Framework for Identifying Gripper Requirements for Collaborative Robot Applications in Manufacturing

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Abstract. Robots designed for collaborative applications based on the interaction between human operators are on the rise in the industry. With the involvement of humans, special consideration should be given to select the end effector of cobot generally referred to as grippers. This paper presents a framework for the identification of gripper requirements in a systematic way. The paper first provides general information on DFAA analysis and task allocation methods used in the framework. Different levels of interaction and gripper principles are also presented. Scenarios for varying levels of interaction are presented, followed by the framework to identify gripper requirements with an explanation for each step in the framework. The advantages of using the proposed framework are shown in the discussion, followed by concluding remarks.

Keywords: Collaborative Application, Gripper, Framework, SII-Lab,

1 Introduction

Robots designed for collaborative applications, as a stand-alone entity, is a manipulator with advanced sensors that enhance its capabilities to work alongside a human [1]., Cobots need to work together with humans to achieve an actual collaboration. The complete setup of cobot, gripper, and workspace arrangement to perform a specific task along with a human is called a collaborative application. There is a growing interest in collaborative applications in industry. With cobot applications, the interplay between the human operator, the manipulator, i.e., the robot arm and the gripper, are central for performance. While the manipulator controls the movement of components, the gripping tool is responsible for grasping and holding onto the component, thereby playing a pivotal role in realizing the cobots activities.

This paper aims to improve the understanding of how to identify gripper requirements for different levels of cooperation in collaborative applications within manufacturing settings.

The paper takes on a conceptual approach to address its' aim, considering the gripper requirements for different levels of cooperation in kitting and assembly processes. For each process type, gripper requirements for four different levels of interaction are discussed based on the available literature about the topic and based on the previous case research that has involved the different process types. This is followed by a method to identify gripper requirements for collaborative applications. The scope of the Gripper selection processes is limited to operational requirements. Strategic requirements are not considered in this paper.

The structure of the paper is as follows. The theoretical framework is presented in sections 2, 3, and 4 reviewing previous research. Additionally, the four levels of cooperation are described in the context of an assembly and kitting process in section 5, followed by a framework outlined in section 6. The paper ends with a discussion and conclusion with future research presented.

2 Design for Automated Assembly (DFAA)

Design for Assembly (DFA) is an integral part of any product and process development. The aim of this process, as stated by Boothroyd in [2], is to achieve efficient assembly by reducing complexity in product design and assembling the product in the form of manual or automated assembly with the lowest possible cost. The ease of assembly is not just dependent on DFA but also in the way the part or component is fed, handled and assembled and involves issues such as placing and handling problems and feeding difficulties [2]. This method is further developed to increase automation. Design for Automated Assembly (DFAA) is presented in [3] where the need for addressing part presentation in the form of shapes and sizes, alignment, and complexity in assembly operations is highlighted. A further step towards automatic assembly is to understand the assembly sequence of components. step towards automatic assembly is to understand the assembly sequence of components. This is done in the DFAA analysis on a component level to determine if the component is a candidate for integration with another component. The analysis is based on the properties of the component such as shape, weight length, graspability, orientation, error rate, degree of roughness and ability to hooking and the components in relation to the component it will be assembled with, which includes the assembly motions, access for assembly, fitting, tolerances, risk to loose orientation after assembly, method of attachment, control/adjustment.

Further development of this relationship is to use a Hierarchical Task Analysis (HTA), a precedence graph [4], or an ABC-analysis (Assembly By Constrains) [5]. All three methods give relation to how and when the different components need to be assembled. It could differ depending on if the assembly is manual or automatic.

2.1 Task Allocation and levels of interaction

For any type of collaborative work, it is essential to learn and understand the skills and capabilities of the operators and machines before designing the process. This can be done in the skill-based task allocation process [6]. Weichhart [7] has extensively presented agent (represented as humans operator) based task allocation process. Operators 4.0 typology is based on using industry 4.0 technology along with human operators to carrying out manufacturing tasks [8]. Task allocation is done using operator 4.0 focusing on operator skill matching and using industry 4.0 technology which can be useful in the collaborative application if the workspace requires extra support tools for the operator such as exoskeleton or AR/VR glasses

While considering task allocation, it is essential to consider the different levels of interactions a collaborative application can achieve. As defined by Bauer et al. [9] following are the different levels of interactions in the context of collaborative applications.

1. Cell: Traditional cage scenario where the robot is isolated in a cage.
2. Coexistence: Human and robots work alongside each other without the presence of any cage though workspace is not shared
3. Synchronized: Human and robot shared workspace. Only one interaction partner (i.e., either human or robot) is actively working in the workspace.
4. Cooperation: Shared workspace where both humans and robots have tasks to perform. This task is not simultaneously performed at the same location of a product or component.
5. Collaboration: Humans and robots work simultaneously on the same product or component.

2.2 Gripper principles, selection criteria's and frameworks

Grippers are highly influenced by the geometry of the part, and it's graspability [6]. Guidelines for designing grippers are presented in [10] from two different perspectives, one to increase throughput and others to increase reliability. These guidelines include different kinds of advice, for example, to avoid the unnecessary weight of gripper, include functionality on gripper fingers, design gripper to grasp parts securely, having sufficient approach clearance while picking and placing a part which can be applied even while selection a gripper for collaborative application. Traditional frameworks for gripper selection focus on parameters such as part geometry, handling process, and process environment. For example, the methodology developed by [11] focuses on grasping principles for parts defined by DFA methods. The grasping principle generates minimum requirements for grippers along with environmental requirements, advice, and warning. Though the method is extensive and well developed with feedback for redesigning parts for assembly, a limitation for its use in a collaborative application is the lack of specification on human involvement in an assembly task. Pham [12] defines five primary factors in a gripper selection process, namely, component, task, environment, robot, and gripper. Each factor has its sub-criteria, which helps in finding vital requirements for gripper selection. The method developed by Schmaltz [13] uses the factors presented by Pham[12], such as part data in the form of its geometry, environmental factors along with the assembly information, and the device used. The method generates a set of grippers based on the input parameters. The methods consider environmental and task parameters but lack human factors, thus unsuitable for collaborative application. Thereby, the current paper, which takes human factors into account in the context of gripper selection, make up an important extension of the available literature.

3 Collaborative robot applications in manufacturing

Pick-and-place tasks the most common tasks for collaborative robot applications [14] these pick-and-place tasks can be performed in assembly, kitting, and load-unload operations. Different levels of interactions between the robot and the human demands different requirements on the gripper. Below are examples from assembly and kitting.

Coexistence Assembly: A coexisting assembly is where the cobot and operator work in series in a shared workspace. An example of coexistence assembly is present here [15] where cobot used for assembling nut on wheel hub while operators' tasks include replenishing the material rack and check the assembly if the robot reports so.

Coexistent kitting: Boudella [16] considered a coexistent kitting process. In the process, the operator and the robot prepared kits in series, working at different workspaces. In addition to picking components, the robot was also responsible for removing empty bins and discarding internal packaging.

Synchronized Assembly: Operators and cobot perform work in a synchronized manner in the same workspace with only one entity working at a time in a simultaneously performed in a synchronized manner. As shown in figure 1.1, the operator waits with a nut in had while the cobot puts fuse in the box. Only after the cobot finishes placing the fuse and leaving the fuse box area, the operators start assembling the nut.

Synchronized kitting: Based on the setup presented in [16], it is easy to imagine a process where an operator and a cobot take turns at kitting components at the same workspace. This shared workspace would take up more space than the individual workspaces in [16], as all components would have to be stored at the same workspace

Cooperative assembly: Operator and cobot share the workspace and work alongside each other. Similar to synchronized work, the but operator and cobot are working on the same part parallelly. As shown in figure 1.2, the operator is assembling nuts while the cobots in placing fuses on the same battery box.

Cooperative kitting: Fager in [17] considered a cooperative kitting process. The process involved a cobot mounted on an AGV that helped the operator sort components into a batch of kits. The operator and cobot worked on different order lines, cooperatively.

Collaborative Assembly: A fully collaborative assembly is where the operator and cobot work together on the same part at the same time. As shown in figure 1.3, the cobot pick's and places the nut at the designated location with the use of its gripper while the operator tightens it.

Collaborative kitting: While it is not apparent how a collaborative kitting process could be set up, tasks such as removing packaging where the robot holds a component for the operator or a quality inspection where the operator could display a component to the cobot, which then, by utilizing, e.g., object recognition, checks that the component is free from damage.

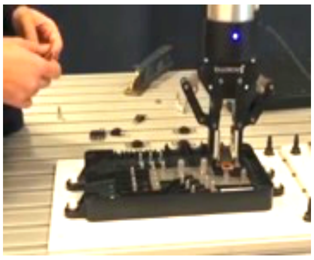
Figure 1.1: Synchronized Work


Figure 1.2: Cooperation work

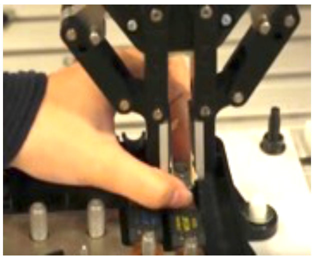
Figure 1.3: Collaboration work

4 Analysis

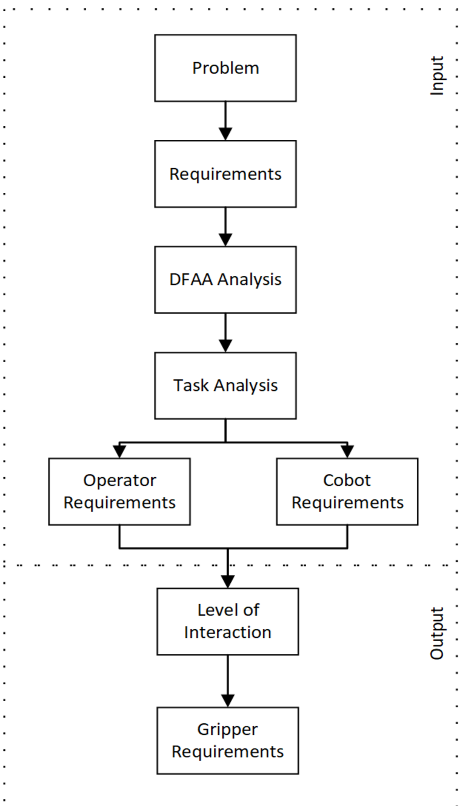

Figure 2: Framework for identifying gripper requirements

Problem
. A clear problem description should be formulated about the proposed operation. Problem description can include, for example, why and how the task can be solved.

Requirements
. All the requirements to solve the problem presented in step 1 should be gathered. These requirements can include, for example, the number of components, part geometry, cycle time.

DFAA Analysis
DFAA analysis is explained in section 2.1. Tools such as DYNAMOO++ are helpful in DFAA analysis.

Task Analysis
. Task analysis present in 2.2 should be used to identify the potential of task allocation between human operator and machine, i.e., cobot.

Operator Requirements
. Operator requirements are, for example, ergonomic requirements that should be considered. Furthermore, the skill and comfortability of the operator to work together with a cobot should be analyzed.

Cobot Requirements.
. Cobot requirements include the payload capacity, TCP reach, degrees of freedom, speed and acceleration should be considered

Level of Interaction
As a result of previous steps, a few options of the level of interaction are generated based on the DFAA and Task analysis. All levels obtained should fulfill the requirements of safety and security standards for industrial robots listed in ISO 10218-1:2011, ISO 10218-2:2011 and for collaborative robots in ISO/TS 15066:2016

Gripper Requirements
Specifications for gripper required to solve the problem are generated form the input process. The requirement specification should include gripper types such as two or three-finger gripper, power types such as pneumatic or electric, and other similar specifications that can be either be purchased as off the shelf gripper or making a customized gripper.

5 Discussion and conclusions

Identifying and choosing gripper should be based on exact requirements to avoid unnecessary cost and compatibility issues, as well as in making the collaborative application safe. This choice should be based on systematically generated requirements. The method presented in this paper provides such a framework with a focus on the combined requirements of humans and cobot requirements in a collaborative application. Furthermore, the proposed steps of DFAA and task allocation provide feedback on changing and improving product design, generating assembly instructions, and methodically distributing tasks by matching skills with competence. It is crucial to find the right balance between the task distribution to achieve an optimal rate of productivity and quality. Having these steps well in advance helps avoid the unnecessary cost in money and time that may cause due to changes and modification to product and operation in later stages. Having a human working together with a machine such as a cobot requires a lot of safety and security. ISO standards mentioned earlier presents many of such requirements.

Assembly and kitting operations in the context of collaborative applications are explained in section 3. Different levels of interaction present many similarities in their operating procedure. For example, the principles of pick-n'-place and grasp- ability apply to both assembly and kitting operations. An advantage for such similarities is useful when finding requirements for selecting a gripper. Thus, the framework can be applied for selecting gripper for assembly operation or kitting operation or collectively for both. The advantage of the collective approach is the reusability of the gripper for other operations in either kitting or assembly. Reusability also increases the flexibility of the collaborative application with the possibility to apply at various workstations with similar requirements.

To conclude, this paper presents a framework for identifying gripper requirements for collaborative application. The steps presented in this framework, such as DFFA and task allocation, not only help in identifying gripper requirements but also in detecting potential improvement in design, as well as workstations. Additionally, the steps in the proposed framework involve human consideration at every stage, thus making this paper an essential contribution to the available literature, where consideration to humans and collaborative tasks, for the most part, have been neglected in frameworks for gripper selection.

The proposed framework also helps in identifying potential safety threats in the context of developing a collaborative application. Future work will focus on build collaborative robot application demonstrators with different levels of interaction using the proposed framework.

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