Journal of Autonomous Intelligence (2024) Volume 7 Issue 4
doi: 10.32629/jai.v7i4.1216

ORIGINAL RESEARCH ARTICLE

Enhancing autonomy in social robots through a real-time teleoperation system

Tareq Alhmiedat[1,2]

[1] *Faculty of Computers and Information Technology, University of Tabuk, Tabuk 71491, Saudi Arabia; t.alhmiedat@ut.edu.sa*

[2] *Artificial Intelligence and Sensing Technologies (AIST) Center, University of Tabuk, Tabuk 71491, Saudi Arabia*

ABSTRACT

The utilization of socially assistive robots (SARs) has shown great potential in various applications. However, there are practical challenges that hinder their widespread adoption. Recent studies have explored the use of teleoperation systems as a solution to overcome these challenges by streamlining data collection and communication with SARs. This paper introduces a cloud-based teleoperation system for robotics that enables real-time control of the robot platform, allowing remote users to view video streams and manipulate the robot system. The proposed teleoperation system was implemented in a cloud environment and tested with two different social robot platforms. The experimental results demonstrate the system's quick response and stable communication performance, meeting the requirements for remote-controlled teleoperation. Consequently, employing the proposed mobile-based teleoperation system in social robot applications enhances operator productivity, expedites operations, and reduces task completion time.

Keywords: Teleoperation; social robot; remote control; cloud-based control

ARTICLE INFO

Received: 5 September 2023
Accepted: 23 November 2023
Available online: 23 January 2024

1. Introduction

Recently, robots have been used in a wide range of applications, from civilian, healthcare, manufacturing, and space exploration to education and entertainment. Robot applications are therefore varied and vast, with high potential for future growth and development. In several environments, the user (operator) needs prior experience and training to make complex decisions outside of the autonomy of the robot. In such cases, teleoperations allow the operator to interact with and guide the robot through complex tasks from a distant location[1].

Robot teleoperation as a field has received recent attention due to its necessity in many applications, including agriculture, healthcare, education, industry, military and social uses. For instance, the teleoperation of Unmanned Aerial Vehicles (UAVs) is an important task since it involves remotely controlling a UAV when several tasks cannot be automated and need a human operator. Several teleoperation-based UAV systems[2–4] have been presented recently with diverse functionalities and capabilities. In addition, the teleoperation of industrial robots has also received recent attention[5–7], where it is beneficial to have the teleoperation extend the users in a remote location.

Rapid progress has been made on all robotics technology, the fundamental components of which are necessary for developing socially situated, autonomous robot systems. Efficient robot teleoperation techniques are usually critical to Wizard-of-Oz (WoZ) paradigm. Socially assistive robots (SARs) offer social assistance rather than physical and have the potential to positively influence the environment. For example, SARs may engage in therapeutic interventions[8,9], act as companions to the elderly[10,11], or assist people in public[12,13].

Communication technologies and robots support a wide range of social applications. As these technologies advance, they spread to even more diverse applications; service robots have received considerable attention recently, and in medical applications, a teleoperation system allows a human operator (such as a parent and medical assistant) to interact with a remote robot platform to perform different tasks.

Usually, SARs work in two different ways: they may act autonomously by using environment recognition, or they can be controlled remotely by an operator[12], since the operator (remote-control user) may need to accomplish several tasks remotely, where this is considered as a complicated task as teleoperation systems are not universal (robot platforms employ different communication protocols) and most of the existing teleoperation systems have been developed to work with a certain robot platform.

This paper presents the design and development of an efficient, cloud-based, teleoperation system for social robot applications. In addition, it presents a validation methodology for remote control systems, with a focus on the social robot applications. The research process begins with developing a cross-platform application for smart phones (iOS and Android), and then obtaining a simple method to communicate with the social robot platform.

This paper considers two different cases: a social robot named SARA (Saudi Arabian Robotic Assistant)[14] that was designed to interact with diabetic children, and an obesity robot platform[15] based on a well-known social robot called NAO. Both robot systems were designed to interact with children in an attractive and fun manners. Therefore, this paper:

a) Analyses and critiques recent teleoperation systems for SAR applications.
b) Develops a universal teleoperation control system for social applications.
c) Presents a set of evaluation metrics to assess the efficiency of any teleoperation robot system for social applications.
d) Validates the performance of the developed teleoperated robotic system using two different case studies.

The remainder of this paper is organized as follows. Section 2 presents the recent developed teleoperation systems for social robot applications. Section 3 presents the cloud-based teleoperation system. The experiment-testbeds and the obtained results are presented in Section 4. Section 5 discusses the results and shows the main contribution of this work. And finally, section 6 concludes the work presented in this paper and draws future works.

2. Related works

Recently, robot teleoperation has been widely explored and adopted by diverse fields. A review of mobile robot teleoperation is presented by Opiyo et al.[16], where the authors discussed systems' architectures, communication methods, and situational awareness creation. Moniruzzaman et al.[17] reviewed existing teleoperation methods and techniques for mobile robots. In addition, several research works[18–24] have been developed with the purpose of remote teleoperation of robots, with no intensive focus on teleoperating social robots. This paper focuses on teleoperation for social robots, with the purpose of remote controlling and monitoring social robot systems. This section summarizes recent SAR approaches and discusses the main challenges associated with each.

Several recent works focused on teleoperation for social robots; however, there are no single study surveys the recent developed teleoperation systems for social robots. Therefore, this paper discusses and categorizes existing teleoperation approaches for social robots into two main categories: application-based and reality-based approaches, as presented in **Figure 1**. The former involves the adoption of a computer application that is designed to communicate with the robot platform through peer-to-peer communication protocol, where the computer applications are categorized into three main categories: Windows-based, web-based, and mobile-based. On the other hand, reality-based applications use reality technologies that are able to remotely control the robot platform through a virtual device, so that the remote users can be transported into a number of real-world and imagined environments. Reality technologies can be further classified into virtual reality and augmented reality systems.

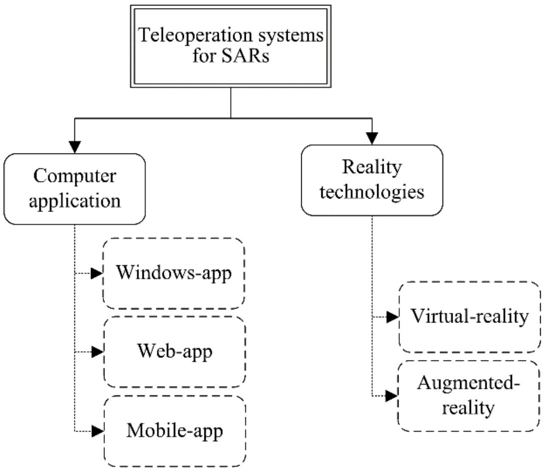

Figure 1. The classification of SAR teleoperation robot systems.

Recently, computer-based teleoperation systems have been employed with SARs. Elbeleidy et al.[25] analyzed archival data of therapists' teleoperation robots as a part of the children's regular therapy sessions, using a Windows-based application. In addition, Glas et al.[26] developed a single framework that was able to simultaneously control four robots in conversational interactions; the authors presented a set of metrics for predicting robot performance and demonstrated the effectiveness of their proposed framework through simulations and laboratory experiments based on real-world scenarios.

The work presented by Song et al.[27] focused on the use of teleoperated robots with a human operator to perform sales tasks. The developed robot system acted as a salesperson for toothbrushes; the authors found that the robot had the ability to attract people's attention and influence their shopping behavior.

A validation methodology for the remote operation of social robots was presented by Barbecho-Jimbo et al.[28]. They employed the CeCi robot platform, and their method offered a stable connection in comparison to previous teleoperation systems. The authors revealed that their most significant result was the response of their remote sensing, which was less than 320 milliseconds. In addition, the developed application achieved a positive acceptance rate of 90% for a total of 52 users.

Ma et al.[29] developed a novel scheme to deliver real-time video contents via an enhanced UDP-based protocol, which consisted of four main parts: wireless body area networks, a robot, a software system, and a cloud platform. The proposed system targeted healthcare applications and was based on robotics and cloud computing. The aim of this system was to measure the patient's physiological information in order to provide feedback and analyses by means of a robot integrated with sensors. The implemented system monitored health status in real-time, where it can be remotely controlled by specialists or other users.

An intelligent mobile robot platform based on Android was presented by Ma et al.[30], using multiple wireless communication functions (Internet and WLAN). The developed platform consisted of speech recognition functions to control the movement of the robot and established a simple man-machine conversation. Moreover, the developed platform was able to transmit video remotely and in real time.

The work presented by Zhou et al.[31] designed and implemented a remote-control system for mobile robots based on a cloud platform. The implemented system consisted of three parts: the robot system, cloud platform, and android client. Users could control the robot's motion remotely; they could also access real-time video surveillance and remote environmental information through the android mobile application. Similarly, the work discussed by Laniel et al.[32] demonstrated the feasibility of integrating autonomous navigation, artificial audition, and vital sign monitoring into a commercial remote-control robot; the authors picked a Hybrid Behavior-Based Architecture (HBBA) as the robot control architecture.

Second, the reality technologies-based approaches are considered. Several virtual reality teleoperation systems have been proposed recently[33–36] to provide friendly and easy-to-use remote robot systems. The researchers explored how modern augmented and virtual reality technologies might improve robot teleoperation. For instance, the work presented by Bodala et al.[37] developed a teleoperation framework that allowed an experienced human coach to conduct mindfulness training sessions digitally, by replicating their upper-body and head movements on the Pepper robot in real time. This research[37] focused on bridging two important enablers for enhancing physiological wellbeing: telepresence robotics and mindfulness training.

As presented above, several teleoperation robot approaches have been proposed to remotely control different robot systems. The existing teleoperation systems for social robots are compared according to several parameters. **Table 1** presents a comparison of the existing teleoperation systems discussed above, according to the following parameters:

1) Remote control method: The application has been designed to control the robot system (via a web application, mobile application, or desktop application).
2) Robot platform: Various robot platforms are available for the research and development, and each one has its own characteristics and capabilities. Therefore, it is critical to note which platform has been employed in the experiment testbed, as each robot has its own functionalities.
3) Communication method: This describes the method that is employed to communicate between the robot system and the remote-control application.
4) Database environment: Remote-control systems may require a database to store the data obtained from the robot's onboard sensors.
5) Social application: This specifies the scope of the teleoperation robot platform, since each application has specific requirements.

Table 1. A Comparison between the existing teleoperation systems.

Work	Remote control method	Robot platform	Communication method	Database	Application
[25]	Windows app.	Misty robot	Wi-Fi	NA	Healthcare
[26]	Web app.	Unspecified	Wi-Fi	NA	Sales
[27]	Web app.	Sota	Wi-Fi	NA	Sales
[28]	Mobile app.	CeCi robot	Wi-Fi	NA	Marketing
[29]	Windows app.	EPIC robot	Wi-Fi & ZigBee	Cloud computing	Healthcare
[30]	Android app.	iRobot	Internet & Wi-Fi	NA	Healthcare
[31]	Mobile app.	Customized robot	Internet & Wi-Fi	Cloud platform	Home use
[32]	Windows app.	Beam + robot	Wi-Fi	NA	Healthcare
[37]	Augmented reality app.	Pepper robot	Wi-Fi	NA	Healthcare

3. Cloud-based teleoperation system for social robots

This section discusses the developed teleoperation robot system for social applications, which is presented in **Figure 2**. The proposed architecture consists of three sides: the robot side, user side, and cloud side. All three communicate to each other using different methods to send data to a remote user and allow remote access to the robot platform.

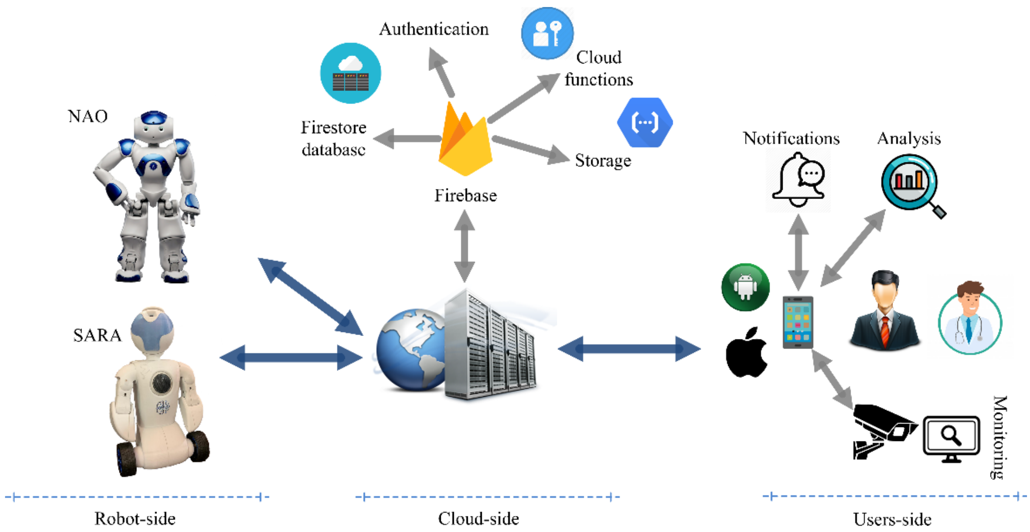

Figure 2. The three sides of the proposed teleoperation robot architecture.

First, the robot consists of a robot platform (SARA or NAO) as case studies. These include an interface service developed using Python in order to allow two-way communications between the user and the robot unit. **Figure 3** presents the architecture of the remote-control API, which includes all the functions needed for communication tasks. The remote-control API has the ability to interact with the high-level API of the robot system (for instance, speech recognition, and vision), where it can communicate with the hardware in order to accomplish a certain task.

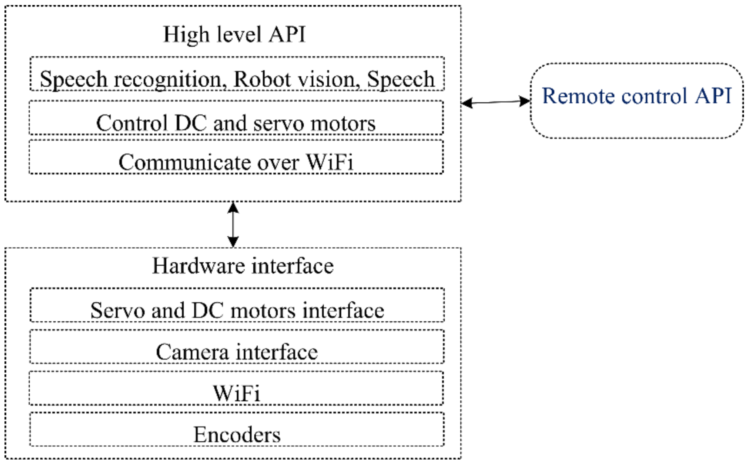

Figure 3. The architecture of the remote-control API.

Second, the user side includes a mobile application designed to facilitate the two-way interaction between the user and the robot. The user can perform several remote functions using the developed mobile application, including: monitoring, collecting of data, activating speech, and controlling the robot system.

Third, the cloud-based function offers two main services: data storage for recording the sensed data, and data communication to exchange data between the user and robot system. The collected data from the robot platform includes information such as: last seen, child mode, quiz scores, and story records, all of which are stored in Firebase. Additionally, the video live-streaming and two-way voice communications are processed through Firebase. For security reasons, the users' data are anonymized, moreover, the Firebase services encrypt data in transit using HTTPS and Firebase adopts extensive security measures to minimize unauthorized access.

The user can communicate with the robot system through the cloud, which includes all necessary functions for gathering sensed data and for remote controlling. The robot interface offers several desired functions for controlling the system and for gathering required data from onboard sensors and then uploading these data to the Firebase cloud server.

For the purpose of building an efficient teleoperation robotic system, various cloud services have been adopted and integrated, including:

1) Cloud Firestore is a NoSQL and flexible cloud database to store and sync robot data. It keeps the robot data in sync across the developed mobile application by adopting real-time listeners. Firestore keeps the robot's data including: child glucose level and time, child last seen by the robot, child's total activities, etc., all of which are located in the Firestore cloud service[38].
2) Firebase Cloud Messaging (FCM) is a cross-platform messaging solution that allows the teleoperation system to send messages at no cost. Through FCM, the user (a parent or medical monitor) can be notified whenever a new action has been processed. For instance, it will alert the user when high blood sugar levels are recorded.
3) Cloud functions for Firebase include a serverless framework that runs backend code in response to certain events triggered by Firebase features and HTTPs requests. A notification will be issued to the parent whenever the diabetic level exceeds a certain threshold value. Other notifications include: obtain blood sugar level, obtain child's activity, and update the list of stories.

Figure 4 presents the data exchange process between the robot platform and the mobile application through the Firestore cloud server and via FCM. The collected data from the robot system is transferred to the Firestore cloud server, and then fed to the mobile application. The mobile application may access the robot's functions through the Firestore cloud server.

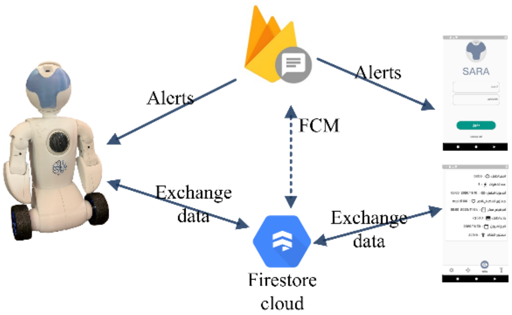

Figure 4. The data exchange between the robot platform and the mobile application.

Real Time Communication for Web (WebRTC) offers a reliable service to integrate real-time communication capabilities to the developed application in order to allow for video data to be shared between the child (diabetic child and obese child) and their parents and healthcare providers. **Figure 5** shows the data exchange process of voice and video between the robot platform and the mobile application through the WebRTC service.

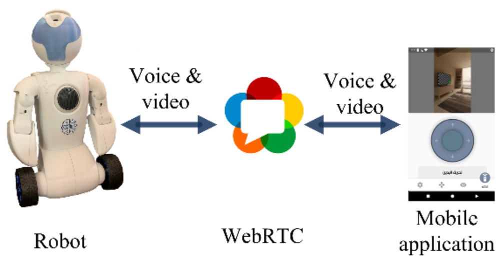

Figure 5. The voice and video data exchange between the robot platform and the mobile application.

4. Experimental results

This section discusses the experimental testbed and the results obtained from real experiments conducted during two case studies employing two different robot platforms.

4.1. Development environment

As presented earlier in **Figure 2**, the developed teleoperation system consists of three main components. The user side consists of the mobile application, developed using a cross-platform environment. The cloud side consists of the Firebase platform, which both stores the data gathered from the robot system and offers messaging functions. And finally, there is the robot system, which involves a teleoperation function that acts as an interface between the user (through Firebase) and the robot. The integration of the above components facilitates the communication between the user-side and the robot-side.

The user side consists of a mobile application developed for the purpose of communicating with the robot system. A group of GUIs have been developed using Flutter to allow easy communication between the user and the robot. **Figure 6** presents the developed GUI for the user side, with three main interfaces: the login, child activities, and remote-control screens. Three other GUI forms have also been developed, including: games, add a story, and control a story's frequency. The presented GUI are adaptable to any social robot application.

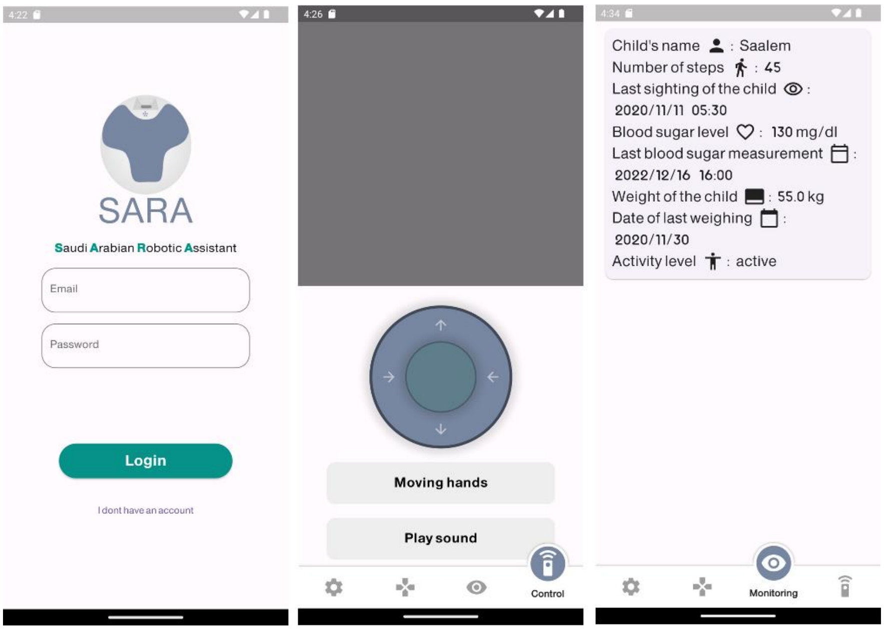

Figure 6. Samples of the developed GUI screens.

4.2. Case studies

The experimental results were obtained from two different case studies: the first case study employed the developed teleoperation platform with a social robot named SARA, depicted in **Figure 7**, which offers therapy for children with diabetes[14]. SARA is a Raspberry-Pi based robot platform with a set of servo and DC motors, and an array of sensors to sense the robot's surrounding.

Figure 7. SARA robot platform.

In this case study (SARA robot platform), the teleoperation function is essential for several reasons; the medical assistant requires access to: the daily health records for each child, interact with the diabetic child, and offer necessary recommendations through the robot system. In addition, the child's parents can access several functions including: information on when the child was last seen by the robot, a video feed that allows them to communicate with their children, and data on their child's activities.

The second case study adopted the developed teleoperation system with a social robot to interact with obese children[15], using the NAO robot platform. NAO is a small humanoid robot designed to interact with people, depicted in **Figure 8**. NAO was able to interact with obese children who wore a smart watch that collected daily activity information and transmitted that data to the NAO robot platform. The child-robot interaction, along with the child's activities, must be available for healthcare personnel. In this project, the teleoperation function allowed for remote interaction with the child, and to obtain necessary information collected by the robot system, including the number of steps taken and last seen services.

Figure 8. NAO robot platform.

Both case studies, SARA and NAO robots offer diverse autonomous tasks, including: child identification through face recognition function, communicate with the child using speech recognition, and play function through adopting quiz and game functions.

4.3. Results

For validation purposes, the developed teleoperation system has been tested using two case studies (on SARA and NAO robots); this section presents a set of validation metrics to fully assess the efficiency of the developed teleoperation system for social robots. The validation metrics are categorized into two main parts: the metrics that are relevant to measuring the performance of the developed teleoperation system, and the metrics that are relevant to assessing user acceptability, as shown in **Figure 9**.

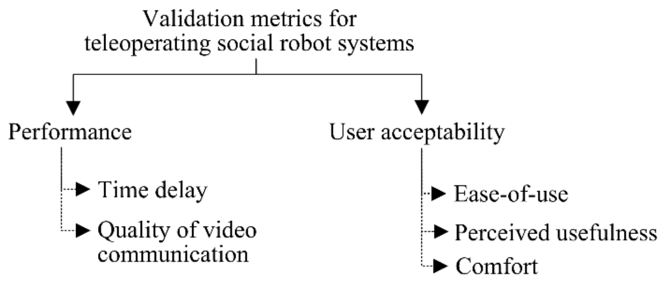

Figure 9. The validation metrics for evaluating teleoperation social robot systems.

Performance metrics are considered first (evaluating the application response time and the quality of real-time video communication). For evaluation purposes, three different experiments in three different locations were carried out. For the three tests, the average internet speed was approximately 54 Mbs for both the sender and receiver. In all experiments, the robot platform was located in the Artificial Intelligence and Sensing Technology (AIST) research center at the University of Tabuk, in the City of Tabuk, whereas the remote users were located in three different locations: Riyadh, Jeddah, and Amman.

The response time for remote control functions refers to measuring the time delay between the actual action time and the processed action. For each experiment, the response time was estimated in order to assess the time delay for accessing and controlling several functions of the robot platform. All communications from the user side to the robot platform are passed through the Firestore cloud server, where the delay time was estimated for five different actions (functions) as follows: move robot forward, backward, right, left, and move head.

Figure 10 shows the time delay for five different actions repeated six times for each of the three experiments. As presented, the average time delay was around 1038 milliseconds (ms), which is almost a one-second delay between the actual action and the processed action, where a one-second delay is reasonable.

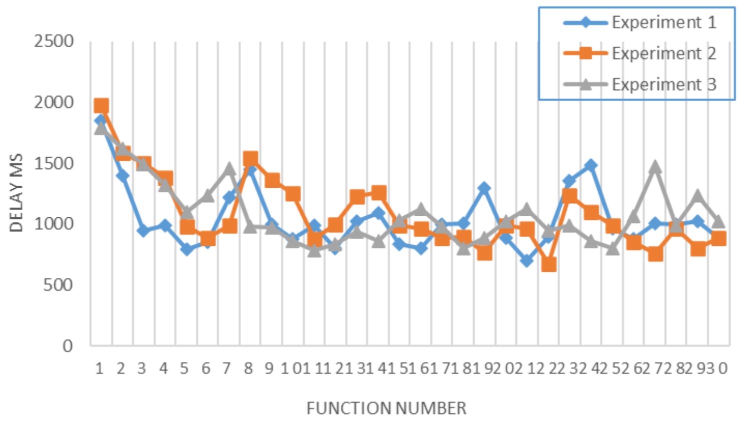

Figure 10. Average time delay in ms for three different experiments.

Real-time video communication is an essential function in teleoperation platforms for social robots, because it allows the parent or medical assistant to communicate directly with a child and offers advice and recommendations. For video streaming, various image parameters have been tuned; the original resolution for both cameras in SARA and NAO was set to (640 × 480 pixels). Lower than this can increase the throughput; however, doing so may decrease user experience. For evaluation purposes, the image quality was set to 95%, 80%, 70%, 60%, and 50% with respect to the original image source. The obtained results are shown in **Table 2**, where a reduction of the quality below 70% does not further enhance the packet per second (pps) rate in a noticeable way; therefore, the image quality was set to 70%. Scapy Python library was adopted to estimate the average number of received packets, where Scapy is a powerful interactive packet manipulation library and its able to decode packets using a wide number of communication protocols.

Table 2. A comparison between packet size, PPS, and throughput.

Size	Quality	Average pps
77.0 KB	95%	7.2
45.0 KB	80%	9.5
33.5 KB	70%	12.1
20.4 KB	60%	12.5
18.9 KB	50%	12.8

In general, the size of the packet affects both the quality of video streaming and the throughput. Therefore, **Figure 11** presents the tradeoff between the packet size in KB and the video streaming quality as a percentage, whereas **Figure 12** shows the tradeoff between the packet size and the average received packets per second.

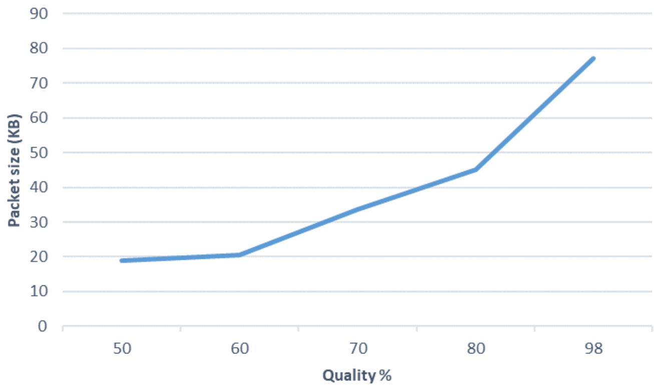

Figure 11. The tradeoff between the packet size and the communication quality.

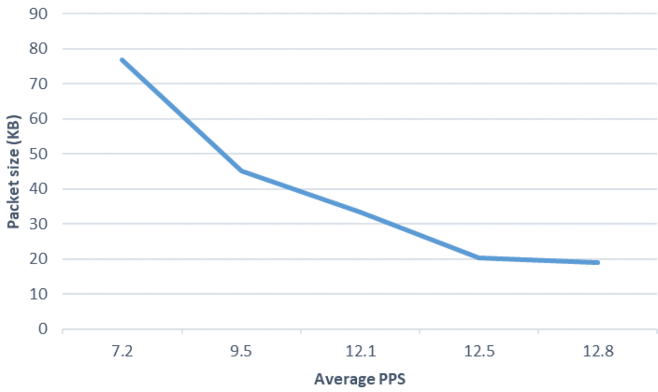

Figure 12. The tradeoff between the packet size and the average received PPS.

To validate the video communication metric, the number of received frames per second was estimated in order to show the video communication efficiency. **Figure 13** presents the total number of frames per second for the period of 30 seconds in each experiment test. The average FPS for test 1, 2, and 3 was around 16, 18, and 18, respectively. The average number of FPS for all three different tests was around 17 FPS; this was enough for two-direction communication transmission.

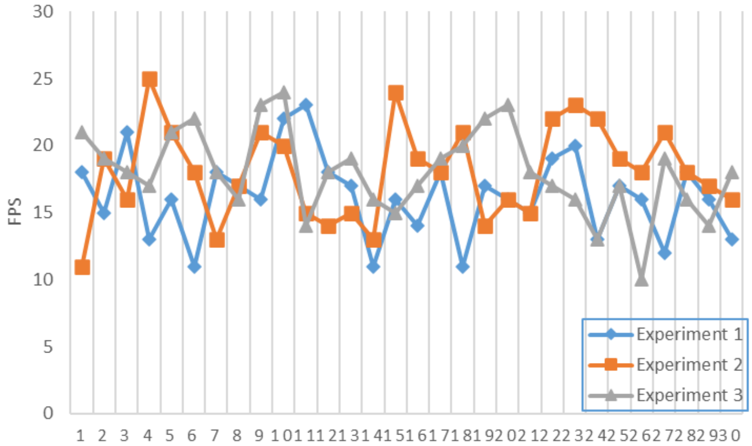

Figure 13. Estimating the number of FPS across three different tests.

Second, the metrics that are relevant to assess user acceptability are discussed. According to this research investigation, no previous work has discussed the usability metrics for assessing the efficiency of teleoperation systems for social robot applications. Therefore, after considering several research works[39,40] that focused on evaluating the usability of mobile applications, a set of evaluation metrics has been introduced, for the purpose of assessing the efficiency of mobile-based social robot applications. The evaluation metrics include: ease of use, perceived usefulness, and comfort. All users received (5–10) minutes training for the purpose of interacting with the developed mobile application.

To assess these parameters, several guided interviews were conducted to get a comprehensive insight into the perspectives of the teleoperation system's users. The total number of users who have been involved in this study, altogether, was 33 (18 male and 15 female), where the mean age was 43.8 years old. After each session, the user was asked to fill out a questionnaire that considered three main parts: user acceptability, ease of use, and reliability; there were 10 different questions about how the parent felt, answered on a five-point Likert scale: 1 (I never do) to 5 (I always do).

The ease-of-use metric refers to how easily the users interacted with the developed teleoperated application. In order to assess the ease-of-use metric, each user was asked to test several remote functions including: control the robot platform, monitor the child's activities and status, communicate with the child through real-time video communication, and test the notification functions. Then, users were asked to fill out the short questionnaire. As presented in **Figure 14**, a ratio of 89.8% of users found the developed teleoperation system easy to use. According to the obtained result, the developed teleoperation system offered attractive and efficient interfaces, where the user could work with the collected data remotely in an easy and reliable manner.

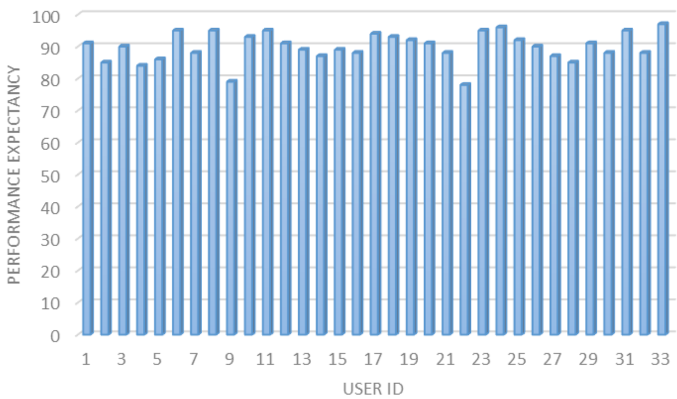

Figure 14. Estimating ease of use for 33 users.

The perceived usefulness refers to how the developed teleoperation system has improved the user's tasks or roles, in terms of effectiveness and efficiency. This has been estimated for all users who were involved in the studies. **Figure 15** shows the perceived usefulness metric for 33 users, with an average of 87.4. This indicates that the developed teleoperation system has significantly enhanced the users' capabilities to achieve certain functions.

In general, it is a very complicated task for a parent to obtain their children's activities without the employment of the teleoperation system. Hence the adoption of the teleoperation system has successfully made this task more comfortable and easier. Similarly, medical assistants need to communicate with diabetic or obese children for the purpose of health advising. This task is inefficient with the use of the traditional communication systems (for instance: phone calls), but the employment of the proposed teleoperation system has allowed medical assistant and parents to communicate with children in a reliable manner.

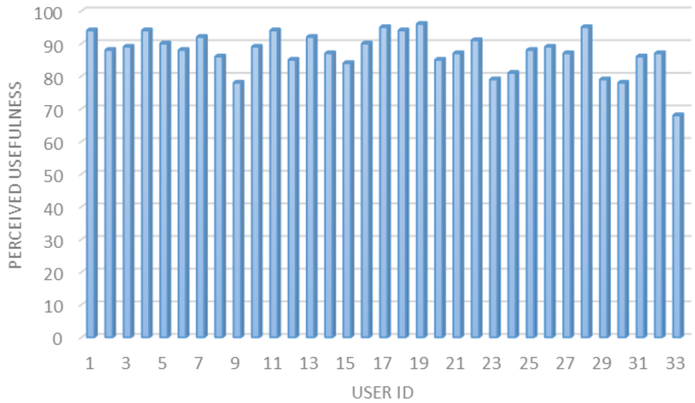

Figure 15. Estimating the perceived usefulness for 33 users.

Finally, the comfort metric refers to how comfortable the user was in accomplishing a certain task or function using the developed teleoperation mobile application. Overall, the results of the data analysis show that most users felt comfort using the developed teleoperation application in terms of access, convenience, and facilitation in interactivities usage, where users achieved 91% success for access different functions and 86.8% for navigation between the developed GUIs. **Figure 16** presents the assessment results of the comfort parameters for 33 users.

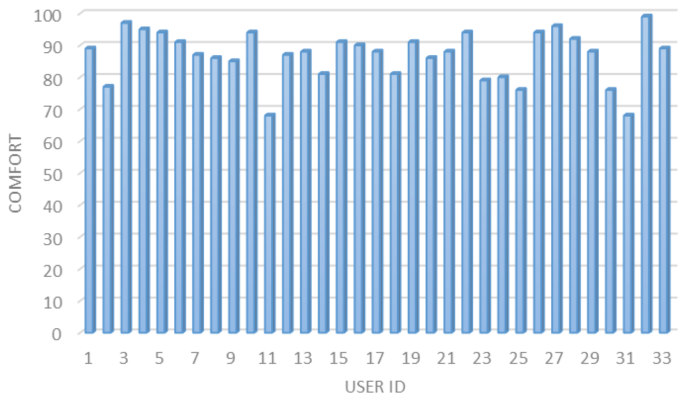

Figure 16. Assessing the comfort parameter for 33 users.

5. Discussion

Recently, with the high development of communication systems and computer networks, teleoperations can be effectively used in home, rehabilitation, and social robots. Teleoperation is a significant and promising area. Recently, the teleoperation of social robot systems has been deployed and tested in various healthcare applications[29,30,32,37]; however, most of the recent systems are developed for one robot platform architecture. Therefore, in this paper, a universal cloud-based teleoperation system has been developed for different robot systems.

Westlund et al.[41] explored the challenges faced by teleoperators through a group of usability tests with a number of expert therapists who had never worked with SARs. The group usability tests uncovered important teleoperation and challenges facing the adoption of SARs in the wild. The authors found that experts needed to protect client-specific information and maintain their own profession boundaries when employing electronic communication methods. Therefore, the system developed in this paper employed a secure cloud architecture system that keeps all health information secure.

The work presented by Elbeleidy et al.[25] revealed that there had been few achievements in teleoperation interface design for social robots in the context of therapy for children. According to the investigation study, only seven research works[27–32,37] focused on developing teleoperation systems for social robots, whereas only four of them[29,30,32,37] concentrated on developing teleoperation systems for healthcare applications specifically. The developed teleoperation systems are either Windows based[29,32], web based[37] or mobile based[32]. Windows-based and web-based remote-control applications are efficient in terms of appearance; however, the user needs to access a computer system to communicate with the child, and this might not be available all the time. Therefore, mobile-based applications are more suitable for social robots.

The remote control of distant social robots necessitates the adoption of a communication protocol to access the robot's system sensors, actuators, and memory. Most of the existing teleoperation systems have been based on the Wi-Fi communication protocol (IEEE 802.11), which allows the social robot to be connected to a cloud server through an Internet connection. However, the integration of other communication protocols (ZigBee, Bluetooth, and RFID) within the developed teleoperation system in this paper is possible due to its design flexibility. Several parameters need to be recorded in a global database (a cloud server, for instance) in order to allow remote users (parents and medical assistants) to access this information. The research works[30,32,37] involved the implementation of efficient teleoperation systems for social robots; however, they lacked cloud databases, which may affect the teleoperation system ability to perform autonomous decision-making tasks.

The virtual reality-based teleoperation systems[33–36] are attractive solutions in terms of appearance and control mechanisms. However, they are complicated solutions for novice users; an intensive training process is required in order for users to be familiar with the robot system[42]. In addition, virtual reality systems require an extra device unit to allow for translating body motion. Therefore, mobile-based applications are more comfortable and easier to use by all users who already have a smart phone, as mobile applications are easy to access anytime and anywhere. The best approach, therefore, is to remotely control the robot using a mobile application. The integration of a mobile application with Firebase cloud services offers a reliable remote-control solution for social robot applications.

Most of the existing teleoperation systems for social robots have been assessed based on either their throughput or control mechanism. However, this paper extends the validation metrics to involve more valuable parameters to fully assess any teleoperation system for social robot applications; this paper proposes a new set of validation metrics that assess both the system performance and the user experience.

The developed teleoperation system has been evaluated using two different case studies: SARA and NAO robot platforms. According to the obtained results in the previous section, there was no significant variance in the performance of employing the developed teleoperation system with NAO and SARA robot platforms.

6. Conclusion & future works

The teleoperation of social robots is a significant issue, though little attention has been paid to this area recently. To fill this gap, this paper developed an efficient teleoperation robotic system that consists of three main subsystems (cloud-based, robot-based, and mobile application), and second, validated the developed system through several real experiments, conducted for two different case studies (on NAO and SARA robots). A mobile application was developed using a cross platform in order to facilitate the usage of such an application for end users. The initial results showed that the adopted technology performs well in real time in terms of remote controlling, providing feedback, and video streaming. For future works, the use of larger data will be addressed, including point cloud in navigation and 3D maps, in order to implement additional cloud robotics applications.

Conflict of interest

The authors declare no conflict of interest.

References

1. Elfaki AO, Abduljabbar M, Ali L, et al. Revolutionizing Social Robotics: A Cloud-Based Framework for Enhancing the Intelligence and Autonomy of Social Robots. Robotics. 2023, 12(2): 48. doi: 10.3390/robotics12020048
2. Perez-Grau FJ, Ragel R, Caballero F, et al. Semi-autonomous teleoperation of UAVs in search and rescue scenarios. 2017 International Conference on Unmanned Aircraft Systems (ICUAS). Published online June 2017. doi: 10.1109/icuas.2017.7991349
3. Zhang D, Yang G, Khurshid RP. Haptic Teleoperation of UAVs Through Control Barrier Functions. IEEE Transactions on Haptics. 2020, 13(1): 109-115. doi: 10.1109/toh.2020.2966485
4. Courtois H, Aouf N, Ahiska K, et al. OAST: Obstacle Avoidance System for Teleoperation of UAVs. IEEE Transactions on Human-Machine Systems. 2022, 52(2): 157-168. doi: 10.1109/thms.2022.3142107
5. González C, Solanes JE, Muñoz A, et al. Advanced teleoperation and control system for industrial robots based on augmented virtuality and haptic feedback. Journal of Manufacturing Systems. 2021, 59: 283-298. doi: 10.1016/j.jmsy.2021.02.013
6. Solanes JE, Muñoz A, Gracia L, et al. Teleoperation of industrial robot manipulators based on augmented reality. The International Journal of Advanced Manufacturing Technology. 2020, 111(3-4): 1077-1097. doi: 10.1007/s00170-020-05997-1
7. Toquica JS, Benavides D, Motta JMST. Web Compliant Open Architecture For Teleoperation of Industrial Robots. 2019 IEEE 15th International Conference on Automation Science and Engineering (CASE). Published online August 2019. doi: 10.1109/coase.2019.8842847
8. Cao HL, Van de Perre G, Kennedy J, et al. A personalized and platform-independent behavior control system for social robots in therapy: development and applications. IEEE Transactions on Cognitive and Developmental Systems. 2018, 11(3): 334-346.
9. Alotaibi M, Alnajjar F, Cappuccio M, et al. Efficacy of Emerging Technologies to Manage Childhood Obesity. Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy. 2022, Volume 15: 1227-1244. doi: 10.2147/dmso.s357176
10. Salichs MA, Castro-González Á, Salichs E, et al. Mini: A New Social Robot for the Elderly. International Journal of Social Robotics. 2020, 12(6): 1231-1249. doi: 10.1007/s12369-020-00687-0
11. Khaksar SMS, Khosla R, Chu MT, et al. Service Innovation Using Social Robot to Reduce Social Vulnerability among Older People in Residential Care Facilities. Technological Forecasting and Social Change. 2016, 113: 438-453. doi: 10.1016/j.techfore.2016.07.009
12. Clark HH, Fischer K. On depicting social agents. Behavioral and Brain Sciences. 2023, 46. doi: 10.1017/s0140525x22002825
13. Alhmiedat T, Marei AM, Messoudi W, et al. A SLAM-Based Localization and Navigation System for Social Robots: The Pepper Robot Case. Machines. 2023, 11(2): 158. doi: 10.3390/machines11020158
14. Alhmiedat T, Alotaibi M. Employing Social Robots for Managing Diabetes Among Children: SARA. Wireless Personal Communications. 2023, 130(1): 449-468. doi: 10.1007/s11277-023-10293-8
15. Alhmiedat T, Alotaibi M. Design and Evaluation of a Personal Robot Playing a Self-Management for Children with Obesity. Electronics. 2022, 11(23): 4000. doi: 10.3390/electronics11234000
16. Opiyo S, Zhou J, Mwangi E, et al. A Review on Teleoperation of Mobile Ground Robots: Architecture and Situation Awareness. International Journal of Control, Automation and Systems. 2020, 19(3): 1384-1407. doi: 10.1007/s12555-019-0999-z

17. Moniruzzaman M, Rassau A, Chai D, et al. Teleoperation methods and enhancement techniques for mobile robots: A comprehensive survey. Robotics and Autonomous Systems. 2022, 150: 103973. doi: 10.1016/j.robot.2021.103973
18. Wu S, Chen Y. Remote robot control using intelligent hand-held devices. In: Proceedings of The Fourth International Conference on Computer and Information Technology, 2004. CIT '04; 16 September 2004; Wuhan, China. pp. 587-592.
19. Cho YC, Jeon JW. Remote robot control system based on DTMF of mobile phone. In: Proceedings of the 2008 6th IEEE International Conference on Industrial Informatics; 13-16 July 2008; Daejeon, Korea (South). pp. 1441-1446.
20. Ju D ying, Zhong R, Takahashi M. Development of Remote Control and Monitor System for Autonomous Mobile Robot Based on Virtual Cell Phone. Second International Conference on Innovative Computing, Informatio and Control (ICICIC 2007). Published online September 2007. doi: 10.1109/icicic.2007.264
21. Do HM, Mouser CJ, Gu Y, et al. An open platform telepresence robot with natural human interface. 2013 IEEE International Conference on Cyber Technology in Automation, Control and Intelligent Systems. Published online May 2013. doi: 10.1109/cyber.2013.6705424
22. Chenxi Z, ZhongHua M, Changxin H, et al. Remote Monitoring System of four-wheel Drive Robot based on Web and Cloud Platform. 2019 IEEE 4th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC). Published online December 2019. doi: 10.1109/iaeac47372.2019.8997696
23. Manzi A, Fiorini L, Limosani R, et al. Use Case Evaluation of a Cloud Robotics Teleoperation System (Short Paper). 2016 5th IEEE International Conference on Cloud Networking (Cloudnet). Published online October 2016. doi: 10.1109/cloudnet.2016.49
24. Kaarlela T, Arnarson H, Pitkäaho T, et al. Common Educational Teleoperation Platform for Robotics Utilizing Digital Twins. Machines. 2022, 10(7): 577. doi: 10.3390/machines10070577
25. Elbeleidy S, Rosen D, Liu D, et al. Analyzing Teleoperation Interface Usage of Robots in Therapy for Children with Autism. Interaction Design and Children. Published online June 24, 2021. doi: 10.1145/3459990.3460715
26. Glas DF, Kanda T, Ishiguro H, et al. Teleoperation of Multiple Social Robots. IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans. 2012, 42(3): 530-544. doi: 10.1109/tsmca.2011.2164243
27. Song S, Baba J, Nakanishi J, et al. Teleoperated Robot Sells Toothbrush in a Shopping Mall: A Field Study. Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. Published online May 8, 2021. doi: 10.1145/3411763.3451754
28. Barbecho-Jimbo E, Vallejo-Ramírez D, Cobos-Torres JC, et al. Remote Operation of CeCi Social Robot. Robotics. 2023, 12(1): 19. doi: 10.3390/robotics12010019
29. Ma Y, Zhang Y, Wan J, et al. Robot and cloud-assisted multi-modal healthcare system. Cluster Computing. 2015, 18(3): 1295-1306. doi: 10.1007/s10586-015-0453-9
30. Ma Y, Xiao D, Li R, et al. Android-based intelligent mobile robot for indoor healthcare. 2015 17th International Conference on E-health Networking, Application & Services (HealthCom). Published online October 2015. doi: 10.1109/healthcom.2015.7454548
31. Zhou B, Chou W, Wu S. Remote control system of mobile robot based on cloud platform. 2017 2nd International Conference on Robotics and Automation Engineering (ICRAE). Published online December 2017. doi: 10.1109/icrae.2017.8291360
32. Laniel S, Letourneau D, Labbe M, et al. Enhancing a beam+ telepresence robot for remote home care applications. 2017 International Conference on Virtual Rehabilitation (ICVR). Published online June 2017. doi: 10.1109/icvr.2017.8007479
33. Sun D, Kiselev A, Liao Q, et al. A New Mixed-Reality-Based Teleoperation System for Telepresence and Maneuverability Enhancement. IEEE Transactions on Human-Machine Systems. 2020, 50(1): 55-67. doi: 10.1109/thms.2019.2960676
34. Li S, Jiang J, Ruppel P, et al. A Mobile Robot Hand-Arm Teleoperation System by Vision and IMU. 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). Published online October 24, 2020. doi: 10.1109/iros45743.2020.9340738
35. Walker ME, Hedayati H, Szafir D. Robot Teleoperation with Augmented Reality Virtual Surrogates. 2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI). Published online March 2019. doi: 10.1109/hri.2019.8673306
36. Liang C, Liu C, Liu X, et al. Robot Teleoperation System Based on Mixed Reality. 2019 IEEE 4th International Conference on Advanced Robotics and Mechatronics (ICARM). Published online July 2019. doi: 10.1109/icarm.2019.8834302
37. Bodala IP, Churamani N, Gunes H. Teleoperated Robot Coaching for Mindfulness Training: A Longitudinal Study. 2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN). Published online August 8, 2021. doi: 10.1109/ro-man50785.2021.9515371
38. Sukmana Y, Rosmansyah Y. The Use of Cloud Firestore for Handling Real-time Data Updates: An Empirical Study of Gamified Online Quiz. 2021 2nd International Conference on Electronics, Communications and Information Technology (CECIT). Published online December 2021. doi: 10.1109/cecit53797.2021.00220

39. Uğur NG, Turan AH. Mobile Applications Acceptance. International Journal of E-Adoption. 2019, 11(2): 13-30. doi: 10.4018/ijea.2019070102
40. Jankowski J, Grabowski A. Usability Evaluation of VR Interface for Mobile Robot Teleoperation. International Journal of Human-Computer Interaction. 2015, 31(12): 882-889. doi: 10.1080/10447318.2015.1039909
41. Elbeleidy S, Mott T, Liu D, et al. Practical Considerations for Deploying Robot Teleoperation in Therapy and Telehealth. 2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN). Published online August 29, 2022. doi: 10.1109/ro-man53752.2022.9900526
42. Westlund JMK, Breazeal C. Transparency, teleoperation, and children's understanding of social robots. 2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI). Published online March 2016. doi: 10.1109/hri.2016.7451888