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Optimising acceptability using a user-centred design approach of a robotic software in Industry 4.0: A case study

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Abstract: While robotics and collaborative robotics are becoming increasingly commonplace in industry, operators do not always have full control over these tools. The aim of our robotics software is to give operators back the power to act. A user-centered design approach (UCD, ISO 9241-210, 2019), through four steps, has therefore been put in place within Industry 4.0. The first study aims to understand and specify the context of use through three objectives: To understand the organisational context in which the robotic software is to be designed and implemented, to characterize the end users via primary personas, and to take an interest in the operators' work to predict likely future situations and guide the development of the new work tool. The second study aims to specify user requirements using a card sort based on different criteria (ergonomic, UX). The third study presents the design solutions for Version 2 of the robotics software. The fourth study evaluates and compares the practical acceptability (UX, usefulness, usability, mental load) and social acceptability (intent to use) of the first and second versions of the robotic software. Our results show, among other things, a significant improvement in acceptability for the second version of the software, suggesting greater acceptability of this technology thanks to the UCD approach.

Keywords: Acceptability, acceptance, collaborative robot, Industry 4.0, robotics software, user-centered design

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1. Introduction

1.1. Background

Today, increasingly complex technologies are being introduced into industry. In this respect, industries have witnessed many transformations for operators, in terms of production systems (craft production, production lines, flexible workshops, toyotism, lean manufacturing, etc.) (Yin, Stecke & Li, 2018), the tools used (i.e., manual tools, gearboxes, command-control, cooperative work with a machine, etc.) (Bobillier-Chaumon, 2021a), and working conditions (i.e., mechanistic logics, standardization of processes, dispossession of work, feeling of passivity, etc.) (Louche, 2018).

Today, the democratization of Industry 4.0 is leading to the emergence of numerous systems that are constantly evolving as technological research advances. The stakes of such investment are often clear for industries: The aim is to improve turnover and competitiveness by automating low-value-added tasks. However, these technologies are also work tools that are becoming increasingly difficult for operators to grasp, understand, and manipulate because of the increasingly technical and digital skills required to perform the task (Bobillier-Chaumon, 2021a). Among other things, this raises the question of the acceptability of these technological work tools to operators, loss of expertise due to industries' overconfidence in technology, and the difficulties associated with communication between the operator and the machine. Today, and even more so in the future, these technologies are becoming increasingly remote from the skills and competence of operators, who may be required to cooperate or work alongside these devices.

1.2. Acceptability and acceptance: Elements of definition

The concepts of acceptability and acceptance of technologies are complex, multidisciplinary, and multi-faceted.

The acceptability-acceptance *continuum* (Bobillier-Chaumon & Dubois, 2009; Bobillier-Chaumon, 2016; Bobillier-Chaumon, 2021b) makes it possible to link and group together the above approaches to acceptability into a trajectory of use: (1) *Social acceptability*; (2) *practical acceptability;* and (3) *situated acceptance* (Figure 1).

Social acceptability focuses on individuals' intentions to use a technology both before and after actual use, assessing their subjective perception of the technology (Bobillier-Chaumon, 2016). Models like the Technology Acceptance Model TAM: (Davis, 1989; Venkatesh & Davis, 2000; Venkatesh & Bala, 2008) and the Unified Theory of Acceptance and Use of Technology UTAUT: (Venkatesh et al., 2003; Venkatesh, Thong & Xu, 2012) are usually employed to measure social acceptability. There are also models that are part of a hedonic approach (Alexandre et al., 2018).

Practical or instrumental acceptability evaluates the interactions between an individual, their tasks, and the technology, emphasizing usability and usefulness (Bobillier-Chaumon, 2016). It also incorporates user experience (UX) to consider hedonic aspects and emotional responses to technology. To measure practical acceptability, heuristic evaluations, the System Usability Scale SUS: (Brooke, 1996), and user experience questionnaires like Attrakdiff (Hassenzahl et al., 2003) or the modular evaluation of key components of user experience meCUE: (Minge & Riedel, 2013) are commonly used.

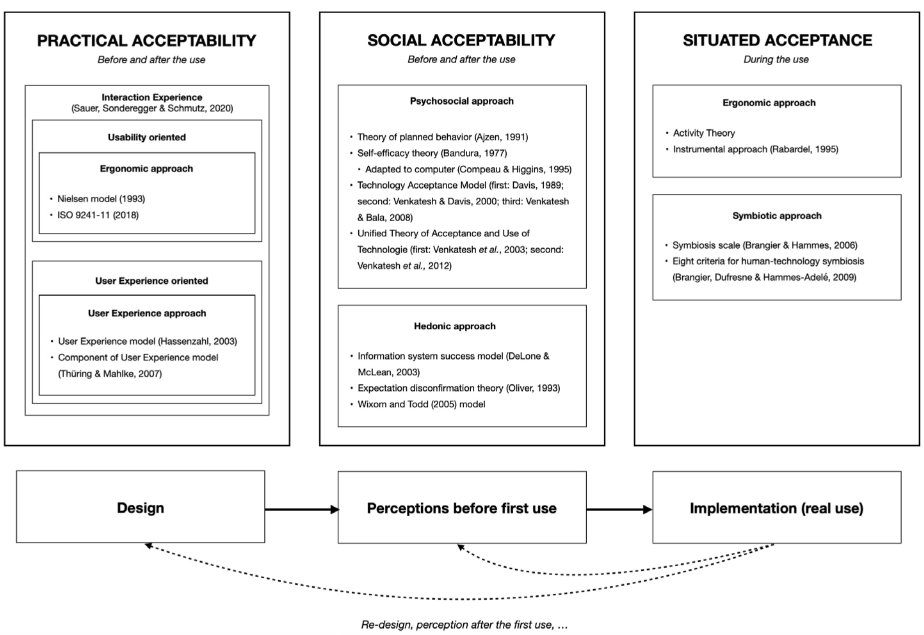

Figure 1. From acceptability to acceptance model.

Situated acceptance examines the actual use of technology within a specific organisational and work context, observing how technology adoption alters work activity (Bobillier-Chaumon, 2016; 2021) to foster a symbiotic relationship (Licklider, 1960; Brangier & Hammes, 2007). Indeed, situated acceptance seeks to understand the adoption of technologies during actual use, which can be promoted or hindered by five dimensions: Intra-individual, inter-individual, socio-organisational, transpersonal, and impersonal (Bobillier-Chaumon, 2021b). Situated acceptance is researched through theories of activity during system use (observations, interviews,…), reflecting the real-world application of technology.

1.3. Robotic software

Robotics software is an interface for programming specific actions for a robot. There are several types of software used in industry, proprietary software from robot arm manufacturers (e.g., Universal Robot).

In this study, robotic programming software enables operators to control an industrial robot, without having to have any programming skills. The software is used to transcribe the actions performed into lines of code that the robot can understand. These lines of code are hidden by the interface but remain accessible to engineers who want to immerse themselves more deeply into how the software works. it is intended to allow the robot to reproduce a sequence of gestures produced by the worker. In this way, the software aims to enable operators to conduct robotic programming, without them needing to call on any technical skills. In addition, this software is adapted to several brands of robotic arm (*i.e.,* Universal Robots, FANUC, Stäubli, *etc.*), which enables it to offer a universal interface, unlike brands of robotic arm that have an interface specific to their brand. Here, the UR3e cobot will be used in conjunction with the robotics software. It is in fact a collaborative robot, i.e., an emerging technology (Anastassova, 2006; Loup-Escande & Burkhardt, 2019; Loup-Escande, 2021) and suppletive (Bobillier-Chaumon & Sarnin, 2012) which, unlike traditional robots, can be manipulated manually through physical contact, thus making human-robot interactions easier.

1.4. Aim of the study

Designing software, and more generally a technological tool, requires a design approach. A user-centered, iterative design approach seems to be the most appropriate for the issues at stake in this research. Indeed, UCD or human operator-centered design (ISO 9241-210, 2019) is a "system design and development approach with the objective of improving the usability of interactive systems by focusing on the use of the system concerned and applying existing knowledge and techniques in human factors/ergonomics and usability" (ISO 9241-210, 2019, p. 3). This is particularly appropriate for the design of a human-machine interface (Abras et al., 2004; Dourish, 2004; Norman, 1988). This method allows the user to be a source of information about, and evaluation of design choices, differentiating it from participatory design, which places the user at the centre of decision-making (Loup-Escande et al., 2014).

UCD is structured in four stages (Figure 2): understanding and specifying the context of use, specifying user requirements, developing design solutions, and evaluating design solutions. If the design solution satisfies the user requirements after the fourth stage, the design cycle ends. On the other hand, if the design solution does not sufficiently meet user requirements, an iteration is conducted towards stage one, two, or three.

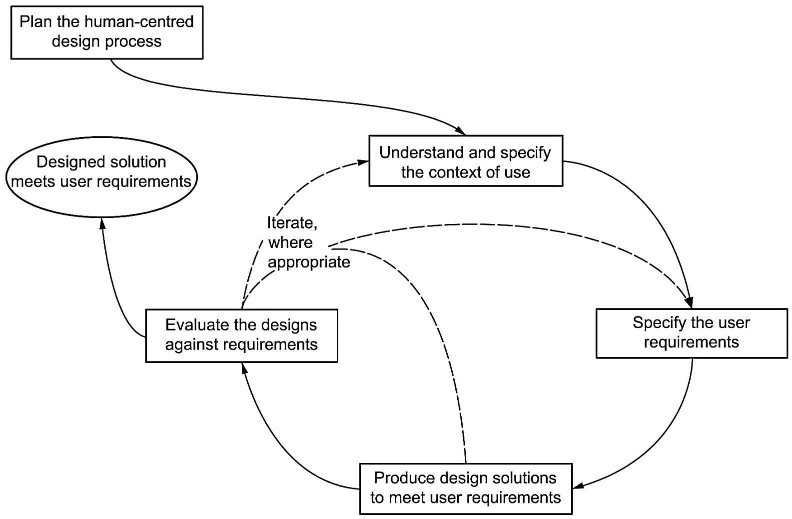

Figure 2. User-centered design, from ISO (9241-210, 2019, p. 13).

To the best of our knowledge, this study is original because no study has conducted a complete UCD of a robotic-robot software system. The aim of this study is to illustrate a UCD of a software robotic, and to show that the UCD of the software will improve the practical and social acceptability of the "software and robot" system.

This case study was conducted as part of a doctoral thesis in a company that had developed no-code robotics software without using the UCD method. The aim of this doctoral work was to redesign the robotics software, using the UCD method in the sense of the ISO 9241-210 (2019) standard, so that it is adapted to the operators and their work and so that they can regain control of their activity with a robot. Traditionally in industry, the use of robotics software requires a high degree of expertise, which is more possible for industrial engineers and roboticists. As a result, they have a direct impact on the working conditions of operators collaborating with a robot or cobot. The lack of adaptation of robotic software to operators can lead to degraded working conditions, in the sense that the operator can only adjust a few variables linked to his activity. They may then feel dispossessed of their work activity and, as a result, suffer from RPS (i.e. feelings of uselessness, stress, etc.) (Bobillier-Chaumon, 2021b). Initial user tests with operators on the 'non-UCD' version of our robotics software showed unsatisfactory results (Boutrouille et al., 2022), which motivated the UCD with operators.

The industry involved in the study, which has been awarded the "industry of the future" France label, wanted to create a new workstation involving an operator and a cobot, acting in co-action to install components in an electrical cabinet. In addition, the industry wanted to equip itself with robotics software that would meet the needs and expectations of operators and the demands of their work. For this reason, the participation of operators in the robotics software UCD was facilitated at all stages of the design and was made possible on the strict basis of their consent. In general, operators were enthusiastic about participating in a UCD and being involved in changes to their work.

For that, four UCD studies (ISO 9241-210, 2019) were implemented. Then, we will discuss the results regarding the hypothesis and conclude.

2. Study 1: Understanding and specifying the context of use

2.1. Methodology

The first step in the process is to understand and specify the context of use. The word "context" refers to the environment(s) of the system, the characteristics of the users or groups of users and the goals and tasks of the users (ISO 9241-210, 2019). There are three main objectives:

- Understanding the organisation in which the software will be used. To do this, we conducted a study of company documents (*i.e.,* organisation chart, certificate of deposit, general meetings, *etc.*), informal interviews with three operator-fitters and a team leader, and three semi-structured interviews with industry executives (director, R&D manager, operations manager). The interview guide included questions relating to the organisation (*i.e.,* history of the industry, corporate culture, internal communication, values, modes of recognition, decisions) and the change project (*i.e.,* operator support, perception, ambitions, vision, difficulties encountered).
- Understanding future software users. We created personas (Blomquist & Arvola, 2002; Cooper, 1999) using qualitative and quantitative data. We based our data collection with semi-directive interviews with twenty operator-fitters, cable workers, and inspectors to co-construct summary sheets containing information on bibliographical elements, as well as their needs and expectations linked to work and technology (Lallemand & Gronier, 2018). The operators were also asked to position themselves along five axes representing different personality traits and attitudes towards technology. Two main groups were identified, from which we created two personas. These personas were then evaluated by twelve operator-fitters, cable workers, and controllers to check their relevance, leading to the creation of a third persona which considered the specific characteristics of the plant's youngest operators.
- Identifying users' tasks to understand the work situation in which the software is used, and identify the levers, but also the potential obstacles, risks, and constraints to the deployment of a new robotics solution within the reference industry. An analysis of the activity, work situations, and work constraints were conducted by means of *in situ* observations and informal interviews with three operator-fitters over a two-day period. Non-participant observations involve observing operators in their natural context without actively participating in their activities, to collect objective data on their behaviours, interactions, and work environment (Chevalier & Stenger, 2018; Lemoine, 2012; Leplat, 2015). We also conducted a study of work supports (i.e., written traces, work objects) to obtain a macro-ergonomic vision of the organisation.

2.2. Results for characterising the organisation

This section deals with the organisation (*i.e.,* in what context is the UCD conducted?), the characteristics of the users (*i.e.,* who are they? What are their needs and expectations of a technological tool?) and of the work (*i.e.,* what tasks will the software assist or transform?)

From our interviews, we know that the organisation in focus is a French SME, engaged in the design and production of low-voltage electrical enclosures. It has navigated through fluctuations, crises, and innovation since its inception in 1994. After being acquired in 2006, it faced significant challenges during the subprime crisis, resulting in substantial job cuts. This period, often referred to as the 'dark years', eventually gave way to a more hopeful phase with new leadership in 2013, leading to significant improvements in working conditions and competitiveness, as evidenced by the "industry of the future" accolade in 2020.

The company's structure is a mechanistic bureaucracy due to its work specialization and process formalization, with a blend of adhocracy in its R&D sector (Mintzberg, 1982). The company has progressed to a technocentric approach, which, despite increasing productivity, has been met with some apprehension from the workforce regarding the pace of technological adoption.

Culturally, there has been a shift from a focus on control to one of innovation, a movement steered by the head of the company, whose charismatic leadership is pivotal in fostering support for organisational and technological transformations.

2.3. Results for user specification

In our study, we categorized plant operators into two groups based on their comfort with technology. Group A, typically older and longer-tenured employees with families, showed less technophile. In contrast, Group B, younger, were more technologically adept and open to innovation.

The analysis revealed both groups favour autonomy, with Group B associating it with skill enhancement. Attitudes towards robotics were quite different, with Group B showing greater acceptance. These findings inform our user-centered design (UCD) approach and training for technology implementation.

We encapsulated the operators' profiles into three personas: (1) Didier (Group A): A seasoned operator, hesitant about tech changes, favouring traditional methods; (2) David (Group B): A rational employee, open to skills development and new technologies, yet cautious until proven useful; (3) Thomas: A young, technophile worker, adaptable to change but sometimes impeded by the older generation's resistance.

2.4. Results for work analysis

Stage of which is strictly defined according to the customer's specific requirements. We found that the time cost of assembly varied according to several factors, including the size of the cabinet and the unpredictability of component delivery. Operators resort to various strategies to improve efficiency, including the use of tools in a context not intended by their designers. However, this practice can lead to safety risks.

In addition, we identified several work constraints, both internal (such as ageing operators and associated pain) and external (such as delivery delays), using systematic observations and informal interviews. These constraints can have an impact on operators' mental health, increasing the risk of stress and other psychosocial problems. Production deadlines, which are often set by sales staff, may also necessitate an increase in the production rate, which could lead to workplace accidents, errors, increased absenteeism, or demotivation. These constraints need to be considered when integrating robotics software designed using the UCD approach.

In addition, we explored the implications of workstation automation, with a specific focus on the use of robotic software, and the associated issues concerning the health, safety, and well-being of operators. Automation could lead to a reduction in tasks requiring specific manual skills, but it could also increase the cognitive load on workers, due to the need to establish a relationship of trust with the software and the robot.

We have identified various risks associated with automation, including those related to health and safety in the workplace. Rapidly evolving technology requires continuous adaptation and training of operators. In addition, the introduction of robots can lead to the risk of accidents. We stress the need for proper communication and training on the processes and tools involved in the recent technology. Automation could also have socio-economic implications, particularly in terms of job losses and cost reductions for companies. In addition to involving operators in all stages of the UCD and the changes to their work, several responses to these risks have been identified. In particular, the implementation of a programme to prevent accidents at work (i.e., physical impact), RPS (i.e., mental overload, isolation) and TMS (i.e., wrist, shoulder, and back pain), by identifying tasks that could be at risk and proposing ergonomic solutions to minimise them.

3. Study 2: Specifying end-user requirements

3.1. Methodology

A second step in the UCD is to define the user's requirements in terms of the context of use and the software's objectives. To do this, we launched focus groups to understand the ergonomic and user experience requirements of operators in the industry. Designers sometimes use prioritization to decide between alternatives, but it does not often involve the end user (Loup-Escande & Christmann, 2013). In ergonomics, particularly in user-centered design, this prioritization stage is crucial for gathering data on user needs to guide design choices for the prototype (Bastien & Scapin, 2004; Loup-Escande & Christmann, 2013).

Four operator-fitters, cable workers, and controllers were asked to prioritize cards created for the purposes of this study, which expressed various potential needs based on user-experience elements taken from meCUE items (Minge & Riedel, 2013; Minge et al., 2016; Minge et al, 2017; Lallemand & Koenig, 2017), non-instrumental criteria (Hassenzahl, Burmester & Koller, 2003; Lallemand & Koenig, 2017; Minge & Riedel, 2013) and instrumental criteria of usefulness (Lallemand & Koenig, 2017; Minge & Riedel, 2013; Nielsen, 1993), and usability (ISO 9241-11, 2018; Nielsen, 1993; Bastien & Scapin, 1993). The cards were shuffled and presented to the operators for sorting into groups. We analysed the data collected by grouping the cards into five categories ranging from (1) 'useless' to (5) 'very important'. Operators were also given the opportunity to add cards to express needs not covered by the existing cards. We also analysed the verbal data to justify and explain the scale scores.

3.2. Results

Robotics software operators give greater priority to instrumental qualities (usefulness, usability) than to hedonic qualities (appeal, attractiveness). Six of the ten aspects related to instrumental qualities are considered as important and three as important. For example, guidance is considered essential for effective navigation in the interface. As one operator put it: "*When you're a bit stuck, you can always come back to it*".

Not increasing the workload is another key criterion. One operator commented: "It's the basis of the software, if I have to work on top of it, well, I might as well not use it and get on with my work".

In addition, usefulness, efficiency, ease of learning, and ease of use are considered essential. As these extracts illustrate: "*If it starts wiring instead of assembling, there's no point*;" "*You say that, if the software does everything backwards or any other way, um... like I mean I might as well do it myself.*"

Satisfaction, whose classification as an instrumental quality is debatable, is moderately important: "*If we do the program and it works as you planned at the end, you're satisfied, you're happy, you see.*"

Data confidentiality and control over the maintenance of the robotics software are also important to operators. On this last point, one operator suggested the integration of a troubleshooting function: *"Let's say we should rather make a maintenance page, i.e., let's say it gives you error so much, you have to go and see error so much to understand*".

Operators attach slightly less importance to non-instrumental qualities. Aesthetics are of moderate importance. Operators do, however, link the use of colours to usability, which can facilitate action more quickly: "*If we can get reflexes in the mode 'ah him, the orange with the orange', that's really good*".

That said, they are prepared to sacrifice aesthetics for more instrumental needs ("*if it does what I like but is a little less beautiful, that's fine*"). Other aspects, such as positive emotions, recalling memories, image in the eyes of others, or expressing identity, are considered unnecessary. One operator, for example, said: "*Your boss will be happy when you've done it, but if you make a mistake, he'll come down on you. Who cares about your colleagues if I am not bothered? It is a stupid thing to say*".

Four interrelated fears are expressed and commonly shared in relation to the future arrival of the software on workstations: The fear of being replaced, due to a reduction in the expertise needed to carry out the activity; The fear of over-simplifying the task, which could limit the operator's room for manoeuvre; Fear of a last-minute change by operations, suggesting a lack of confidence in the operator's ability to carry out a complex task ; The fear of deskilling, a direct consequence of the first two fears.

This study allows us to identify and capture operators' priorities regarding instrumental and non-instrumental needs, as well as their emotional reactions. Additionally, it helps us gather the meanings they assign to these needs for robotic software. Furthermore, understanding fears related to the organisation aids in addressing change management and strategizing the implementation of the software in industries.

4. Study 3: Developing a design solution

4.1. Methodology

The third stage of the UCD concerns the development of design solutions. Based on the previous studies, a list of operator requirements was drawn up, followed by a meeting with the design team of three robotics engineers to discuss the most appropriate solutions. The design solutions for the software were developed using QT Design Studio, a prototyping tool that generates C++ code. The design was adapted in line with operator requirements and guidelines, leading to a new software prototype (V.2). The Apple Guidelines were also used to guide the design of the latest version of the software, because of their emphasis on aesthetics, accessibility, and good practice.

4.2. Results

This V.2 mock-up attempts to meet the requirements expressed by the operators on all the studies and sub-studies previously described to improve guidance and adaptability and reduce errors. V.2 incorporates a configuration wizard to guide operators through the robotic programming process. In addition, the menus have been reworked compared with V.1 to better match operators' technological skills (Word, Excel). See Figure 3.

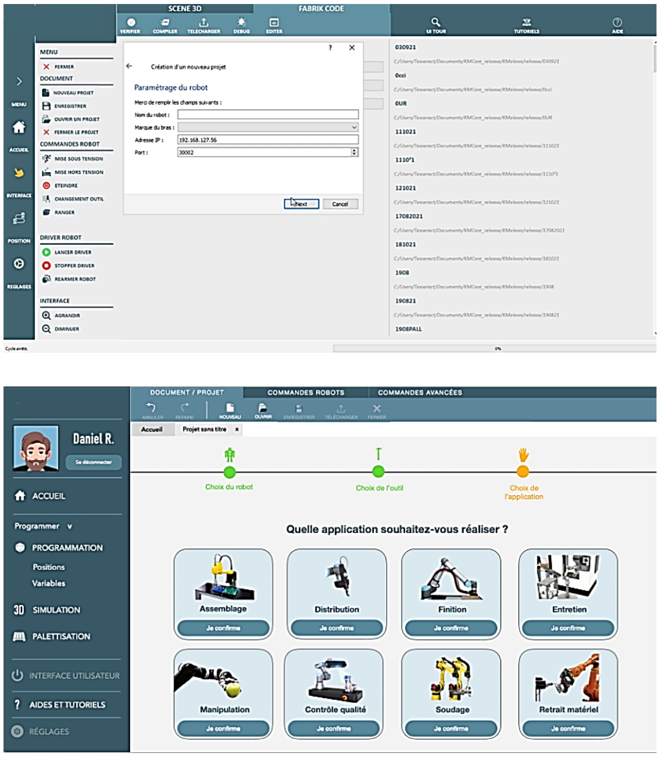

Figure 3. Robotic software: V.1 (up) and V.2 (down).

The V.2 mock-up also incorporates the technological needs expressed during the persona creation stage and the needs arising from the activity during the job specification stage (Table 1).

Table 1. Implementation in the V.2 mock-up of the operators' technological needs raised during the persona creation stage.

Needs identified when creating personas	Implementation of the requirements in the V.2 model
Skills development	Familiarization with robotics programming (programming a robot without any specific IT skills). Advanced functions for operators with more IT and robotics skills.
Training in the use of technology	Integration of videos and tutorial into the software. Integrating documentation into the software.
Improving technology	QWidget interface for incrementing new functions.
Enriching relations with colleagues	Improving equal opportunities in robotics programming. Opportunity to collaborate with peers. Possibility of automating repetitive and tedious tasks, allowing to concentrate on more rewarding tasks.
Do not make mistakes	Informs the operator of the steps to follow to avoid or correct errors.
Reducing cognitive load	Improved clarity. Implementation of a robotics configuration and programming assistant.
Limiting the risk of accidents	Implementation of security options.
Improving the future of work	Improving the human-robot interaction.

Finally, the V.2 mock-up incorporates all the needs identified in the previous requirements specification study. For example, a step-by-step guide for robot selection and task execution, simplified displays and menus for better task focus, pre-setting capabilities for personalized robotic programs, enhanced error messages and a streamlined programming interface, in-software assistance reducing dependency on external documentation, separation of configuration and programming to facilitate learning, a cleaner interface with intuitive visuals and colour coding, encouraging messages upon task completion to boost user morale and advanced options for skilled operators and familiar interface elements to lower learning curves.

Some operators point out the difficulty of remembering a task that was conducted a long time ago when it must be repeated in the absence of another operator, which justifies the use of information aids such as videos and written guides integrated into the software.

5. Study 4: Evaluating the design solution

5.1. Methodology

The fourth stage of the UCD sought to evaluate the design solutions. Practical acceptability (UX, ergonomics) and social acceptability (intentions of use, attitude towards robots) are assessed both for the robotic software (V.1 and V.2) and for the robot during a user test. Thus, twenty operator-fitters, cable workers, and controllers (average age: 45.17 years; average length of service in the company: 8.67 years; Average length of service in the job: 4.44 years) carried out a *pick-and-place* task with, for the first half of them, the V.1 robotic software (Boutrouille et al., 2022) and a collaborative robot (UR3e) and, for the remaining half, the V.2 robotic software and the same collaborative robot. The practical acceptability of the software and the robot are measured using:

- The meCUE (Lallemand & Koenig, 2017; Minge & Riedel, 2013) for user experience.
- Effectiveness (*i.e.,* time to complete the task), efficiency (*i.e.,* the number of errors and glances towards the documentation), and satisfaction

System Usability Scale; (Bangor et al., 2009; Gronier & Baudet, 2021; Jordan et al., 1996) for usability.
- The NASA-TLX (Hart & Steveland, 1988) for workload.
- A questionnaire for prioritizing the functionalities of the software, the robot, and the constructive collaboration between these two systems (Loup-Escande & Christmann, 2013).

Social acceptability is measured using the three usage intention items of the French version of meCUE (Lallemand & Koenig, 2017; Minge & Riedel, 2013).

5.2. Results

The practical and social acceptability of the software were compared for Versions 1 and 2 (see Table 2).

Table 2. Comparative statistics on the practical and social acceptability of the two versions of the robotics software.

Measures		Statistic	p
Usefulness	Usefulness	t	0.028*
Usability	Effectiveness	t	0.001***
	Efficiency	t	0.001***
	Satisfaction	M-W U	0.008**
	Usability (meCUE)	t	0.014*
UX	Visual aesthetics	t	< .001***
	Status	T	0.028*
	Positive emotions	t	0.226
	Negative emotions	t	0.014*
	Commitment	t	0.117
	Product loyalty	t	0.0425
	Overall evaluation	M-W U	0.004**
Mental Workload	Mental demand	t	0.024*
	Temporal demand	t	0.014*
	Performance	M-W U	0.044*
	Effort	t	0.021*
	Frustration	M-W U	0.004**
	Overall demand	t	< .001***
Social acceptability	Intent to use	t	0.224

Note: Ha. V.1 < V.2, except for negative emotions and mental workload

Note 2. MWU = Mann-Whitney U; t = Student's t

Also, the practical and social acceptability of the robot were compared after the use of Versions 1 and 2 of the software (see Table 3).

Table 3. Comparative statistics on the practical and social acceptability of the robot after the use of the two versions of the robotics software.

Measures		Statistic	p
Usefulness	Usefulness	M-W U	0.037*
Usability	Usability	M-W U	0.050*
	Satisfaction	t	0.168
UX	Visual aesthetics	t	0.004**
	Status	t	0.079
	Positive emotions	t	0.170
	Negative emotions	t	0.057
	Commitment	t	0.213
	Product loyalty	t	0.183
	Overall evaluation	M-W U	0.042*
Social acceptability	Intent to use	t	0.480

Note: Ha. robot after using V.1 < robot after using V.2, except for negative emotions

Note 2. MWU = Mann-Whitney U; t = Student's t

The comparative analysis between Versions 1 and 2 of the robotics software revealed significant improvements in both practical and social acceptability measures for Version 2. Notably, there were statistically significant advancements in satisfaction (mean V.1/V.2 = 57.8/78; p = 0.008), usefulness (mean V.1/V.2 = 4.17/5.30; p = 0.028), and usability (mean V.1/V.2 = 4.70/5.70; p = 0.014) under practical acceptability. UX also saw enhancements in visual aesthetics (mean V.1/V.2 = 4.10/5.70) and status (mean V.1/V.2 = 3.43/4.57), both with p-values of 0.028, while negative emotions experienced a significant reduction (mean V.1/V.2 = 5.88/5.03; p = 0.014). However, no significant changes were observed in positive emotions, commitment, or product loyalty. Mental workload factors, such as mental and temporal demands, showed marked improvements (mean V.1/V.2 = 177/114; p = 0.024 and mean V.1/V.2 = 97.5/34.5; p = 0.014, respectively), as did performance and effort (mean V.1/V.2 = 125/52; p = 0.044 and mean V.1/V.2 = 182/77; p = 0.021, respectively), with frustration showing a significant decrease (mean V.1/V.2 = 90.5/6.00; p = 0.004). The overall evaluation also significantly favoured Version 2 (mean V.1/V.2 = 44.5/19.2; p < .001). There was no significant difference in the intent to use between the two versions, indicating that social acceptability remained stable.

Similarly, after using the two software versions, the robot's practical acceptability showed improvements in usefulness (mean V.1/V.2 = 4.10/5.07; p = 0.037) and usability (mean V.1/V.2 = 4.90/5.50; p = 0.050), and UX was significantly better in terms of visual aesthetics (mean V.1/V.2 = 4.20/5.50; p = 0.004) after the use of V.2. Moreover, overall evaluation improved after using Version 2 (mean V.1/V.2 = 3.50/4.00; p = 0.042), yet no significant changes were noted in the robot's social acceptability post-usage.

6. Discussion

The two objectives this study was to illustrate a UCD of a software robotic, and to show that the UCD of the software will improve the practical and social acceptability of the “software and robot” system. The hypothesis on which this article is based is that the UCD of the software will improve the practical and social acceptability (Bobillier-Chaumon, 2016) of the software-robot system.

We have illustrated the UCD through 4 complementary studies corresponding to the four stages of the UCD (ISO 9241-210, 2019). During the first stage, we tried to understand the organisation in which the robotics software and the robot would be implemented. We saw that the company adopted a technocentric approach, to the detriment of the technological needs of the operators in our persona Didier. He is not comfortable with technology and organisational change and have a negative attitude to robots, notably for fear of losing their jobs or qualifications, as has already been illustrated in the literature for similar profiles (Meissner et al., 2020; Lotz et al., 2019). These aspects raise the question of the risks to operators' health and safety at work, but also the impacts on job roles, skill requirements, and workplace dynamics, all of which are challenges to be resolved in subsequent studies. During the second stage, operators prioritize software utility and usability, and value aesthetics primarily to enhance usability, consistent with the work of Tractinsky et al. (2000) and Tuch et al. (2012). This is also consistent with Mahlke (2008), who has already shown that most individuals prefer strong usability to aesthetics. During the third stage of developing design solutions, a V.2 prototype of the robotic software was created, meeting the criteria of guidance, legibility, and workload management (Nielsen, 1993; Shneiderman & Plaisant, 2010) and incorporating ergonomic improvements, in particular improving legibility (Bastien & Scapin, 1993), aesthetics (Nielsen, 1993), and reducing cognitive load (Sweller, 1988) via an organised visual presentation. The prototype also respects the principles of modular design (Baldwin & Clark, 2000) and improves user guidance (Bastien & Scapin, 1993).

Our evaluation of Versions 1 and 2 of the software and robot through user testing revealed that UCD significantly improved the practical acceptability of the second version. The enhanced version demonstrated notable improvements in perceived instrumental qualities (*i.e.,* usefulness, usability, UX), along with reduced workload (mental demand, temporal demand, effort, frustration, overall demand). However, intentions to use the technology remained unchanged, due to its limited utility for most operators who were not involved in the organisational change project. These findings align with existing literature on technology acceptability (Davis, 1989; King & He, 2006; Lee et al., 2003), especially in industrial settings (Sagnier, 2019). This also supports the fact that the acceptability of a robot does not only concern the operators affected by a change, but all the operators in an industry (Salvini et al., 2010). Despite these advancements, the robot's user experience optimization after the use of the second iteration of the software did not significantly affect UX. However, it significantly affects usability and usefulness, which is encouraging.

7. Conclusion and future work

This study proposes a comprehensive, reproducible, and detailed approach to the design of an operator-centred industrial technology to investigate the acceptability of a software-robot system. The aim of this study is therefore not to generalise its results, but rather to propose a complete and detailed case study with a reproducible method.

Our study provides encouraging evidence to support the hypothesis that UCD of robotic software improves the practical and social acceptability of the software-robot system. It has been shown that the implementation of a UCD that actively integrates end-users in the development of the software has led to improved acceptability of the technology, both practically and socially.

Despite the above-mentioned contributions, our study suffers from limitations. The first concerns the fact that we did not measure the operators' expectations (in terms of task difficulty, ease of use) before and after using the software. Based on the theory of the (dis)confirmation of expectations (Oliver, 1977; 1980), it would be interesting to study from a longitudinal perspective how these expectations evolve over time and how they are influenced by various factors, such as training, experience, and technological changes within the industry.

The second limitation concerns the lack of measurement of the situated acceptance of the robotic software system. Indeed, a technological tool may be accepted prior to its implementation, but when it is implemented in the workplace, it may not be accepted (Bobillier-Chaumon, 2016). Indeed, the acceptance of human-robot collaboration is never disconnected from its implementation context. For example, it depends on the attitudes towards organisational change (Meissner et al., 2020). In addition, the implementation of a longitudinal study would be relevant for monitoring changes in the use of these tools, but also in the working conditions, health, and safety of operators in the context of automation and robotization. To conduct this study, data relating to practical, social, and situated acceptability would have been collected in the same way on four occasions and over a total period of five months:

- The practical acceptability of the robotic software could be measured from the point of view of the interaction experience (Sauer et al., 2020), through (1) the user experience using the meCUE questionnaire (Lallemand & Koenig, 2017) (2) usability using the F-SUS (Gronier & Baudet, 2021) and (3) ergonomic criteria (Bastien & Scapin, 1993) using a questionnaire. We would have supplemented these quantitative measurements with qualitative measurements obtained during a semi-structured interview.
- The social acceptability of the software could have been measured by a questionnaire designed specifically for the software (questionnaire including the classic UTAUT variables, organisational dimensions and human-cobot collaboration). Qualitative data could have been collected by means of interviews on attitudes to organisational change and attitudes to human-cobot collaboration, to gather data that would complement usage intentions. In addition, we would have looked at the influence of appearance and proximity to the robot on the feeling of trust and perceived security. These elements could have been measured using the Godspeed Questionnaire (Bartneck et al., 2009).
- Finally, the measures of situated acceptance of the robotic software would have been structured around a triangulation of data collection (Caillaud & Flick, 2016), using both qualitative and quantitative measures and observations, to study the influence of the dimensions of this acceptance (Bobillier-Chaumon, 2016) on the adoption of the technology. On the dimension of individual acceptance, we would have measured the cognitive load using the NASA-TLX, while we would have measured the affective/emotional load using the items in Module 2 of the meCUE. Interviews would have supplemented these measures. On the organisational dimension, we would have investigated the regulation and prescription of the activity, supervision, and control of the individual at work, imposed autonomy and gains/losses using semi-structured interviews. Similarly, the relational dimension (i.e., work collectively, weakening of the collective) and the professional/identity dimension (i.e., meaning of work, requalification - deskilling) would have been measured by semi-structured interviews. Site observations would also have been conducted to understand the appropriation of the technological tool (Rabardel, 1995) and the feelings associated with its use.

As far as the introduction of robots can affect operators, jobs, task allocation, working relationships and organisational dynamics, research must address concerns about job change through automation and the transition to new forms of work. Robotics also raises several issues (fairness, well-being at work, respect for privacy, operator safety, liability in the event of accidents, etc.) that need to be included in the analysis for future research.

Conflict of interest

The authors have no conflict of interest to declare.

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