongoing work. In our ongoing work, we are seeking to use the approach and supports identified in the prior study to answer **RQ1** through the development of an algorithm and end-user interface. The algorithm uses Proximal Policy Optimization reinforcement learning [15] with action masking [7] to simulate collaborative interactions and produce a policy that determines how best to collaborate on a given task while accounting for economic and ergonomic factors that affect the level of benefit from a cobot during interaction [3, 12]. The model learns from simulated interactions, being rewarded for completing the manufacturing process while receiving a negative reward proportional to the process's impact on the economic and ergonomic metrics. The developed interface allows users to use this model by focusing on knowledge they are familiar with, such as desired tasks and the environment. The interface then produces collaborative plans while informing the user about the effects of implementing each one, addressing the gap in knowledge that would otherwise be required for users to integrate cobots into their processes successfully. We will compare the output of our algorithm to analyses computed by ergonomics and economic experts to demonstrate its capability, and then evaluate user interactions with the interface, exploring how to leverage their existing knowledge while supplying critical decision information.

3 PROGRAMMING

In the *programming* stage, we seek to answer **RQ2** by supporting novice cobot programmer knowledge with expert level feedback about collaborative interactions.

Cobot Programming – Prior work. In our prior work, we have worked on the creation of a programming system that attempts to address **RQ2** by assisting novice programmers in creating successful cobot programs by identifying issues with their programs that an expert might have [14]. The system is designed with the programmer in mind, giving them a structured method for building programs, using drag-and-drop-based programming, while allowing for a more complete visualization of the program in action and the issues with it. As the user investigates each issue the system brings to their attention, they are given information about what the problem is, what it looks like visually, where it occurs in their program, and tips on addressing the issue. The feedback the system provides is based on the work of Siebert-Evenstone et al. [17], and is meant to help the user learn about cobots and assist them in building safe and more collaborative programs.

Programming Evaluation – Ongoing work. We are working to evaluate the programming interface with both industry roboticist experts and novice students to ensure usability for all types of users. This two-fold evaluation approach seeks to verify the design choices for the system with industry experts, by discussing what problems they encounter, whether the system is equipped to address those problems, and what else needs to be done to close the skill gap for programming cobots. In parallel, we are evaluating the system with novice cobot programmers to understand their experience with the system and how the programming supports affect their usage.

4 INTERACTION

In the *interaction* stage, we seek to answer **RQ3** by understanding the workflows of cobot operators, analyzing breakdowns in the interaction, and developing systems that support their collaborations.

Understanding Cobot Interactions – Future work. In our future work, we will investigate the needs of cobot operators in manufacturing through participatory design methods [18] in which we will engage operators in discussions about their workflow, work through hypothetical interactions with a cobot, discuss whether providing information or control mechanisms would assist their workflow, and develop a paper prototype of potential interfaces. Using this qualitative data we will identify supports for **RQ3** through an understanding of the operator's needs, the breakdowns and difficulties in their interactions, where support is needed, when they are applicable, and design suggestions for facilitating that support.

Synthesizing UIs – Future work. Our future work seeks to utilize the knowledge from the previous study in the development of an interaction system for providing users with the information needed for a successful cobot interaction and the ability to adjust and control the robot and interaction. This future work will leverage the principles of program synthesis and analysis [4] to dynamically build user interfaces through which the operator can effectively understand and interact with the cobot during collaboration. These interfaces will incorporate information about the program, robot, and user to display information and control schemes as understood from the prior study while allowing for flexibility between different workflows of individuals. We plan to evaluate this system with cobot operators in the manufacturing industry to understand how the supports affect cobot interactions and user perceptions of them.

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