Formulating User Requirements for Designing Collaborative Robots

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***Abstract*— This paper is concerned with a methodology for gathering user requirements (URs) to inform a later design process of industrial collaborative robots. The methodology is applied to four use cases from CoLLaboratE, which is a European project focusing on how industrial robots learn to cooperate with human workers in performing new manufacturing tasks. The project follows a User-Centered Design (UCD) approach by involving end-users in the development process. The user requirements (URs) are gathered using a mixed methodology, with the purpose of formulating a list of case specific requirements, which can be also generalized. The results presented in this paper consist of the list of user requirements, which will serve as a basis in establishing scenarios and system requirements for later design of a Human-Robot Collaboration (HRC) system. The described methodology contributes to the field of design of HRC systems by taking a UCD approach. The methodology is aimed at improving the solution performance and users' acceptance of the technology, by early involvement of the users in the design process. It can also be adaptable to other development projects, where users play an essential role in creating Human-Robot Collaboration solutions.**

I. Introduction

Over the past 30 years, robotics technology has brought remarkable efficiency gains to industrial manufacturers. Robots have applications in many different domains, each having its own needs and specifications [1]. As the field of robotics continues to advance, an increased concern related to Human-Robot Interaction technologies can be observed. It advocates for more flexible and efficient Human-Robot Collaboration (HRC) in environments where humans and robots co-exist. It also can be applied in implementing robotic solutions in human-only environments [2].

From one point of view, robots are considerably faster and more efficient than humans, but there is a number of tasks which are better performed by the human, in cases where the work is more complex. This delicate HRC balance has been intensively researched in industrial environments, where the need for such interactions is the highest [3]. From this perspective, more challenging robotic tasks, such as the assembly application, result in low flexibility and higher programming time. Thus, robotic assembly has proven challenging to automate due to complex materials, precise grasping, part variations, high precision operations, etc. [1].

When designing an HRC solution, the entire system should be considered, taking into account all the factors that have an impact on the robot itself, as well as on the humans interacting with it [4]. As robots are known to improve performance while humans can contribute with their experience, the transfer of knowledge and robots' supervisory functionalities can greatly aid in a successful accomplishment of a wide range of tasks [5][6]. Thus, the human as a user, can interact directly with a robot, by sensing its position, by manipulating its configuration, or by using an interaction device [4]. Considering these facts, the study performed in the CoLLaboratE project focuses on gathering requirements from users, to design robotic technologies which recognize all the factors within a given scenario and can work together with humans. This is mainly important because involving the users in the early stages of product development helps in understanding the user needs and how to build robotic technologies which are more acceptable to users. Therefore, the user requirements will be the starting point for formulating specific scenarios for the new solutions, for establishing the system requirements.

II. Project Background

The CoLLaboratE strategy is based on a continuous and iterative interaction between the end-user, who sets the requirements for integrating robotic platforms in collaborative assembly lines, and the Artificial Intelligence (AI) Technologies providing new and advanced tools for introducing robustness and flexibility to the robotic assembly platforms. By combining industry needs and AI research on robotics, CoLLaboratE follows a UCD approach, by involving end-users to develop an efficient solution to achieve a more streamlined development and a more flexible deployment. To accomplish this, the project's objectives are to develop: a framework that enables non-experts teaching HRC tasks from demonstration, technologies that will enable autonomous assembly policy learning and improvement, techniques for controlling the production line while making optimal use of the resources by generating efficient production plans. Moreover, the project aims to validate the system's ability to facilitate genuine collaboration between robots and humans and to equip robotic agents with basic collaboration skills. In order to verify the technologies developed within the project, four use cases have been identified for CoLLaboratE, from different industries and applications. They will enable capture, analysis and communication of user needs and requirements.

A. Use Case 1: Windshield visual quality check

In this use case, a robot is intended to automatically pick a variety of components and aid in the cooperative assembly process with the operator. The components, such as customized sensors and rear-view mirror are to be installed on the windshield. The robot then performs the installation of the windshield on the car chassis, minimizing the human

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involvement in the assembly process. The proposed system eliminates many passive components, minimizes work cell area, reduces lead time and specifically learns to personalize operator preferences based on good ergonomics. All key aspects of collision detection, collision avoidance and ergonomics are carefully addressed, to ensure a safe HRC.

B. *Use Case 2: Aerospace structure riveting*

This use case is related to the assembly of aeronautical structures by riveting. The percussive riveting is a truly collaborative process involving two human operators. Although different robotic solutions have been proposed for the automatization of this type of riveting, it mostly remains a manual process, given the complexity of the technology and of the associated geometry on which it is applied. By replacing one human operator with an industrial, collaborative robot, the process becomes more efficient and ergonomic. As opposed to fully automated riveting processes, the collaborative riveting will also rely on a human operator for making the sort of choices and decisions that normally prove difficult for a robot.

C. *Use Case 3: LCD TV assembly*

This use case refers to the complex and rapidly changing assembly tasks of LED TVs. Picking and placing of the integrated circuits components and fixing of these components will be completed by the collaborative robot system developed in CoLLaboratE. The robot and the human operator will share the same workspace, where the robot brings the integrated circuits and the operator fixes them on the TV. The continuous production line requires accurate conveyor tracking and part locating algorithms, so advanced vision systems will be developed for these purposes. The entire interface will be flexible, thus whenever a new TV model is produced, operators will easily teach the new positions and orientations by demonstration.

D. *Use Case 4 - Car starter assembly*

The subject of the collaborative process in this use case is the assembly of a part of the car starter. A part of the process which comprises the insertion of copper sliding rings into metal pallets, which are then transferred to the moulding machine is to be automated. Currently, the process of inserting sliding rings into the pallet is performed manually and is considered hard to automate. The vision of the project is to develop a robotic system that will assist / replace the worker when he will not be present. Thus, the worker and the robot will be both capable of executing same operations.

III. Methodology

The process of formulating user requirements within the CoLLaboratE project consists in data collection, analysis and interpretation, the process being summarized in Fig. 1. A combination of qualitative and quantitative methods earlier discussed in [7] can result in a variety of methodologies. In this study, a specific combination of the two is used. The qualitative perspective offers an understanding of the users' perceptions by considering non numerical data such as text, pictures or videos [8], while the quantitative approach uses numerical values, used here to quantify the data and validate choices [9]. This methodology is a continuation of work presented in the project [10].

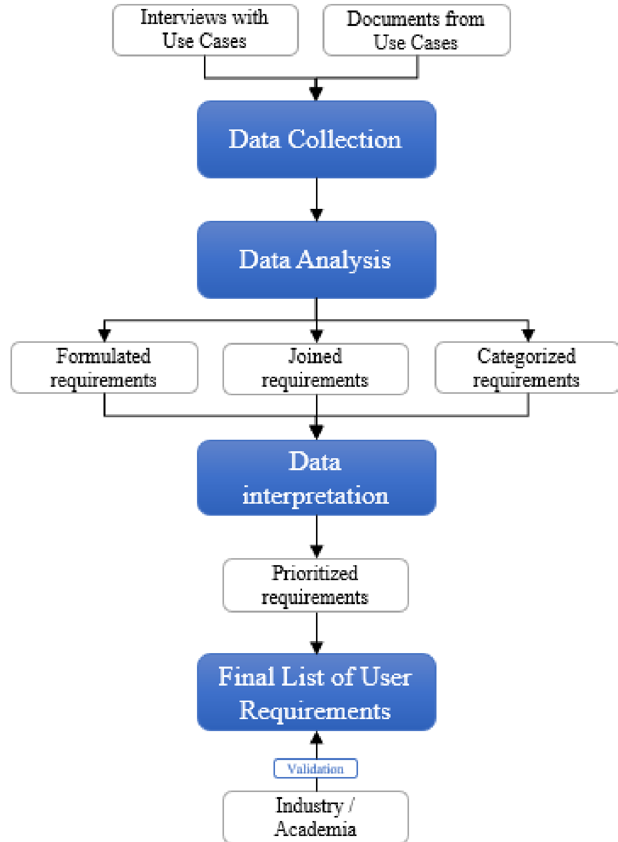

Figure 1. The process of formulating URs in CoLLaboratE

A. *Data Collection*

There are multiple methods of gathering user requirements. In CoLLaboratE, this process was inspired by [4]. Namely, the following questions should be answered: (1) In what environments must the robot operate? (2) Are there any dangers, which the robot must react to? (3) What interaction is required with the environment? (4) Does the user require sensory feedback from the environment? (5) Is it necessary to manipulate the environment? (6) What interaction is required between the user and robot? (7) What is the workload of the user? (8) What training is available? (9) What are the mission requirements? (10) How accurate must it perform its operations? (11) What functions must the robot perform? (12) Are there any optimisation criteria? However, there might be additional important factors to consider, which can be discovered during the process of gathering URs. As such, the methodology is flexible enough to capture this important data.

The data collection within CoLLaboratE has been conducted using qualitative methods. Firstly, the use cases representatives were asked to provide text, pictures and video files of the use cases, in order to better understand their applications, and the environment the HRC should take place in. Secondly, interviews with use cases representatives were chosen for data collection, having the previously received files as a starting point. Based on these, a semi-structured interview was defined, focusing on three subjects: *current situation* (how do they currently solve problems in each of the use cases and what other problems are there, which are relevant for the technologies developed within CoLLaboratE), *the user environment* (who the end-users are, including their background information, and what kind of services would they need to use these technologies), *non-functional requirements* (expectations about performance, maintenance, support, security, installation, safety and others). The interviews were planned for two hours for each use case.

B. Data Analysis

Upon collection, the data was analyzed with the purpose of formulating a final list of URs. Thus, the raw data (transcriptions and notes from all interviews) were analyzed, with the purpose of reformulating them in URs, in the format of "The user needs […]", "The user wants […]" or "The system shall […]", format suggested by [11]. URs from separate use cases, which represented the same need, were summarized in one UR. Therefore, the final list consists of case specific and common URs, together with the use cases they have been identified within. Thus, a common UR has more than one source, being applicable to more than one use case. In order to structure the final list of requirements and have a clearer view on which areas the users have more needs in, a categorization was made, based on 11 pre-defined categories: (1) Communication (between user and robot), (2) Configuration / Adaptability (to various applications), (3) Data Handling (by the robotic system), (4) Safety / Security (related to Standards and ergonomics), (5) Fail Safe, (6) Functions, (7) Documentation, (8) User Interface, (9) Training (of the operators), (10) Maintenance, (11) Availability / Accessibility.

C. Data Interpretation

The need for interpretation of the data derives from the necessity of offering meaning to the research findings [9]. In this study, the results of the data analysis have been integrated into a prioritization tool, the result being the basis for formulating system requirements and scenarios.

The matrix used for prioritization considers three ranking perspectives, with three criteria each: (1) Operators (Usability, Intuitivity, Satisfaction), (2) End-Users (Costs, Risks, Added Value) and (3) Development (TRL, Feasibility, Integrability). Each use case representative will be asked to rank the user requirements individually, from the Operators and End-Users perspectives, while the partners involved in the technical development will rank them from the development criteria. A 1 to 5 Likert scale is used and an average for each identified UR will be calculated to establish the final scores. Based on these perspectives, a prioritization of requirements will be possible, based on the value for the operator and ease of development, by also considering the value for the end-users. In order to assess the impact of a specific UR not being implemented, a dissatisfaction score is included in the matrix. This is especially useful to retrieve the system requirements from the URs. For this, the Volere methodology will be used [12].

Based on the Volere template, the system requirements are separated into two fundamental categories, functional and non-functional. The Functional Requirements describe the desired functionalities that the project should have and how they should be connected in a complete useful final product. The Non-Functional Requirements on the other hand describe the desired properties of all the components of the system such as their performance, efficiency, and usability.

D. Validation

Since the presented methods helped in understanding and documenting the use cases, a more general approach is adopted as well, to collect information from other representatives of industry and academia. A survey with 15 questions was prepared to gather insights about collaborative robots. It focuses on the type of organizations the subjects represent and depending on this, their needs are classified if they were to adopt collaborative robots to automatize their processes. A sample of minimum 20 subjects is expected to answer this survey [13]. The results of this questionnaire will be used to validate the user requirements gathered from the use cases within the Collaborate project.

IV. Results

The results of this study are compiled in a final list of requirements gathered from all the four use cases. The initial analysis of the data revealed 101 UR. Their sources can be seen in Fig. 2. As it can be observed, the number of URs is evenly distributed, each use case offering 20 to 27 URs.

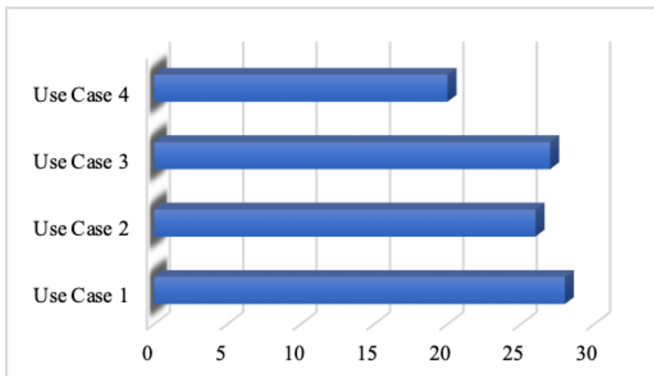

Figure 2. Number of Requirements per Use Case

After analyzing this list, it was observed that there are requirements which were mentioned in more than one use case (common URs). The repeated ones were joined together, thus the final list consists of 77 URs. Table 1 shows an example of URs which were present in more use case and how the joined one was formulated.

TABLE I. Joined URs

Initial Data Analysis		**Final Requirements List**	
Source	***Initial URs***	***Source***	***Joined UR***
Use Case 1	The user needs an adaptable and flexible solution, which can handle different objects	Use Cases 1, 2, 3	The robot shall be able to adjust to different

Use Case 2	The robotic system shall adapt to various production lines	& 4	applications / production lines / operations
Use Case 3	The robotic system shall be adaptable to various production lines		
Use Case 4	The robotic system shall be adaptable, so it can be used on multiple operations		
Use Case 2	The robot shall be able to perform specific tasks without the human operator	Use Cases 2 & 4	The robot shall be able to perform specific tasks without the human operator
Use Case 4	The user needs to be able to leave the robot to work unattended		

The URs in the final list have been divided among the 11 pre-defined categories, and Fig. 3 presents the number of common URs per each category compared to the case specific ones. It can be observed that most URs can be found under the category "Functions", refering to what the final robotic system has to deliver while few URs can be found under Training and Data Handling. Moreover, 8 categories present common URs, which means that more than one use case identified that specific requirement.

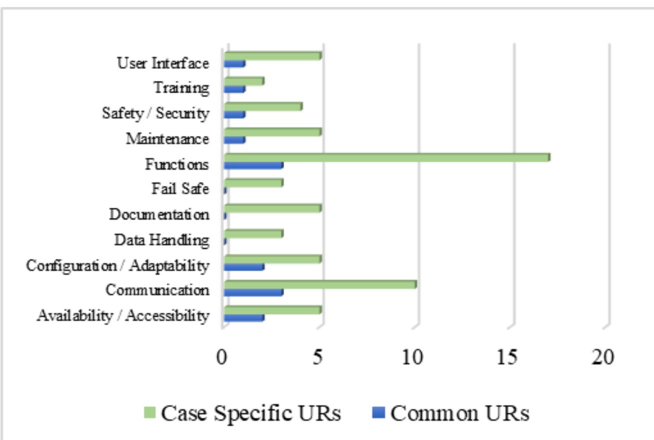

Figure 3. Case specific vs. Common URs per Category

This categorization will be helpful when analyzing the prioritized list received from the partners. It will be possible to assess which categories represent a priority for the development of the robotic solution and discuss on how to handle the use case specific requirements.

V. Conclusion

In this paper, a methodology which can be used to formulate user requirements for designing collaborative robots was described. In this case, the involvement of the use cases from the early stages of the project is essential, helping in assessing their requirements. In this way, their needs are documented and transformed into system requirements. It is also interesting to observe there are user requirements which are common for more than one use case, thus the prioritization results will help understand better the requirements list. Thus, we expect to have a prioritized list of user requirements which will serve as a base for defining the system requirements, including the robot functionalities. The analysis will combine use case related and general requirements which will highlight similarities and differences in designing robotic solutions. Additionally, by using the satisfaction and dissatisfaction scores, it will be possible to differentiate between needs and wants. The analysis will serve as the basis for creating the system requirements which will then be used for the development. The presented methodology is applied in CoLLaboratE, but it can also be generalized to be applied to different collaborative robots' development. These actions will facilitate discussions and decisions needed to successfully introduce robots within the four identified industrial scenarios.

Acknowledgment

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