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Remote Operation of CeCi Social Robot

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Abstract: This paper presents a validation methodology for a remote system with its objective focused on a social robot. The research process starts with the customization of an application for smartphones, achieving a simple method of connection and attachment to the robot. This customization allows remote operation of the robot's movements and an additional level of autonomy for the displacements in previously known locations. One of several teleoperations methods is the direct teleoperations method, which is used in master–slave control mode via a wireless network. Next, the article focuses on proposing a validation methodology for social robot applications design. Under this approach, two tests are performed to validate the designed application. The first one seeks to find the response speed of the communication between the robot and the mobile device wherein 10 devices with different characteristics and capabilities are used. This test is critical since a delay outside the allowable range invalidates the use of the application. The second test measures the application's usability through a user survey, which allows for determining the preferences that people may have when using this type of application. This second test is essential to consider the overall acceptability of the social robot.

Keywords: remote control; remote operation; mobile robot; ROS; android; social robot

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1. Introduction

In recent years, thanks to new technologies, there has been significant progress in mobile robots [1], as well as the development and improvement of software related to robotics [2]. There are currently different social projects where work with robots [3] seeks to implement social care and robot-assisted therapy (RAT) to improve patients' lives significantly. Also, nowadays, large projects allow mobile robots to work in different areas, for instance, education, health, and the support of different work environments [4]. During the COVID-19 pandemic, more than 200 robotic systems were tested to help with different problems caused by this disease [5], obtaining a good result on the issue of liquid spraying.

Similarly, in the hotel industry, it was necessary to implement mobile robots to assist, automate, and facilitate the tasks performed by employees [6], thus demonstrating the solutions that robots can provide. According to the research [7], of 240 cases analyzed in 41 countries where the use of social robots was implemented, there were 86 different models. China is the place with the highest use of social robots globally. In addition, the highest number of robotic implementations were in hospitals and nursing homes. Figure 1 shows the number of robots used during the first outbreak of the pandemic, according to the model and brand of the robots.

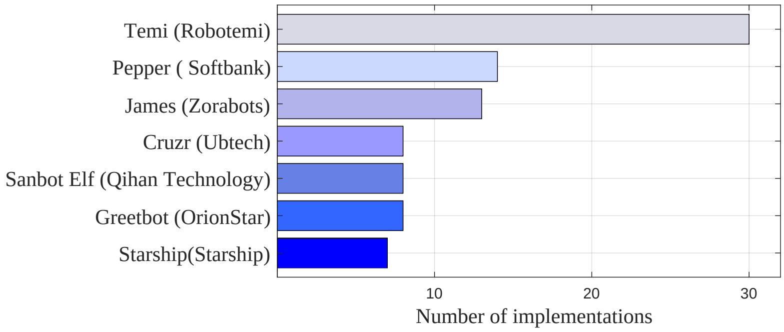

Figure 1. Robot brands used during the COVID-19 pandemic [7].

1.1. Remote Operation

Currently, the use of remote-controlled robotic ssystems is quite broad, even in the military field [8]. This serves as support for performing risky tasks for humans, such as bomb disposal and rescue of living beings, in cases of natural disasters [9,10] and in firefighting [11], through a partial or total assisted control called robotic autonomous systems (RAS) [12].

Due to the coronavirus epidemic, the importance of having robotic telepresence systems [13] became evident. This became useful for physicians and patients to engage in medical care without the risk of catching a disease and, above all, without reducing the quality of the health service.

A critical application that requires remote operation is telepresence. In social robotics, it offers the feeling of being in another environment with the possibility of moving and acting in that location where the main goal of the system is to foster a social interaction between individuals. In the article "Review of Mobile Robotic Telepresence" [14] by Kristoffersson et al., it indicates that 66% of patients surveyed after leaving a minor surgery in a hospital agreed that virtual visits by senior doctors should be part of routine hospital care, indicating that they would prefer to be seen remotely by their own doctor rather than in person by another doctor.

Autonomous navigation of social robots in different spaces is a problem that is not well solved due to the multiple drawbacks of dynamic environments, such as obstacles, pedestrians, and other mobile vehicles [15], which cause the robot to perform poorly, causing discomfort among users. However, a simple alternative solution to many applications that have this problem can be remote operation.

1.2. Social Robots

A social robot should work in at least two ways. First, it should work autonomously through environment recognition [16] and the detection of objects or obstacles [17]. Second, it can be remotely operated by a person to fulfill specific and even complex functions, as in [18,19], which denotes the advantages of flexible remote-controlled robots to interact with children through teleoperation.

Controlling movements in changing environments is one of the problems in the use of mobile robots focused on collaboration with humans [20]. Additionally, the collection of data about the environment where the robot needs to move (maps) is costly, potentially unsafe, and time-consuming in real robot systems [21]. Therefore, a way of mapping environments is proposed under the supervision of a human, who will be in charge of teleoperating the robot without the need to guide it on site through different environments for initial mapping.

By teleoperating a robot, it is possible to have a collaborative human–robot system [22], which, as mentioned above, can be used in hazardous environments thanks to real-time video transmission systems that can work simultaneously with multiple terminals such as a central server, visualization, and remote control system [23]. In tests conducted in real conditions with a social robot called GUI3DXBot [24], there is a 70% satisfaction result when it performs tour guide functions, proving to be a friendly, valuable, and intuitive system in these types of activities. Within the different applications that a social robot can perform, they must be built by employing a robust structure that considers the need to satisfy the users' expectations, the complexity presented by the users, and the complexity presented by the human–robot interactions [25].

The remote operation incorporated in social robotics gives rise to multiple applications, for instance, a surveillance device to take care of babies [26]. It seeks to avoid accidents by adding devices to a robot that allow control through sensors that monitor the environment's activities [27].

Taking future trends into account, close interaction and collaboration between humans and robots is foreseen. Therefore, this requires improved human–robot interfaces that will increase the ease of interaction. The precise and accurate transformation of human intentions into mechanical actions interpreted by the robot is one of the key elements to improve the future flexibility of automation. A clear example of the above is the case of [28] who developed an algorithm to transform measured orientations into movement commands applied to an industrial collaborative robot.

Social psychology applied to robots at work offers a perspective on the acceptance of the technology that is not often considered in technical circles [29], considering several points concerning the design of the robot and the ease of the interface with which the robot can be operated or teleoperated.

In the study by Koceski et al. [30], an evaluation that aimed to measure user perceptions and acceptance of the robotic telepresence system was carried out. It used a technology acceptance model (TAM), demonstrating that potential users accept the main functionalities of telepresence robotics, expressing positive opinions about the system. In addition, more benefits than concerns were identified about the use of this system. This study highlights the relevance given to the study of user acceptance, which is undoubtedly the primary focus of social robots.

After reviewing 336 studies related to different methods and measures used to qualify or quantify the social acceptance of robots in [31], it was corroborated that this is a new field of research and that there is a lack of evaluation methodologies or standards. Of the studies reviewed in the article, 29% were qualitative, and the rest were at least partially quantitative. Most of this research focused on the fields of health and social care.

In other relevant research, an importance performance analysis (IPA) and a technique of order preference by similarity to an ideal solution (TOPSIS) were performed to explore the quality of service given in a hotel by a service robot [32]. The results indicate that the test robot generated assurance and reliability in service, while empathy and tangibility with users were not present in the interaction.

An approach that encompasses the above, to evaluate remote systems applied to robots [33], suggests that metrics that capture the following properties should be identified:

- Contains the performance parameters of the system.
- Identifies the limitations of the system agents and environment.
- Has predictive power to know the scope of the application.

For the methodology proposed in this research, these three items were considered in order to be able to solve the questions of system performance, limitations, scope, and user expectations in the two proposed validation tests.

1.3. Technology Solutions

A mobile device with an Android operating system was used to control the robot. Mobile devices are among the most used equipment by people in today's world, and 80% of them run on this operating system [34]. Smartphones allow the use of available technology at a low cost due to several functionalities capable of replacing a computer in several aspects [35]. It is even possible to take advantage of these devices used to control a robot through Bluetooth [36,37] and a wireless interface providing a high-speed bidirectional connection. The aforementioned allows the creation of inexpensive robotic systems, as in [38], where two Android phones were used. The first works as the robot processor, which connects to a laptop computer in charge of the connection with different sensors and actuators, while the second Android phone works as the robot's controller.

Regarding compilers to implement applications to control robots, there are programs such as Android Studio, Eclipse IDE [39], and Inventor [40,41], which are programs that have been used in different projects with mobile robots that require a medium level of programming knowledge to create these applications [42].

In the study by Huang et al. a low-cost and low-energy consumption prototype robot was designed. It has remote control through the Wi-Fi network [43] using an Android device. Here, it is seen that there is a lower communication delay in this type of connection, and depending on the environment where the tests are carried out, there is a control distance of approximately 80 meters.

Regarding the use of applications on mobile devices, the analysis carried out in [44], after reviewing 790 documents, identified 75 attributes, of which the most frequent were efficiency (70%), satisfaction (66%), and effectiveness (58%), and the least frequent were simplicity (13%) and ease of use (9%). These results can be included in the user experience measurement that encompasses not only the attributes of the application, but also the beliefs, feelings, and preferences of the users.

The proposal of this paper is a methodology whose approach considers real scenarios and situations for an evaluation of the performance of the operational tools (app) and social attributes included in the robot. In this way, it is possible to perform a more complete validation of the use of robotic tools in challenging scenarios, as was done in [45].

2. Materials and Methods

There are three main types of teleoperation for robots [46]: direct, supervisory, and multimodal teleoperation. The vast majority of existing teleoperation techniques, including the presented system, are based on direct teleoperation, also known as the master–slave control mode.

A robot that works with the Robotic Operating System (ROS) was used due to the ease of integrating various functions [47] and utilities through its node system [48], which makes it suitable for the development of algorithms for robots and the progress of research in robotics-related topics [49]. A social robot called CeCi was used to perform tests on the mobile device.

2.1. Robot CeCi

The social robot called CeCi, short for Computer and Electronic Communication Interface [31], can be used for delivery services, research, or telematics equipment. It is designed for workplaces such as hotels, bars, clubs, universities, industries, and offices. Among the different jobs that this social robot can perform are helping in recreational projects, purifying environments, support with telepresence, and medical assistance in the disinfection of premises [25].

Figure 2 shows that the robot has an Intel Nuc i7 that uses the Ubuntu 16.04 operating system and ROS in its kinetic version due to the compatibility that exists with different installed packages, which are necessary for its regular operation. In addition, it has unique features, as illustrated in Table 1, which allow it to work in closed or indoor environments.

Figure 2. CeCi components [31].

Table 1. Technical specifications [31].

Datasheet	
Dimensions	990 mm (height)/360 mm (depth)/415 mm (width)
Weight	11 kg
Battery	Lithium-Ion: 4400 mAh (2 units) /Lithium polymer: 50,000 mAh
Camera	Orbbec Astra RGBD
Lidar	Slamtec RPLIDAR A3M1 360° laser scanner
Display	GeChic 1306H Monitor Touch Display
Mobile Base	Kobuki
Platform	CeCi1.0
CPU	Intel® Core™ i7-7567U Processor (4M Cache, up to 16.00 GHz)
Networking	Intel® Wireless-AC 8265; Bluetooth 4.2; Intel® Ethernet Connection I219-V
Motion Speed	70 cm/s
Maximum Rotational Velocity	180 deg/s (>110 deg/s gyro performance will degrade)
Threshold Climbing	Climb thresholds of 12 mm or lower
Odometry	52 ticks/enc rev, 2578.33 ticks/wheel rev, 11.7 ticks/mm
Bumpers	left, center, right
Payload	2.6 kg (hard floor); 1.2 kg (carpet)

2.2. ROS-Mobile

ROS-Mobile is an application designed for Android devices [50]. Its main advantage is the easy customization with which it can operate and monitor robots that work with the ROS framework. This application is based on the model–view–viewmodel (MVVM) architecture pattern [51] and can be installed on Android 5.0 or higher devices [50]. Additionally, the download and installation are easy, and the APK can be found on official sites.

The application's design is composed of five tabs that allow configuring, customizing, and communicating with the chosen robotic devices loaded with ROS. The following is an indication of the work of each tab of the application:

- Starting Screen: allows the creation of several control screens.
- Master: wireless connection configuration with the robot.

- Viz: controls and labels configured in the Details tab.
- Details: allow different controls and labels in the Viz tab.
- SSH: allow it to connect using the SSH connection protocol.

2.3. Creation of the Interface between Mobile Device and CeCi Robot

It is necessary to connect each widget (miniature application within an app) that will be used to control any robotic system [52] that works with ROS from the ROS-Mobile application. For that, the ROS publisher–subscriber communication has to be used [53]. In this case, the main idea is to communicate with two essential nodes in the CeCi robot, the same ones that allow for manual control and send the robot to different coordinates [54] as required. In C++ [55], a communication node /redmi was created to link the application buttons and the robot. The following should be considered:

1. Ability to subscribe to the /keyop node, which allows for controlling the robot's movements. Messages between the /redmi node and the /keyop node are transmitted via the /redmi1 topic.
2. Ability to subscribe to the /map_navigation_node navigation node, which enables navigation in environments known to the robot. The communication between the /redmi node and the /map_navigation_node is transmitted through the /redmi2 topic, as seen in Figure 3.

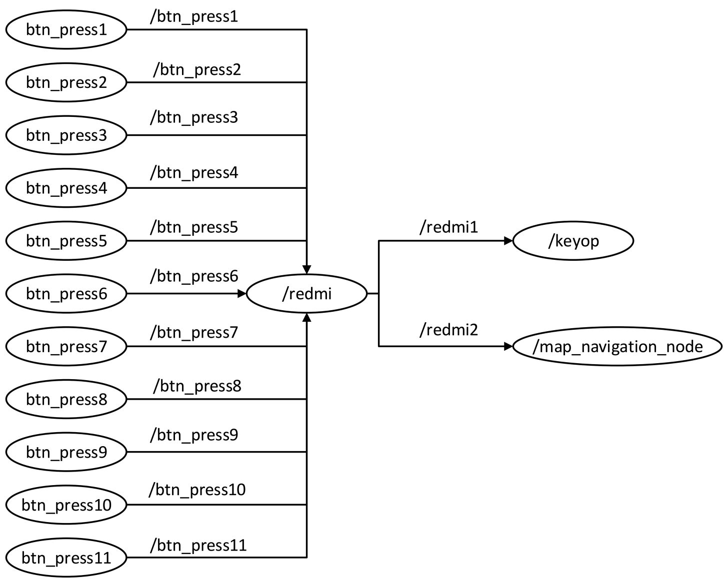

Figure 3. Android device communication with the robot control nodes.

The /redmi node subscribes to the button topics through a message of type Boolean and publishes to the /redmi1 and /redmi2 topics via a String message type.

2.4. Customizing the CeCi Robot Control Application

The following is the required process for the configuration of the application used to control the robot:

1. First, an identifying name is given to the new configuration to be made. Then, the buttons are added as widgets, according to the needs of the application. Next, within each button created, the location (x-y coordinates) and the size of the buttons are configured to improve the appearance and functionality of the interface.
2. Each button behaves as a node in ROS; the next step is configuring the buttons as publishing nodes. To do this, the programming was edited based on the button name. A name type was placed on each button to identify it in any part of the process, be it programming or visualization.

3. Finally, the identification parameters corresponding to the IP addresses of both the robot to be controlled and the mobile device that will manipulate the application are entered. For this step to be carried out and for the application to work, the robot and the mobile device must be connected to the same Wi-Fi network. In addition, the master port of the robot is set, which in this case is 11311.

2.5. Project Simulation

It is important to perform simulations, as this allows developers to perform experiments that only require a PC and an internet connection [56]. Therefore, before starting the tests with the robot, we proceed to make use of two important ROS tools: RViz [57] and Gazebo [58]. These allow testing the application's connectivity to a virtual robot and moving it in different positions. In the simulation, the coordinates of four places in a plane containing obstacles were raised and configured to connect with the application. When running the simulation, the application buttons 1, 2, 3, 4 are used (Figure 4); this allows for sending the robot to the previously raised points, as shown in Figure 5.

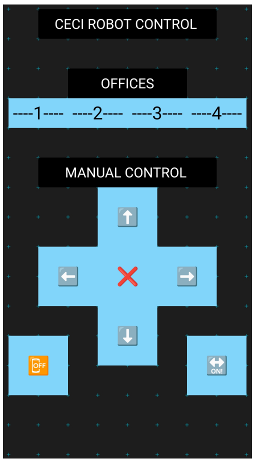

Figure 4. Application display screen.

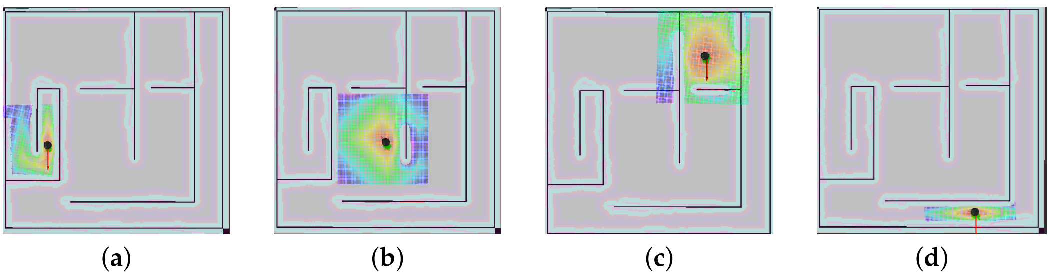

Figure 5. (**a**) First location, (**b**) second location, (**c**) third location, and (**d**) fourth location.

2.6. Tests with the CeCi Robot

To implement the CeCi Robot using the ROS-Mobile application, a mapping of two environments joined by a corridor was performed. In this case, the manual control of the Android device was used; it seeks to use the buttons with the arrow symbols (Figure 4) to go to the required place. Once the sector where the tests were performed with the robot was mapped, some reference points were taken between one environment and another. Then, the same simulation procedure was carried out, which allowed for recording points in the robot's program and then employing buttons 1, 2, 3, and 4 to send the robot to the desired coordinates.

By performing the tests, it was possible to determine the correct functioning of the application when used to control the mobile robot. Once the connection with the robot was made, there was no interruption or failure in the linkage with the Android device (Figure 6).

Figure 6. Raising a map with the robot using the control of the Android device.

2.7. *Application Usability*

Due to the number of applications that exist today, it is necessary to analyze its usability since users not only require the functionality of the app, but the experience of using it must be enjoyed by the consumers [59]. According to PACMAD (People at the Center of Mobile Application Development) [60], usability measurement indicates that an application should be analyzed based on the following aspects: effectiveness, efficiency, learning capacity, memorability, errors, and cognitive load.

In order to carry out the survey, we proceeded to demonstrate the application's work using the remote control configuration of the CeCi robot. The people surveyed were able to make use of the controls of a robot and then give their opinion regarding the experience they had. To measure these characteristics, a survey was conducted with 52 people [61] in which 10 questions divided into 2 sections were presented. Seven of these questions measure usability using the PACMAD method, and three summarize whether the application was to the respondents' liking. The first eight questions are closed, five-points Likert-type questions [62], and the next two are open-ended questions with no word limit. The questions asked are as follows:

1. Does the robot execute the orders given by you from the application?
2. Were the robot's responses to the orders from the application correct?
3. Did the application performance meet your expectations?
4. Would you learn to use the application for yourself?
5. Do you think you could use the app again without prior explanation?
6. After testing the app, what's your opinion about using it as a remote control for the robot?
7. Do you remember the existing buttons in the application and their use?
8. After testing the app, what is your opinion about it?
9. What do you like most about the app?
10. What do you like least about the app?

3. Results

From the tests carried out with 10 Android devices (Table 2), all with Android higher than 5.0, it was possible to verify that they could be connected to the CeCi robot without any inconvenience. The idea was to test the communication time between the robot and different Android devices to identify the best option when using this application on mobile devices.

In the tests performed with different Android devices, all the applications were closed, except for the essential ones necessary for the normal operation of the devices. Therefore, the amount of RAM and CPU load used before the connection test was verified and included in Table 2.

A Tp-link TL-WR841HP wireless router was used; a wireless network was created only for the test devices (only two devices connected to the router for each data acquisition performed). For the connection, a button was created in the ROS-Mobile application of each Android device, and then two connection tests were performed. The first one tries to measure the connection between the robot and the mobile device by doing a packet latency test using the ping command between these two components. The second test tries to do another latency test, in the same way, using the ping command between the robot and a button created in the application of each mobile device so that, by obtaining the two communication times, we can find the time it takes for the robot to act after sending an order by the mobile control device through the difference of these values.

Table 2. Android devices tested in communication with the CeCi robot.

Brand	Model	Processor	Memory RAM	Android Version	CPU Usage	Ram Memory Usage
Samsung	Galaxy Tab S7 FE SM-T733	Octa-Core 2.4 GHz (8xArm Cortex-A55)	4 GB	12	33%	73%
Samsung	Tab A-SMT515	Octa-Core 1.8 GHz (Samsung Exynos, 2xArm Cortex-A73)	2 GB	11	52%	68%
Redmi	Note 9 Pro	Octa-Core 2.32 GHz (2xQualcomm 0x804)	6 GB	11	30%	61%
Samsung	A32 SM-A325M /DS	Octa-Core 2 GHz (2x ARM Cortex-A75))	4 GB	12	30%	69%
Realme	7 Pro-RMX2170	Octa-Core 2.32 GHz (Qualcomm Snapdragon 720 G, Kryo 465)	8 GB	12	31%	51%
Samsung	Galaxy j5 SM J500M	Quad Core 1.19 GHz Qualcomm Snapdragon 400, 4xARMCortex-A53	1.5 GB	6.0.1	72%	60%
Samsung	Galaxy j5 SM J500H	Quad Core 1.19 GHz Qualcomm Snapdragon 400, 4xARMCortex-A53	1.5 GB	5.1.1	67%	63%
Samsung	A12	Octa-Core 2 GHz (8xArm Cortex-A55)	4 GB	11	27%	64%
Samsung	A20S SM-A207M	Octa-Core 1.8 GHz (Qualcomm Snapdragon 450, 8xArm Cortex-A53)	3 GB	11	43%	58%
Tecno	BD4	Octa-Core 1.6 GHz (Unisoc Cortex-A55)	2 GB	11	78%	72%

3.1. *Connection Test with Different Devices*

First, to find the connection time in the two tests performed, find the appropriate sample to be taken at the time of averaging the connection time. For this case, a mobile device was used as a base where 10 samples were taken. To verify that the data were consistent, repetitions were made in the same test, obtaining very distant values between one test and another. Because of this, we proceeded with the collection of 100 samples. When we repeated the collection of values, we could observe a more significant variation between each test performed. In order to obtain stable values, 1000 samples were taken, and the test was repeated 3 times, finding values close to each other, allowing us to determine that the tests performed with the rest of the devices should be performed with data from 1000 samples for each Android device.

According to [46], the communication delay in teleoperation *should be at most 320 ms* because if it is longer, the control of the robot can be compromised. The values obtained (Table 3) show that the average connection time between the CeCi robot and an Android device is 107.40 ms. In comparison, the average connection time of the same robot with a button created in the ROS-Mobile application is 166.23 ms. With these values, it can be observed that the application takes approximately 58.82 ms to execute an action. Even though these values are not perceptible by the person operating the robot, it is of utmost importance to keep in mind these details in other projects related to the use of the ROS-Mobile application since there may be the requirement that the robot gives an immediate reaction to the mobile application. From the tests carried out, it can be seen that the fastest device to operate has the highest number of cores and the highest speed frequency that its processor needs to function. In this case, the Samsung Galaxy Tab S7 device is the fastest-acting device (8-core processor and a frequency of 2.4 GHz).

Table 3. Tested Android devices.

Android Devices	Ping CeCi (ms)	Time Button Action (ms)
Samsung Tab S7	16.98	32.66
Samsung Tab A	19.01	34.89
Redmi Note 9	27.64	49.83
Samsung A32	31.08	57.05
Realme 7 Pro	46.96	96.64
Samsung J5	140.01	191.75
Samsung J5	162.72	234.87
Samsung A12	189.68	253.23
Samsung A20	207.91	246.68
Tecno BD4	232.09	464.72
Average of all devices	107.40	166.23

As shown in the tests performed, the devices are within the expected times, except for the Tecno BD4 device (Figure 7), which exceeds the time values; i.e., it is not recommended to use it. This may be because the device has low RAM (2 GB), is the only one with a Unisoc processor, and has the lowest speed frequency (1.6 GHz with eight cores), all of which is in comparison with the rest of the analyzed devices.

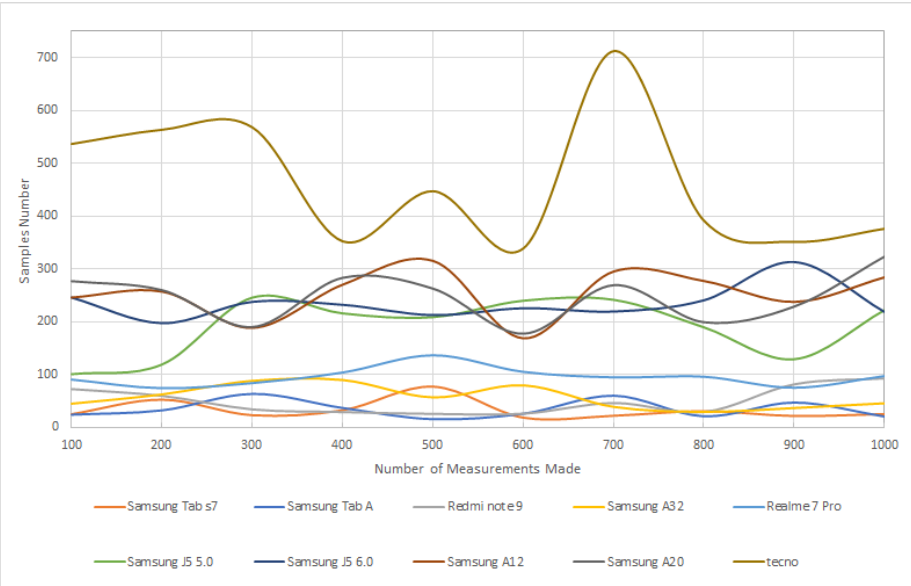

Figure 7. Data obtained from the communication time from the button action.

3.2. *User Survey*

This section describes observations about the usability of the ROS-Mobile application thanks to the survey that was completed by 52 people who were able to test the application without any major inconvenience. The survey was completed by a more significant number of men than women (Table 4), as shown in Figure 8, where about 80% of people were male.

Table 4. Focus group (gender).

Gender	Number	Percentage
Female	11	21%
Male	41	79%
I do not wish to answer	0	0%

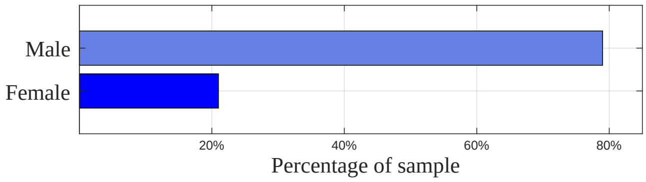

Figure 8. Gender graph.

In the sample, the age ranges are diverse (Table 5). Figure 9 shows a more significant number between 31 and 40 years of age, and a small sample ranging from 51 to 60.

Table 5. Focus group (age).

Age Ranges	Number	Percentage
11 to 20 years	5	10%
21 to 30 years	17	33%
31 to 40 years	21	40%
41 to 50 years	6	12%
51 to 60 years	3	6%

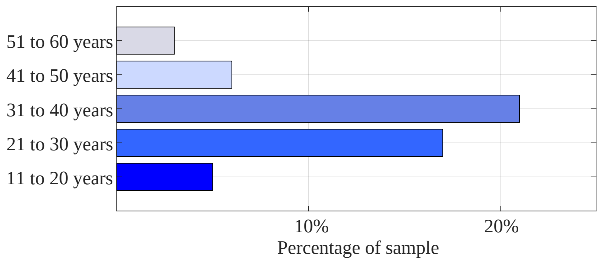

Figure 9. Age graph.

Regarding the level of education, the percentage of people with primary education is very low, while those with secondary and university studies are close (Table 6). Figure 10 shows that most of the people surveyed have an intermediate level of education.

Table 6. Focus group (education).

Education Level	Number	Percentage
Primary	3	6%
Secondary	27	52%
University	22	42%

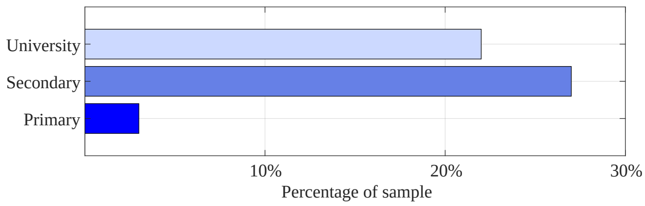

Figure 10. Education graph.

All seven questions related to the PACMAD method show a high percentage of high expectations; these data can be seen in detail in Table 7. Of the sample, 85% could use the application without any inconvenience, while 15% had problems using the application (1).

For 86% of the people surveyed, the speed does not present any inconvenience, which is expected. At the same time, a small percentage indicated that the application takes a long time to respond once the order has been given through the controls (2). Of the sample, 81% agreed that the use of the application met their expectations (3), and 83% found it very easy to use (4). After an explanation of the application was provided and people operated the robot, most people found it easy to remember how the application worked and felt they could use it again without problems (5). People had no major difficulty controlling a robot with a mobile phone. According to the data obtained, only 13% had complications (6) due to the number of existing buttons. Additionally, 35% of the people needed help remembering the use and operation of the buttons used in the application (7).

Using the PACMAD method, the ROS-Mobile application has an effectiveness of 85% and an efficiency of 86%. A satisfaction rate of 81% is observed, the learning capacity is 83%, and 75% of the people surveyed can retain information about the use of the application (memorability). Most people (87% (error)) had no problems using the application. Finally, the ability of people to perform another task while using the application is 65% (cognitive load).

Table 7. Items of the expectation scale.

Items of the Technology-Specific Expectation Scale	Very Low Expectation	Neutral	Very High Expectation
1. Does the robot execute the orders given by you from the application?	0%	15%	85%
2. The robot's response to the orders given from the application was...	2%	12%	86%
3. Did the application performance meet your expectations?	0%	19%	81%
4. Learning to use the application for you was...	4%	13%	83%
5. Do you think you could use the app again without prior explanation?	6%	19%	75%
6. Using this app as a remote control for the robot, in your opinion it was...	0%	13%	87%
7. Do you remember the existing buttons in the application and their use?	0%	35%	65%

With the data obtained from the survey, a good acceptance of the ROS-Mobile application can be observed, especially among women, who all had a neutral value and high acceptance. Figure 11 shows that only 10% prefer to avoid the application.

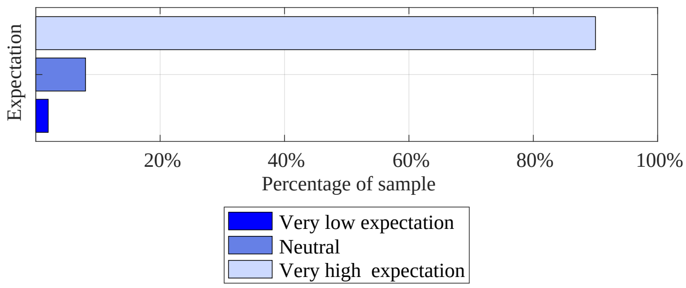

Figure 11. Application Acceptance.

In the open-ended responses, we sought to approximate similar criteria in order to classify them into different groups. Figure 12 shows the positive and negative comments made by the respondents. The comment that stands out most in both the likes and dislikes is the application's appearance. Of the people surveyed, 10% indicated that the application lacks animation, which, added to the dislike of the appearance, results in 54% against the application. Another interesting criterion is that 8% of the sample indicated that the type of remote control should be changed to a joystick type. It also highlights its easy connection and use, effectively fulfilling the application's primary function, meaning that everyone could work with the remote control even if they did not like its interface.

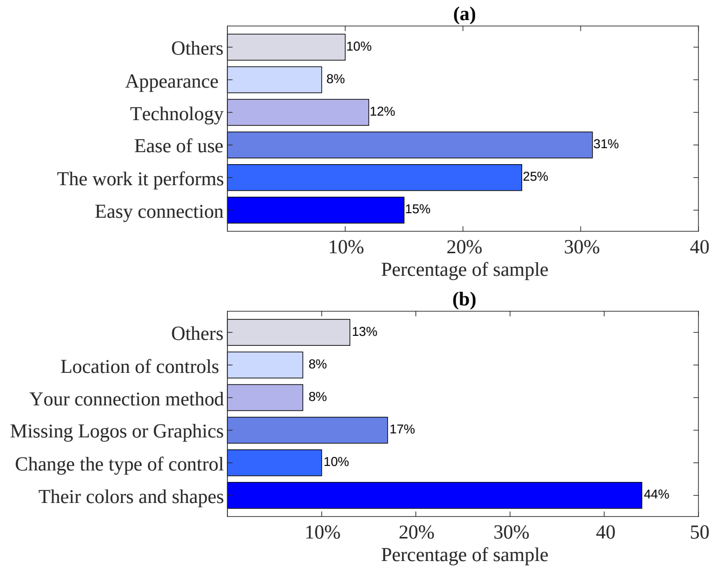

Figure 12. (**a**) Opinion on the acceptance of the application, (**b**) Opinion on the disapproval of the application.

A link to a video demonstration of the tests is included in the Data Availability Statement section.

4. Conclusions

The main contribution of this research is a validation methodology proposal for remote operation with social robots. It differs from the existing state of the art where methodologies for technological or social validations are presented separately, and not precisely for remote operation but in broader contexts. Additionally, this research not only theorizes about this proposal, but also tests it with the CeCi robot in real environments. In comparison with projects using similar communication methods [63], the method used in this article allows for a stable connection. The most outstanding result of this research from the technical point of view is that the response of the remote system is below the 320 ms threshold for 9 of the 10 devices tested. This far exceeds the most crucial limiting factor in remote systems.

The surveys were conducted with a heterogeneous focus group unfamiliar with robots and their applications. According to the PACMAD usability method, this application reaches a percentage of 85, where users confirm that the application fully complies with the task for which it was designed.

Based on the results found in Section 3.2, this application reaches a 90% acceptance rate, which is a very positive result for this proposal.

The results of Section 3.2 also indicate the areas in which future work should be carried out, since those are the weaknesses of the current one. In detail, the design of the graphical interface and the implementation of a joystick instead of buttons for the application should be improved.

As a final suggestion, the implementation of additional functionalities (voice commands, real-time video) to the ones exposed here is recommended to add valuable functionalities for the robot.

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Data Availability Statement: Remote operation tests of CeCi Social Robot: https://youtu.be/d1uJL0v-_wQ (acessed on 10 January 2023). Advertising TEC BOX video Robot Social CeCi: https://youtu.be/41rUGLJfSSk (acessed on 25 September 2022).

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Abbreviations

The following abbreviations are used in this manuscript:

CIITT	Center for Research, Innovation and Technology Transfer
MVVM	Model–view–viewmodel
PACMAD	People at the Center of Mobile Application Development
RAT	Robot Assisted Therapy
ROS	Robot Operating System

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