User Interfaces for Service Robots – Perspectives and Challenges

Georgi Angelov
Institute of Robotics
Bulgarian Academy of Sciences
Sofia, Bulgaria
george@robotics.bg

Yasen Paunski
Institute of Robotics
Bulgarian Academy of Sciences
Sofia, Bulgaria
y.paunsky@ir.bas.bg

***Abstract*—Service robots are becoming an integral part of modern industries, healthcare, homes, and public spaces, requiring user interfaces (UIs) that facilitate seamless interaction between humans and machines. This paper explores the current trends and challenges in designing effective user interfaces for service robots, emphasizing the role of user experience (UX), accessibility, and real-time control. Also the key technical challenges are discussed, including the need for adaptive interfaces that can handle the complexity of robot functionalities while maintaining ease of use. The paper adresses future direction of user interfaces, highlighting the impact of emerging technologies such as distributed computing, VR and AR.**

Keywords—user interface, service robots, UI, UX, robot control

I. Introduction

Service robots are becoming essential across various sectors, such as manufacturing, healthcare, households, and public spaces. Effective user interfaces (UIs) play very important roles in for smooth human-robot interaction, providing intuitive communication channels that allow users, regardless of technical expertise, to easily operate and interact with these machines. This paper examines the types of UIs for service robots, the current trends and challenges in their design, and the future direction of this technology.

As robots take on diverse and complex tasks, UIs must offer intuitive and efficient control while ensuring accessibility and real-time communication. This requires a balance between user-friendly design, robust technical functionality, and adaptability to different user needs. Accessibility is a major consideration, especially when interfaces are designed for individuals with special needs. Developers are exploring various interaction methods, each with its own strengths and challenges, from traditional mechanical controls knobs to cutting-edge technologies such as virtual reality (VR), augmented reality (AR) and brain-computer interfaces (BCIs).

II. Types of Robot User Interfaces

A. Mechanical interfaces / Direct Control Interfaces

Mechanical interfaces, including buttons, switches, knobs, dials, and levers, are among the most traditional forms of UIs used in industrial and manufacturing settings. These interfaces are highly reliable, providing tactile feedback that allows operators to control robotic systems quickly and efficiently, even in harsh environments. Mechanical controls are particularly effective for repetitive tasks, where precision and consistency are critical. However, their limitations in offering complex functionalities require more sophisticated methods for modern service robots handling diverse tasks.

B. Touch Interfaces

Touchscreens have leading role now as they allow for more dynamic and flexible interaction with robots. These interfaces can display visual feedback, menus, and data, providing users with a more comprehensive view of the robot's operations and status. Touch interfaces are widely used in healthcare robots, kiosks, and consumer service robotics, where simplicity and accessibility are key. The ability to program different functions and settings on a single screen makes touch interfaces versatile and scalable. However, challenges such as screen durability, user accuracy, and interface design must be carefully managed to ensure an effective user experience. The emergence of multi-touch technology also allows for gestures, further enhancing interactivity.

C. Web-Based and Mobile Interfaces

Web-based and mobile interfaces are also popular solution as they offer flexibility and remote accessibility. These interfaces enables users to control and monitor robots from virtually any location using web browsers or mobile applications. This is particularly beneficial for applications like fleet management, where multiple robots need to be coordinated across different sites. Web-based UIs enable seamless updates and integration with cloud services, while mobile apps provide on-the-go control with user-friendly touch interfaces using tablets and smartphones. However, these interfaces must address challenges related to device compatibility, network security, data privacy, and latency, especially when critical tasks require immediate response. Practically web and mobile interfaces for service robots are designed to provide a user-friendly and intuitive platform for interaction. They allow users to perform tasks such as starting and stopping robot operations, setting parameters, monitoring robot status, and even troubleshooting issues remotely. The primary goal is to simplify the user experience by presenting clear, interactive, and easy-to-navigate controls. Additionally, these interfaces can be integrated with cloud services to enable real-time data synchronization, allowing the system to access AI services and information and also make decisions based on the latest robot data.

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The design of web and mobile interfaces includes features like:

- Dashboards that display real-time data and alerts.
- Control panels for manual operation and task scheduling.
- Graphical displays for navigation, such as maps or camera feeds.
- User authentication to ensure secure access to robot controls.
- Multi-device compatibility for seamless switching between web browsers, tablets, and smartphones.

On figure 1 is shown an UI developed in IR-BAS for educational robots BeBot and MaxiBot. The interface features manual and semiautonomous control, embedded code editor, where the user can code different scenarios that will be executed by the robot. Also telemetry and access control is implemented.

1. Figure 1: BeBot Web Interface, developed at IR-BAS

D. Voice Interfaces

Voice User Interfaces (VUIs) enable users to interact with robots using natural language, making them ideal for applications where hands-free control is beneficial, such as in healthcare, elder care, kiosk applications and customer service. These interfaces leverage advanced speech recognition and natural language processing (NLP) to interpret commands and respond appropriately. One of the key advantages of VUIs is their ability to simplify interaction, especially for users who may not be comfortable with more technical controls. However, voice interfaces face challenges related to speech recognition accuracy, noise interference, diarization errors and understanding of the context. The development of adaptive systems that can learn user-specific speech patterns, accents, and contextual cues is essential for improving the reliability and effectiveness of voice-controlled robots.

E. Gesture-Based Interfaces for Service Robots

Gesture-based interfaces are an innovative method of interacting with service robots, utilizing cameras and sensors to track and interpret human body movements as commands. This form of control provides a natural, intuitive way for users to communicate with robots, making it especially useful in scenarios where hands-free operation or remote guidance is needed. By leveraging computer vision and motion detection technologies, gesture-based interfaces can enable service robots to understand and respond to a wide range of human gestures, from simple hand signals to complex body movements.

Design and Functionality of Gesture-Based Interfaces

Gesture-based interfaces rely on a combination of cameras, depth sensors, and specialized software algorithms to interpret human gestures. The camera captures images or videos of the user, and the software processes these inputs to recognize specific gestures and translate them into robot commands. Depth sensors, such as Microsoft Kinect or Intel RealSense, help to accurately detect the position and motion of a user's hands and body in three-dimensional space. This is particularly useful for differentiating between gestures and filtering out background noise or irrelevant movements.

Key components of gesture-based interfaces include:

1. Camera and Depth Sensors: These devices capture real-time video and depth data, allowing the system to accurately detect and track movements. Multiple cameras can be used for a wider field of view or to capture movements from different angles.
2. Computer Vision Software: Advanced computer vision algorithms process the input data to recognize patterns and identify gestures. This often involves machine learning techniques, where the system is trained on a dataset of different gestures to improve accuracy.

Figure 2 shows IR-BAS implementation of full body gesture interface using Orbec Astra depth camera. It can detect full body position and hand gestures that can be used to control an robot via web REST API.

2. Figure 2: OrbecAstra Depth Camera Based Gesture Interface at IR - BAS

There are following common types of visual control mechanisms used in the gesture interfaces:

- **Hand Gestures:** Hand gestures are the most common form of gesture-based control for service robots. Simple hand movements such as waving, pointing, or signaling "stop" can be easily recognized and mapped to corresponding commands. More complex gestures can involve finger movements, such as pinching or swiping, to control robot actions like zooming in on a camera feed or selecting items from a virtual menu.
- **Full-Body Gestures:** Full-body gestures involve using the entire body to interact with the robot. This can include actions like stepping forward to signal the robot to follow or raising an arm to draw its attention. Full-body gestures are particularly useful in environments like warehouses or healthcare settings, where operators

may need to control robots without using their hands, for example, while carrying objects.

- **Facial Gestures and Eye tracking:** While less common than hand or body gestures, facial expressions can also be used as part of a gesture-based interface. For instance, a nod or a shake of the head could signal agreement or disagreement, or a smile could trigger a robot to perform a friendly greeting. Facial gesture recognition, however, requires more sophisticated software to accurately interpret subtle expression.

F. Virtual Reality (VR) and Augmented Reality (AR) Interfaces

Virtual Reality (VR) interfaces provide immersive control and monitoring environments for service robots, allowing users to interact with 3D models and visualizations of robot tasks in real time.

By using VR headsets and motion controllers, operators can navigate, manipulate, and supervise robots in complex environments, making it easier to handle intricate tasks like remote surgery, maintenance, or industrial inspections.

VR interfaces also enable training simulations, where users can practice controlling robots in a safe, virtual setting before deploying them in real-world scenarios. Example of monitor based VR based interface is shown on fig.3. It is used for training in Quasar centre of competence - Bulgaria.

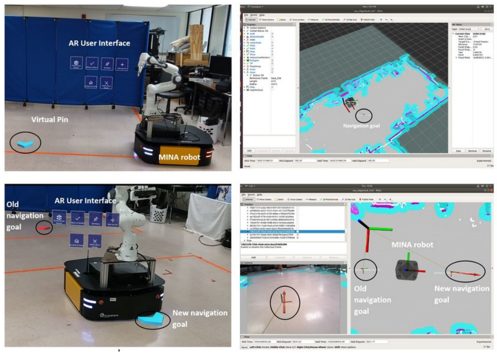
3. Figure 3: VR Interface at Quasar Centre of Competence

AR interfaces are an emerging technology that integrates digital information with the user's physical environment, providing a more immersive and interactive experience.

For service robots, AR can enable users to visualize data, control panels, and interactive elements overlaid on the robot or surrounding objects. This makes complex tasks easier by providing step-by-step guidance, real-time diagnostics, and contextual information.

AR can also enhance training and maintenance procedures by allowing users to see internal components and operational data without physical disassembly. However, the successful deployment of AR interfaces requires high-performance hardware, robust sensor integration, and low-latency network communication to ensure real-time interaction.

A good example is project - MINA a robotic assistant designed to autonomously fetch and deliver items within hospital environments. It is developed in University of Texas at Arlington - USA. It is proposed to assist nurses with everyday object fetching tasks. MINA consists of a manipulator arm on an omni- directional mobile base. Before the operation, an augmented reality interface was used to place waypoints - fig.4 .



4. Figure 4: MINA: A robotic Assistant for Hospital Fetching Tasks

Equipped with advanced SLAM navigation and object recognition capabilities, MINA can locate and transport supplies, medication, or equipment to specified locations, reducing the workload on hospital staff.

G. Brain Interfaces

Emerging technologies are paving the way for more innovative and specialized UIs, such as Brain-Computer Interfaces (BCIs). BCIs enable direct communication between the user's brain and the robot, bypassing traditional input devices. This technology holds promise for individuals with mobility impairments, allowing them to control robots using thought alone.

BCIs can detect neural signals associated with specific thoughts or intentions and translate them into commands, offering a revolutionary approach to human-robot interaction. Despite the potential, BCIs are still in experimental stages and face challenges related to signal interpretation, accuracy, and the need for non-invasive, user-friendly systems.

III. Real-Time Control and Adaptive Systems

A. Real Time control

Real-time control is essential for service robots performing tasks that demand immediate response, such as in healthcare setups where patient safety is a priority. To achieve this, UIs must be designed with minimal latency, enabling swift and accurate communication between the user and the robot.

This necessitates the integration of robust communication protocols and adaptive feedback systems that can adjust to varying conditions and user inputs in real time. Adaptive interfaces are critical as they allow the robot to modify its behavior based on real-time feedback from the user or environment, enhancing efficiency and user satisfaction.

B. Network Communication Challenges and Latency

Effective user interfaces for service robots require robust and reliable network communication. One of the primary challenges is addressing network latency, which can significantly impact real-time control, especially in applications requiring instantaneous feedback. Traditional cloud computing models normally introduce delays due to the time taken to send and receive data from remote servers. To mitigate this fast broadband and mobile 5G networks are a requirement.

Another promising approach is local inference using Large Language Models (LLMs) on edge devices, allowing robots to process complex commands and contextual information without relying on continuous cloud access. This hybrid model of edge computing and local inference ensures robust performance while maintaining the benefits of cloud integration for updates and data storage. However, designing such systems also presents challenges related to energy consumption, computational power, and data synchronization across devices.

IV. Conclusion

The design and development of user interfaces (UIs) for service robots represent a critical component of human-robot interaction, shaping how effectively and efficiently users can control and communicate with these machines. As service robots integrate into diverse sectors, from healthcare to industrial automation, the demand for intuitive, adaptable, and robust UIs continues to grow. This paper has explored various types of UIs, highlighting their respective advantages, challenges, and applications.

The future of robot UIs is poised to be influenced by advancements in technologies such as machine learning, edge computing, and AR, which promise to make interactions more seamless, intelligent, and context-aware. However, significant technical challenges persist, particularly in achieving real-time responsiveness, maintaining secure communication channels, and ensuring usability across diverse user demographics, including people with special needs. Innovations in UI design must focus on reducing latency, enhancing adaptability, and integrating sophisticated machine learning algorithms that can learn and predict user behavior, thus enabling more personalized and efficient robot control.

For educational robotics, developing accessible UIs that simplify programming and operation is essential to encourage learning and engagement, while in fields such as healthcare, the priority lies in creating interfaces that are secure, reliable, and capable of facilitating complex, life-critical tasks.

Gesture-based and voice interfaces will play an increasingly prominent role in enhancing the accessibility of robots, especially for individuals with disabilities, while AR and BCI technologies could redefine the limits of human-robot interaction by providing immersive and direct communication pathways.

Ultimately, the evolution of UIs for service robots must address the fundamental need for safety, reliability, and user-centered design. Continued interdisciplinary research and collaboration will be essential to address the technical and design challenges, ensuring that service robots can be effectively integrated into real-world applications. As the field advances, the focus should remain on developing UIs that are not only technologically sophisticated but also inclusive, intuitive, and capable of meeting the nuanced requirements of varied user groups.

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