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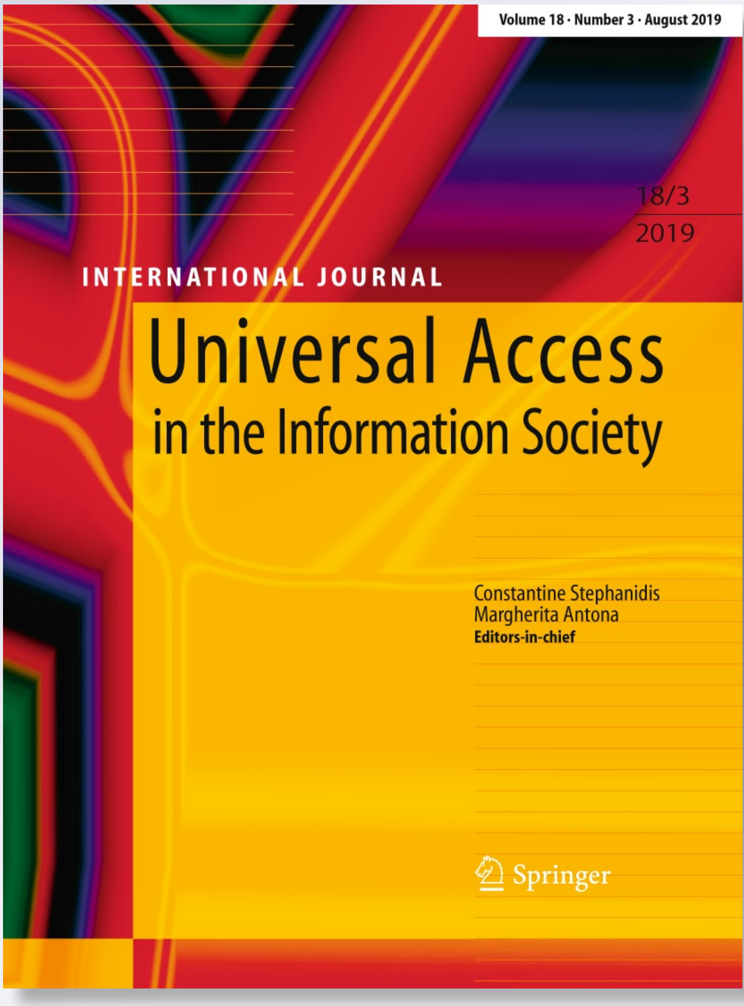

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LONG PAPER

Design and evaluation of a graphical user interface for facilitating expert knowledge transfer: a teleoperation case study

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Abstract

Nowadays, teleoperation systems are increasingly used for the training of specific skills to carry out complex tasks in dangerous environments. One of the challenges of these systems is to ensure that the time it takes for users to acquire these skills is as short as possible. For this, the user interface must be intuitive and easy to use. This document describes the design and evaluation of a graphical user interface so that a non-expert user could use a teleoperated system intuitively and without excessive training time. To achieve our goal, we use a user-centered design process model. To evaluate the interface, we use our own methodology and the results allow improving its usability.

Keywords Teleoperation · Graphical user interface · Usability · Human–robot interaction

1 Introduction

In recent years, the context of teaching and learning processes has changed, motivated by the emergence of Information and Communication Technologies (ICT). Nowadays, ICT is applied in both face-to-face and online learning initiatives, but this is not always linked to an improvement in students' learning [1].

Given this context, the application of ICT could help to address some existing educational problems. One of these problems is how to transfer expert knowledge. Traditionally, teaching and learning were accomplished through apprenticeship [2]. That is, learning by doing. In this way, knowledge is acquired by first looking at an expert carrying out an activity and practicing the same procedure several times until the skill to complete it successfully has been developed. Certain expert knowledge can only be acquired by practicing some activities, for instance, when it is required to develop motor skills (playing an instrument, piloting a plane, performing surgery) [3]. The problem is that the expert is not always there and we do not always have the same context to recreate a specific situation. This problem is mitigated by using ICT and simulators. It is possible to define specific environments with very concrete settings so that students can train until they develop the concrete skills. It is even possible to use Virtual Reality or Haptic Devices to create an immersive learning environment where a student could even have touch feedback. This has been quite popular in military training [4, 5], surgical simulation [6–8], etc.

In the specific field of teleoperation, simulators can help to develop a specific skill. However, two main problems have been detected: (1) knowledge transfer is not easy because the expertise in this field is quite limited even among experts, that not always have access to the expensive equipment and the settings needed to simulate the context and environment are very concrete [9]; and (2) the students (including professionals who aim to improve their skills) are not happy with the existing interfaces for facilitating the acquisition of the desired skills in virtual environments [10, 11].

Given these problems, it is necessary to apply ICT to improve both learning activities regarding teleoperation and students' engagement with the interfaces employed to develop the skills. The idea is to provide students with the proper tools to reduce the learning curve for development of teleoperation skills through virtual environments. But how can one know what the proper tool or the best interface to facilitate teleoperation training is? The aim of this work is

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to answer this question through the design, evaluation and implementation of a teleoperation interface based on haptic devices. The interface will be evaluated by applying different methodologies. In the first stage, experts will test it and after that the interface is to be evaluated following the Ergonomic Guideline for Supervisory Control of Interface Design (GEDIS). From each of the evaluation results and experts' suggestions, different versions of the interface were obtained, until the interface had a level qualitative enough to be applied for to expert knowledge exchange.

The rest of this work is structured as follows: the following section describes the theoretical and technological background of the work. Next, Sect. 3 presents the materials and methods employed for evaluating a teleoperation interface. Section 4 shows the main findings of the experiment that are discussed in Sect. 5.

2 Background

Some tasks, such as surgery, the dismantling of explosives and rescue operations, can be quite complex and even dangerous to be performed directly by a human being. In this type of situation, teleoperated robots or other remote control systems can be very useful, since they reduce the risk involved and potentially increase the overall accuracy of such tasks. This is because such systems allow reducing the human error factor which can be caused by several factors, among them, hand tremor. In fact, these types of systems are frequently used in the areas and tasks described above [12].

These teleoperated systems must provide adequate improvements for the user's experience. To do this, they use different types of interfaces (e.g., cameras, microphones and input devices) so that they can provide enough information to the user and complete their perception of the controlled device and its environment. However, the video feedback obtained from the cameras may be limited by certain technical restrictions [13], such as a decrease in eyesight due to obstacles, the delay in receiving the images, or even poor camera resolution.

To make up for these limitations, haptic devices can be employed. They help users to better understand the systems involved as well as the items in the remote environment [14, 15]. For example, in the case of scenarios such as the aforementioned surgery, the tissue's texture or the weight of other items could be replicated with the help of haptic devices. This information can be presented in a graphical user interface although mere representation by numerical standards would not be as effective as the real feeling that those numbers actually represent. That is why, we believe that this type of tactile information is very valuable in the context of teleoperated systems.

In addition, the incorporation of haptic feedback in a teleoperation system can provide other benefits in different environments, such as increasing the situational awareness of an operator [16] or facilitating spatiotemporal coordination in collaborative environments [17]. Even so, the most commonly used feedback in this type of system is usually visual.stop

It is also necessary to explore the device with which the user is interacting as it is quite common that in teleoperation systems, the element to control is a robot. As described by Weiss in his work [18], one way of interacting to remotely control a robot is to use a graphical user interface (GUI). Another method to control a robot is through a joystick, which, according to [19], is the most effective way to control a robot, compared to other devices. In [20], a multi-touch remote user interface was developed to compensate for the lack of usability due to the limited possibilities of user feedback when using the joystick.

There exist other user interfaces, presented for example in [21–23]. The problem is that in almost all of these cases, the effectiveness and usability of the interfaces could only be demonstrated in a specific context and with highly trained users. It requires a long and tedious training of motor and perceptive skills so that most non-expert users achieve an acceptable performance when using the teleoperation system.

Therefore, it is important to employ a user-centered design process model approach and usability engineering techniques to design highly intuitive interfaces, such as [24, 25]. But how is one to evaluate the usability of these interfaces? How is one to ensure students' engagement toward them? There are several approaches to evaluate human–robot interaction; some have their origin in the techniques applied in the field of human–computer interaction (HCI), as in [26, 27], where different human–robot interaction scenarios were evaluated by means of an evaluation of expert users. Others, however, use different methods and guidelines, such as in [28, 29]. However, nowadays researchers try to avoid this HCI influence and other methodologies such as the Wizard-of-Oz technique (WoZ) (widely used in HRI [30, 31]), to get closer to the domain of research in HRI and use their own methodologies, as demonstrated in [32–34].

Given this context, we have decided to use our own methodology, focused on HRI to evaluate the interface that we are going to design.

3 Materials and methods

To achieve our goal, we propose an experiment in which we have designed an interface to teleoperate a robot controlled by a haptic device trying to complete a simple task. We have evaluated the interface through an experiment. In order to understand it, first it is necessary to explore the work environment and then the architecture the interface and how it is evaluated.

3.1 Environment

A teleoperation system is composed of at the very least two devices, a master device and a slave device that establishes communication between them by using a communication channel connecting them physically. Master device movements are replicated on the slave, being able to control the motion of the latter. In our case, the slave device communicates the master specific information regarding the environment replicated in the latter, in order to provide haptic feedback in certain scenarios.

Our system is comprised of a Geomagic Touch haptic device and a Baxter research robot acting as master and slave devices, respectively (described below). One of the main problems of these systems is how to deal with communication delays. In order to address it, both devices are connected to the same workstation via Ethernet cables.

The task that the users are supposed to carry out is simple and suits Baxter large size. The user has to take a piece (similar to the chip used in a game of checkers) located in an initial position, marked on the table with a red circle and put it into an intermediate position (blue circle). Once the robot arm is placed in that intermediate position, the user should release the chip and bring the robot arm to its resting position, placing the pointer of the haptic device in the 'inkwell.' Then, the user picks the chip from the intermediate position where he/she has left it and takes it to the final position, marked on the test table with a double green circle. At this point, the task is completed.

In order to prove the utility of the interface feedback, the user is not able to see the slave device directly due to the presence of an obstacle. Additionally, the user has access to a second monitor to practice previous to the aforementioned task so as to easily grasp the concepts of movement, picking and releasing. This training process does not have available haptic feedback, and it simply serves to focus the user on the understanding of those concepts.

The entire environment can be seen in Fig. 1. It shows the Baxter robot; in the upper right corner, it is possible to

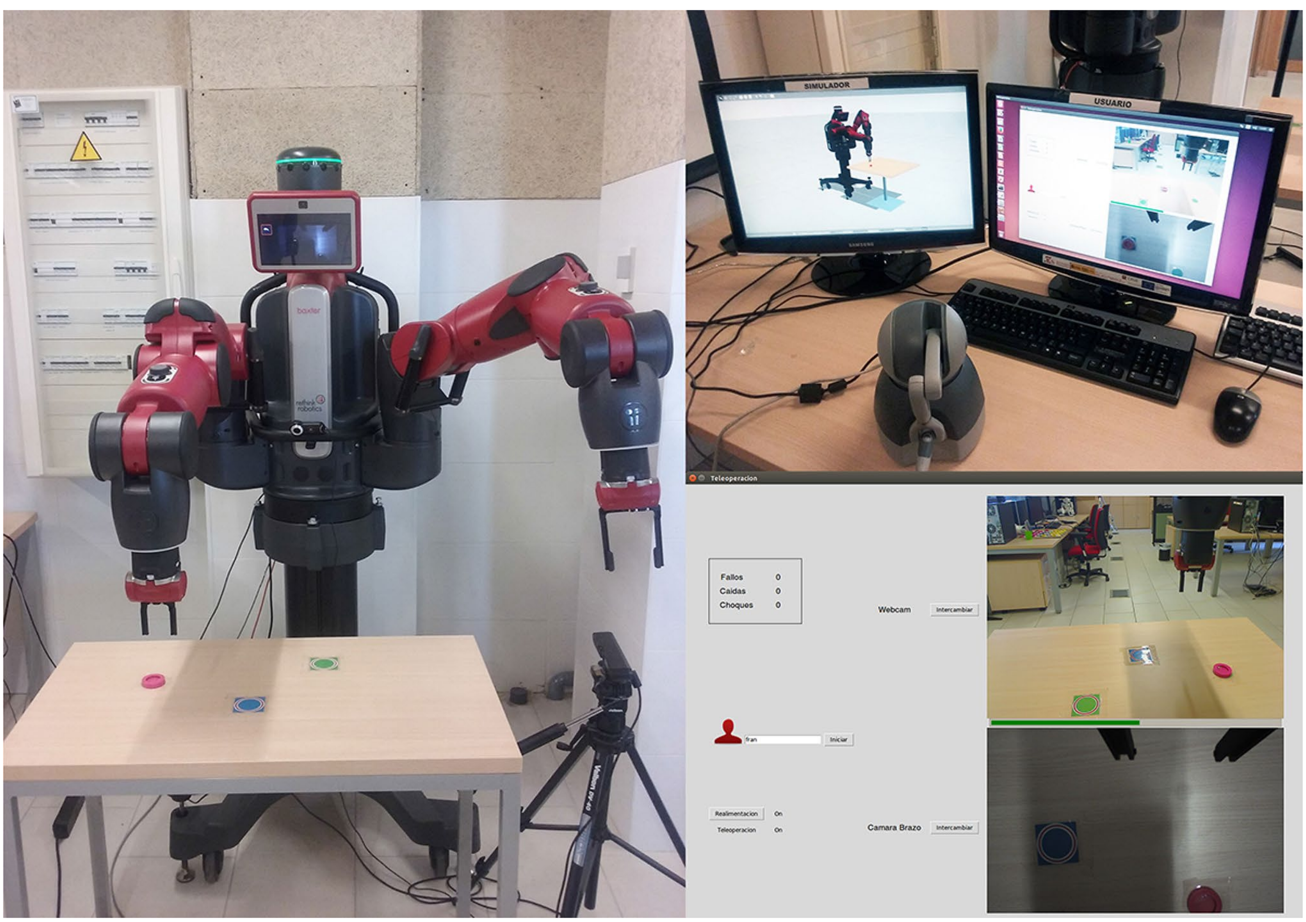

Fig. 1 Detail of the environment

see the user control room with the two monitors described above, and the haptic device. Finally, in the lower right part of the image, an interface prototype is displayed.

3.1.1 Architecture

For the experiment, the master device must be able to send its movements to the slave robot, but it also has to be able to provide the user with kinesthetic information, that is, to reflect the forces or vibrations sensed by Baxter. For these reasons, the authors decided to use a Geomatic Touch haptic device, a 6-DOF (degrees of freedom) device that has 3 DOFs dedicated to standard movements (*X*-, *Y*- and *Z*-Cartesian coordinates), while the remaining 3 help replicate orientation (pitch, roll and yaw movements). In order to make it work in the experimental workstation, the authors used the package 'Phantom Omni,' developed by Suarez-Ruiz [35] which was adapted to ROS Indigo distribution.

As commented above, the selected slave device was a Baxter Research Robot. Baxter consists of 2 arms with 7 DOFs, with inbuilt feedback systems, although for the experiment only one of the arms was necessary. It was developed to allow collaborative human–robot co-work and to improve human–robot interaction.

Its 7-DOF system provides kinematic redundancy, which allows enhancing object manipulation. It also has several mounted sensors, one camera located in each gripper that was used for display purposes, and an infrared range sensor with a 4–40 cm range. It is connected to the same workstation as the master device via Ethernet so as to reduce delay between them as much as possible.

In order to interact with the environment, it is necessary to properly translate the movements of the master device to Baxter. However, this requires some adjustment [36] because both devices have a different number of DOFs. Our approach has reduced the number of joints used in both systems, trying to replicate a standard 3-DOF movement on the *X*-, *Y*- and *Z*-axis.

3.1.2 The interface

When designing the interface, the first problem to be solved is known as the 'confusion matrix' [37, 38]. It refers to the mapping of the directions of entry (given by the user through the haptic device and which are in his local coordinate system) and the direction resulting from the movement of the robot arm (executed by the robot's coordinate system).

To solve this, there are several options. It is possible to do a fixed mapping together with the option to switch between different cameras or points of view. However, this solution can lead to behavior which is quite unexpected or prone to errors since the user is responsible for taking into account the implicit coordinate transformations [39]. Other research projects try to solve this problem using augmented reality (AR) to visualize the coded systems by color or label of the corresponding axes of the input device [40, 41]. This solution is not the most appropriate either, since the users' expectations and the controls of the input devices can imply a high degree of freedom to allow for Cartesian movement.

This work proposes an intermediate solution. We have used several cameras, and the user can choose the one which offers the most adequate reference. With this approach, the mapping of the haptic device can be adjusted according to the selected reference coordinate system and the point of view of the camera from which the user observes the robot. Moreover, this will reduce the degrees of freedom necessary to control the system.

Following these premises, we have designed a first GUI prototype (Fig. 2). This figure shows the two cameras used in the upper part; the one on the left is the camera located on the body of the Baxter robot, and the one on the right is the camera located at the end of the robot arm. In addition, two buttons were added below the image of each camera so that the user can swap the cameras. It is also possible to see that the user can know the number of errors, falls and hits that occur during the simulation.

3.2 Evaluation methodology

In order to evaluate the interface, two methodologies were applied. First, an expert testing was carried out and after that the interface was evaluated following the GEDIS [42]. All the phases of this evaluation methodology are shown in Fig. 3.

3.2.1 Expert testing methodology

In the first phase, the authors found it necessary to evaluate the interface by taking into account experts' perceptions. The idea of this 'expert testing' is to test the interface for teleoperation by experts in the use of these systems. In order to do this, a scenario is proposed in which each expert user should complete the task described in Sect. 3.1.

A Cognitive Walkthrough (CW) [43] has been used to explore the scenario by using the interface. This is a useful way of highlighting potential problems in the concept or implementation of the interface. The primary concern is to support the development of usable systems by identifying design deficiencies [44].

The CW results have been complemented with a Think Aloud (TA) technique [45]. Think Aloud protocols involve participants talking about their experience while performing a set of specified tasks. Each expert interaction was recorded with a video camera that takes into account their interaction and their perceptions of the system.

Moreover, the testers were asked some open questions and a qualitative evaluation was made. The answers of the text were

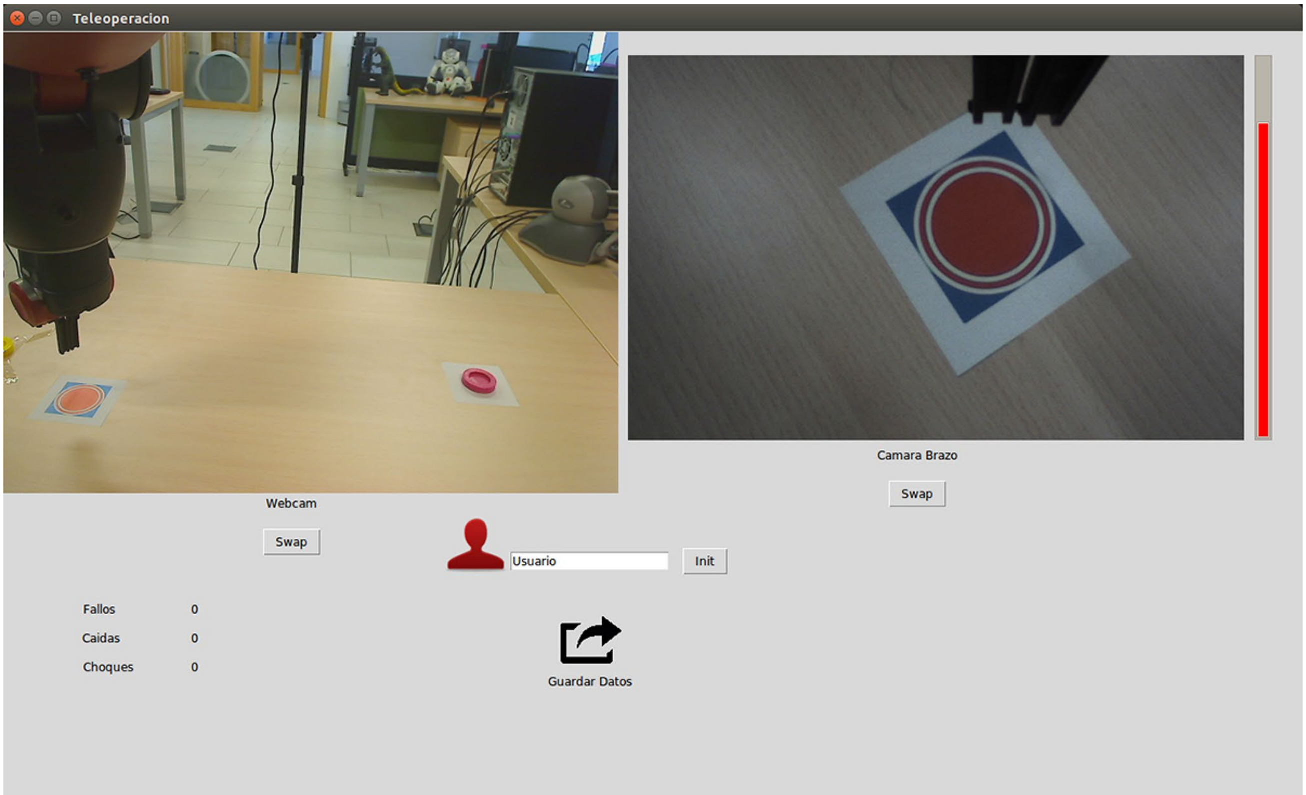

Fig. 2 First version of the interface

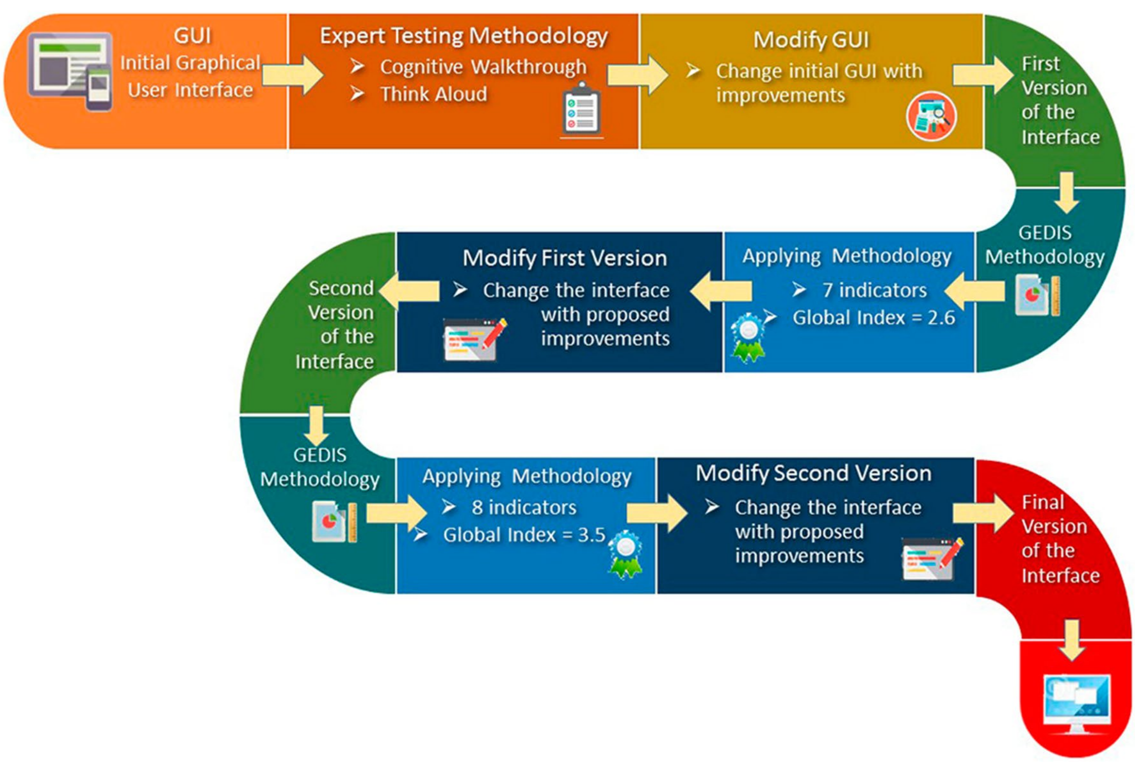

Fig. 3 Phases of the evaluation methodology

analyzed and units defined depending on the component and/or the thematic area to which they refer; after that the outcomes were synthesized and grouped according to the units. Later, the results were shown in two matrixes and conclusions posed from that information [46].

Among the challenges of analyzing the data produced by this method, distinguishing particular types of errors and determining the severity of those errors were the priority. In terms of the former, patterns of recurrent 'breakdowns' [47] in practice were identified through an analysis of the videos. The degree of severity of breakdown was determined by the extent to which the breakdown caused a disruption to the flow through the CW. In effect, what is produced is a probability distribution of breakdown moments in the experience of the expert user testing group.

3.2.2 GEDIS methodology

For the evaluation of interface prototypes, we used GEDIS. The GEDIS guideline provides a set of recommendations to consider when designing an interface or evaluate interfaces already created [42]. GEDIS is not standard, but it is a validated guideline that seeks to cover all the aspects of the interface design. In this case, the authors decided to use it because it provides a clear view of the usability of the interface by the end users.

The guide is based on the analysis and evaluation of 10 indicators to finally get an overall index of the interface quality and possible areas for improvement. These indicators are: architecture, distribution, navigation, color, text font, status of the devices, process values, graphs and tables, data-entry commands, and finally alarms. This analysis was carried out by usability and interaction experts.

For the correct use of the GEDIS guideline, the collaboration between the teleoperated technical team and the human factor technician is necessary.

Each subindicator is punctuated numerically in a scale from 1 to 5. The indicator value is calculated by solving the following formula:

$$Indicator = \frac{\sum_{j=1}^{j} w_j subind_j}{\sum_{j=1}^{j} w_j} \quad (1)$$

where j = number of subindicators of the indicator, $subind$ = subindicator assessment value and w = weight. In this case, each subindicator has the same weight ($w1 = w2 \cdots = wj = 1$).

The values of the indicators are used to calculate the global evaluation by solving the following formula:

$$GlobalIndex = \frac{\sum_{i=1}^{10} p_i ind_i}{\sum_{i=1}^{10} p_i} \quad (2)$$

where ind = indicator and p = weight. As explained before in this case, all indicators have the same weight ($p1 = p2 \cdots = p10 = 1$).

The guide recommends that the global evaluation index should not be lower than 3 points (on a 0–5 numeric scale). A positive evaluation should reach at least 4 points.

4 Results

4.1 Results of expert testing

Twenty incidents of breakdown were identified from the CW and the TA application. The indication of severity level followed the Nielsen classification [48]. Table 1 shows the number of errors per level for the teleoperation interface.

While many breakdown incidents did not severely disrupt the teleoperation activity (i.e., those from levels 1 and 2), it is fair to say that the video recordings showed that the cumulative effect of these was more disruptive in terms of user disposition to complete the activity, so they should be addressed with high priority. Some other issues were more serious and did cause significant interruption for the completion of the task (those from level 3 and especially from level 4). These results gathered from the flow of activity were used as feedback to improve the interface proposed for teleoperation.

Regarding the opinions of the experts, a matrix of results was defined, which includes their perception of the interface when using it for Baxter robot teleoperation.

Table 2 shows that most of the experts seem to feel comfortable with this interface and will use it for teleoperation simulation. However, they consider that although the interface is quite straightforward a previous explanation or training is required. Regarding the issues described by experts, some of them are related to accuracy of the haptic movement. Small movements were not always represented by the robot, and there was some delay. This is caused by communication failures between the master device and the slave and can be solved by re-establishing communication via Ethernet.

With regard to the improvements, most of them were related to the camera positions or to using more or fewer cameras. This was solved by positioning the cameras at other angles and positioning the Baxter robot in such a way that

Table 1 Number of issues per Nielsen classification for the teleoperation interface

Component	Severity				
	Level 0	Level 1	Level 2	Level 3	Level 4
Interface	1	3	5	7	4

Table 2 Qualitative analysis of the opinion of experts

	Issues	Improvements	Advantage
E1	Workspace constraint by the haptic	Change the cameras position	Quite straightforward
E2	Interface feedback	Change mirrored camera position	Correct interface
E3	System accuracy	Remove warnings from the interface	–
E4	Delay in robot movements	Change in cameras position	Good with previous training
E5	–	Change the feedback (chip weight)	Very useful with previous explanation
E6	–	Change in camera positions	Pretty straightforward
E7	Issues related to how Baxter arm goes down	Remove some of the cameras	Good feedback and information provided
E8	Some issues when closing the application	Use of pictures to simulate more complex movements	It can be useful in my work
E9	System accuracy	Add three cameras and a different background color	Once trained I could use it
E10	System accuracy and work space	Use three cameras at the same time	Good help for training
E11	Vertical movement	Include a spotlight to improve visibility	With a previous training it could be a great tool
E12	–	Change the camera without interacting with the interface	Very straightforward
E14	Movement is not natural	Provide more training	–
E15	Movement constraints	Add reverse controls	I will use it

the cameras have clear visibility of the table. In any event, it would be possible to include other cameras and some spotlights; however, this could increase the complexity of the use of the interface, so for the first version this change was not carried out.

4.2 Results of GEDIS

Once this first phase is concluded, and with the improvements proposed by the experts in teleoperation, the interface is evaluated following the GEDIS methodology, carried out in this case by usability and interaction experts. Table 3 shows two evaluations of the first and second versions of the interface (where a = appropriate, m = medium, na = not appropriate). In our study, only seven indicators of this methodology were measured in the first version of the interface and all the indicators in the second version. This is due to the fact that in the first prototype some of the indicators could not be measured since there were no elements in the interface that allowed doing so. (There are neither graphs nor tables, data-entry commands, alarms.)

4.2.1 Evaluation of the first version

Taking into account the results from the GEDIS indicator evaluation, some changes were required for the first version. These include the following:

- *Architecture*. It is recommended that a main home screen be added. In it, we should differentiate how the different stakeholders (user and facilitators) interact. Since there are two screens in the designed environment, the user must access the screen related to the task to be performed. In the same way, the facilitator (usability testing expert) must have access to the configurable parameters: method of recording the data, frames per second that are monitored on the screen, list of numerical values for tracking failure in the grip of the part, number of collisions detected.

  Another issue to address is the evaluation of data gathered, that can be downloaded to an Excel file for later analysis. Furthermore, it is interesting to record Baxter's behavior and the user's behavior;
- *Distribution*. It is recommended to improve camera and information position in the screen so both have the same weight. In addition, the process flow should be clarified. The users are confused by the lower part where *'Save Data'* is indicated, and they do not know whether to push the button in order to save their progress in the system. In any case, the user must have a step-by-step guide to complete the task.

  In addition, more information for users is required. Developers could add a textbox with the information about errors (when the user tries to pick the chip and he/she is unable), drops, and collisions (when the user collides with the work space);
- *Navigation*. Adding screens and navigation buttons between screens is recommended so that the user can move from the main screen to the home screen, and can return or quit the application;
- *Color*. The use of a gray background is appropriate as it highlights the image of the cameras; this improves the

Table 3 Applying the GEDIS guideline

Indicator and subindicator name	Qualitative/numeric value	First evaluation	Second evaluation
Architecture		**2.6**	**2.6**
Map existence	[YES, NO] [5, 0]	0	0
Number of levels le	[le < 4, le > 4] [5, 0]	5	5
Division: plant, area, subarea, team	[a, m, na] [5, 3, 0]	3	3
Distribution		**2.0**	**3.7**
Model comparison	[a, m, na] [5, 3, 0]	3	3
Flow process	[clear, medium, no clear] [5, 3, 0]	0	5
Density	[a, m, na] [5, 3, 0]	3	3
Navigation		**0.0**	**3.0**
Relationship with architecture	[a, m, na] [5, 3, 0]	0	3
Navigation between screen	[a, m, na] [5, 3, 0]	0	3
Color		**5.0**	**5.0**
Absence of non-appropriated combinations	[YES, NO] [5, 0]	5	5
Color number c	[4 < c > 7, c > 7] [5, 0]	5	5
Blink absence (no alarm situation)	[YES, NO] [5, 0]	5	5
Contrast screen versus graphics objects	[a, m, na] [5, 3, 0]	5	5
Relationship with text	[a, m, na] [5, 3, 0]	5	5
Text font		**4.5**	**5.0**
Font number f	[f < 4, f > 4] [5, 0]	5	5
Absence of small font (smaller 8pt)	[YES, NO] [5, 0]	5	5
Absence of non-appropriated combinations	[YES, NO] [5, 0]	5	5
Abbreviation use	[a, m, na] [5, 3, 0]	3	5
Status of the devices		1.5	**2.5**
Uniforms icons and symbols	[a, m, na] [5, 3, 0]	3	5
Status team representativeness	[YES, NO] [5, 0]	0	0
Process values		**3.0**	**3.0**
Visibility	[a, m, na] [5, 3, 0]	3	3
Location	[a, m, na] [5, 3, 0]	3	3
Graphs and tables data-entry commands		Non-assessed	Non-assessed **3.0**
Visibility	[a, m, na] [5, 3, 0]		3
Usability	[a, m, na] [5, 3, 0]		3

Table 3 (continued)

Indicator and subindicator name	Qualitative/numeric value	First evaluation	Second evaluation
Feedback	[a, m, na] [5, 3, 0]		3
Alarms		Non-assessed	Non-assessed
GLOBAL INDEX		**2.6**	**3.5**

Fields in bold are indicators and those which are not in bold are subindicators

sense of presence of the user in the remote place where the task is being carried out. It is important to evaluate the color of the table in which the piece of the game of checkers is placed. That color is the one that is captured by the camera on the graphic screen, and hence the user must be able to see the contrast between the bottom of the table and the chip to be taken through the image of the camera;

- *Text Font*. The recommendation is to avoid a font size below eight. Some words are in Spanish; however, others such as *Swap* appear Swap in English. It is also recommended to check the nomenclature used for the cameras: *Webcam* is the body Baxter camera?
- *Status of the Devices*. It is recommended to check the iconography used because it shows a combination of text and icons. The save icon suggests leaving the application. When the user is using the haptic device and the robot is moving, this feedback of the movement should be visible on the screen. Therefore, a small box in the upper center that indicates the state of the robot (if it is at rest, if it is in movement, if the grippers are open or closed) is lacking. Round objects, emulating LED lights within a text box, can provide this information;
- *Process values*. Which variables and which numeric value should appear on the screen should be checked. Failure and collision information can be logged, and subsequently, an analysis to provide historical trends was carried out. The question is whether this information should be accessible while the task is being carried out or shown at the end of the task.

  Regarding the haptic feedback, it is necessary to assess whether it can be specified that the force that the users' hand is exerting on the haptic device is low, medium or high;
- *Graphs and Tables*, *Data-entry commands* and *Alarms* indicators were not assessed for this version.

Finally, the *Global index* for this interface was 2.6 points in a 0-5 numeric scale.

4.2.2 Evaluation of the second version

After analyzing the first evaluation iteration, a second prototype interface was designed, taking into account the suggestions of the experts. It was also evaluated following the same methodology. Figure 4 shows this version of the interface.

The figure presents a display of two interchangeable cameras for better perception, boxes indicating whether teleoperation is currently enabled or not, as well as haptic feedback and the number of errors, drops and collisions occurring during the teleoperation. It also displays a progress bar that indicates the proximity of an item using Baxter's infrared capabilities.

With this version, we also recorded the overall time spent performing the task as well as the time spent on each of the cameras in order to understand which of them is more useful for users.

Once again, the interface is assessed following GEDIS methodology with the following results:

- The *Architecture* indicator was not changed. To improve it, a screen must be added to the initial 'Welcome screen.' This screen may contain navigation buttons that link to secondary screens and a brief description in text mode of the task to be performed;
- The *Color* and *Process value* indicators were not changed either, though in this case it is because they had already reached its maximum value in the first version;
- The score was improved in the following indicators: *Distribution*, *Navigation*, *Text font* and *Status of the devices*.

In addition, it has been possible to evaluate the indicator *Data-entry commands* which improves the final score.

The global evaluation index of the second version is 3.5 (on a 0-5 numeric scale). This indicates that the evaluation of the first prototype has been improved by almost one point, although this is not enough considering that it does not reach the 4.0 points necessary for a positive evaluation according to the GEDIS methodology [42]. This means that a new GUI version is required.

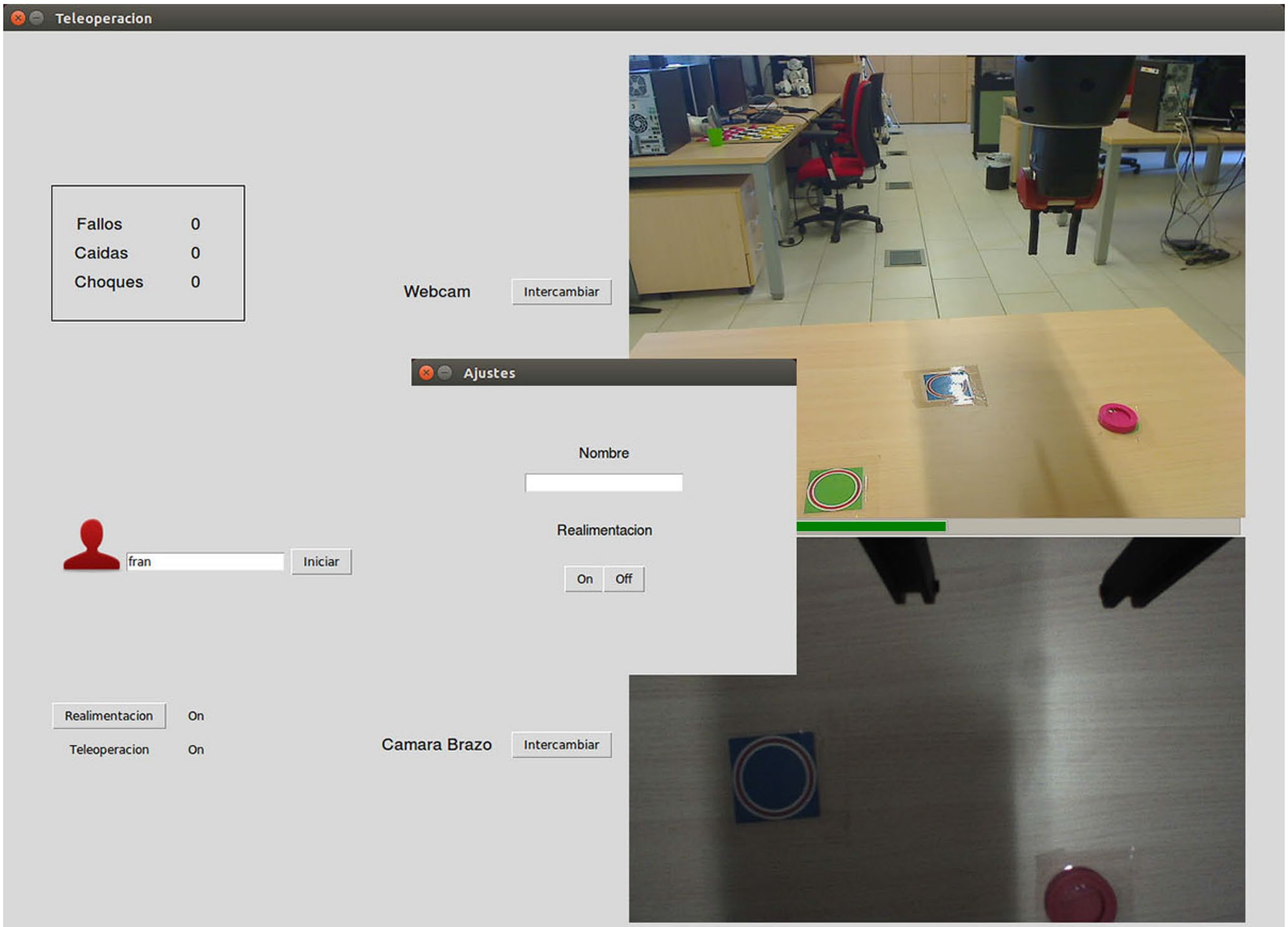

Fig. 4 Second version of the interface

4.2.3 Proposal for interface improvements

Given the results obtained from the GEDIS methodology, it is possible to propose some changes for a final version of the interface. As described above, the *Architecture* indicator could be improved by adding a 'Welcome' screen when the test starts. It would also be necessary to add a second screen ('Calibration'), in which the user could configure the teleoperation environment according to their preferences. The users could choose, for example, three different levels for simulating the objects weight (low, medium and high).

The *Navigation* indicator could also be improved. For this, it is important to improve the visibility of the navigation buttons. Therefore, it is recommended that the different buttons on the screen can be distinguished according to their function. To do this, the font size should be modified, the background highlighted or the color of the buttons changed.

The *Status of the devices* indicator could be improved by adding a square box with text labels and round LEDs which indicate whether the robot is stopped or moving. Finally, some type of alarm should be added to the interface in order to evaluate whether teleoperation is properly working. In this sense, the first aspect that must be evaluated is whether the operator can recognize the alarm situation when viewing the message on the screen and pressing a confirmation button or doing so by means of a visualization message. As our goal is to design an intuitive interface that can be used by non-expert users, we consider that the best option would be that the user only visualizes the message in a visible part of the screen.

With these improvements, a GEDIS recommended evaluation value could be achieved.

5 Discussion and conclusions

In this paper, the authors have dealt with the challenge of training with teleoperation systems and the engagement with the interfaces that they provide for training. The paper designed and evaluated an interface for a haptic teleoperation system. From the experiment, it is possible to conclude that the use of teleoperation systems by non-expert users can be improved by defining intuitive graphic interfaces that provide visual and haptic feedback. Moreover, it is possible to evaluate the usability of this interface, as shown during the experiment, and improve it to perform a simple task following the advice of teleoperation experts and the information gathered by applying GEDIS. As the interface has been defined taking into account the end users, their learning curve should be improved [49], although this must be evaluated in future investigations.

Given the defined interface and the evaluation results, the question to explore would be: Is it possible to apply the same teleoperation interface in other context or for other tasks? The answer is yes, because the methodology used is agile and flexible enough to be applied to define other interface prototypes and/or to carry out more complex tasks. In fact, it can be complemented by other methodologies such as the Guideline for Ergonomic Haptic Interaction Design (GEHID). This guideline provides a method that seeks to cover aspects of the haptic interface design and the human–robot task in order to improve the performance of the overall teleoperated system [50]. In fact, it could be applied in our experiment, because although the task developed in it is valid, the temporal interval in which forces and moments can appear due to the haptic feedback by the human performing the task, is very brief. Thus, the task could be improved, but the interface and evaluation methodology will remain the same.

By applying GEDIS and GEHID, it would be advisable to think about a new task to be performed. This should be more complex and needs more time to complete, for example the insertion of one piece into another, in which the contact between the parts causes a force/momentum feedback by the user that is more intense (and measurable) and is carried out in an interval time. In addition, increasing the complexity of the task and the time to carry it out can lead to a posteriori evaluation of physical effort, fatigue, and comfort. There are other future research actions beyond the definition of more complex tasks to be completed during the experiment. First of all, the interface should be adapted following the changes proposed in Sect. 4.2.3. In addition, it is essential to explore the opinions about the system of inexperienced end users who have no knowledge in teleoperation. It is also necessary to involve a large enough number of users to be able to use other existing standardized questionnaires to measure the usability of the user interface and compare the results with those obtained by GEDIS.

Finally, it would also be convenient to carry out a post-test with the expert users who participated in the first evaluation phase. This would allow us to compare the results in order to know whether there is an improvement the interface designed for teleoperation tasks. In addition, time and results obtained required by experts to learn to use the interface should be evaluated in order to analyze whether there is a real improvement in the learning curve.

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