Re-engineering EBO: Advancing Social Robotics for Enhanced Care

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Abstract. This paper outlines the redesign process of the social robot EBOv2, an evolution of the EBO robotics platform. The original version of EBO has been used in various applications, from promoting computational thinking in educational settings to providing cognitive therapy for older adults. The redesign of EBOv2 aims to meet today's needs by incorporating state-of-the-art hardware and a new casing. EBOv2 features differential navigation hardware, an upgraded screen for expressive emotional display, microphones and speakers for personalized user interaction, and optimized components to enhance overall performance. The main goal is to improve the user experience and the robot's versatility for widespread use in occupational therapy, assistance for older adults, and managing neurodegenerative diseases. This article details the co-creation process of EBOv2, focusing on key hardware design aspects, component selection and integration, aesthetic casing design, and comprehensive system integration. Additionally, a group of occupational therapists evaluated the new physical redesign of the robot. This evaluation involved surveys designed by experts in the field to assess the robot's functionality, user acceptance, and overall impact on future therapeutic outcomes. The results highlight significant improvements in the acceptance of the new robot platform, underscoring its potential for broad application in therapeutic and assistive contexts.

Keywords: Social Robotics, Robotics Redesign, Educational Robotic, Prototype generation, Elderly assistance

1 Introduction

As the global population of older adults grows, there is an increasing demand for treatments tailored specifically to their needs. Social robots have emerged as a promising solution, designed to interact with humans in social and therapeutic contexts, providing companionship, entertainment, and support. These robots have effectively delivered therapeutic benefits to older adults [3]. However, traditional approaches often face limitations in personalization, interaction, and engagement.

To address these challenges, social robots must have advanced capabilities to facilitate personalized interactions. This includes enabling the robot to engage in natural conversations with each user, understand and respond to their needs and preferences, and provide affective responses. Such capabilities can significantly improve therapeutic outcomes and the overall user experience. This paper presents the hardware redesign process of the social robot EBOv2 to integrate these new capabilities. EBOv2 is an evolution of the EBO robotics platform, which has been utilized in various applications, ranging from promoting computational skills in educational settings to providing cognitive therapy for older adults.

Originally, EBO was designed for limited interaction capabilities; nevertheless, it has been positively utilized in therapies with older adults [13]. EBO used the CORTEX architecture in its latest version to facilitate personalized interactions. It utilized a series of software agents that maintained an engaging and tailored conversational flow using Large Language Models (LLMs). However, the interaction was constrained by the hardware of the original platform, which was designed a decade ago.

The redesign of EBOv2 aims to meet current needs by incorporating state-of-the-art hardware and a new casing. To address the evolving requirements of the EBO robot, several specific needs were identified in a co-creation process: i) the integration of sensors necessary for occupational therapy activities; ii) a larger screen to facilitate use by older adults; iii) a modular design that separates the base from the body to improve access to components; and iv) a uniform finish to enhance aesthetic appeal. EBOv2 features differential navigation hardware, an upgraded screen for expressive emotional display, advanced microphones and speakers for personalized user interaction, and new components to enhance overall performance. These requirements formed the foundation of the redesign process, guiding the selection of features and design elements to enhance the robot's functionality and usability. The main goal of this redesign is to improve the user experience and the robot's versatility for widespread use in personalized cognitive therapies for older adults.

This article details the co-creation process of EBOv2, emphasizing critical aspects of hardware design, component selection and integration, casing design, and overall system integration. Furthermore, a group of occupational therapists has evaluated the new physical redesign of the robot using surveys developed by experts to assess the new embodiment of EBOv2 and its impact on users. The results demonstrate substantial interest in the new redesign, significant improvements in user acceptance, and the anticipated ease of use of the updated robotic platform in therapeutic and care settings.

This article is organized as follows: After this brief introduction, Section 2 reviews related works, focusing on the use of social robots in cognitive therapy for older adults and the challenges they face, including the Uncanny Valley phenomenon and the importance of robot design for user engagement. Section 3 provides a detailed overview of the original EBO robot, including its hardware and software components and its application in therapeutic contexts. Section presents the redesign of EBOv2, discussing the co-creation process with engineers and occupational therapists, the new hardware components, and the aesthetic improvements in its casing. Section details the evaluation process of EBOv2 by occupational therapists, highlighting the improvements in user acceptance and usability based on survey results. Finally, Section concludes the paper, summarizing the key findings and discussing future work to enhance further the EBOv2 platform for broader application in therapeutic and assistive contexts.

2 Related Works

The use of social robots in cognitive therapy for older adults has been explored in the last decades, with various studies demonstrating their effectiveness in enhancing cognitive functions, reducing depression, and alleviating loneliness. For instance, the study in [2] evaluated the Paro robot, a seal-shaped therapeutic robot, in an Italian Alzheimer's day center. The findings highlighted significant improvements in patients' perceived quality of life when the Paro robot was integrated with usual care, underscoring the potential of social robots in non-pharmacological interventions for dementia. Similarly, in [9], the authors demonstrate the positive impacts on cognitive function, depression, and loneliness among older adults living alone. The intervention used a quasi-experimental design to show significant improvements, reinforcing the therapeutic benefits of social robots. Additionally, the work in [7] investigates the effectiveness of the socially assistive robot Hyodol, finding significant reductions in depression and improvements in cognitive functions among older adults with mild cognitive impairment. Moreover, our study [13] evaluates the earlier version of the EBO robot, demonstrating its positive impact on the interaction and engagement levels of patients with mild to moderate cognitive impairment, further confirming the potential of social robots in therapeutic contexts.

The Uncanny Valley phenomenon, first described by Mori in [11], refers to the discomfort people feel when confronted with robots that appear almost human but not quite. This phenomenon is interesting in the design of social robots, as it impacts their acceptance and effectiveness. Research indicates that robots with a mascot-like appearance, which are less likely to fall into the Uncanny Valley, generally achieve higher acceptance and evoke more positive emotional responses from users. For instance, the work in [1] found that human-like robots often evoke negative emotional responses, hindering their effectiveness in therapeutic settings. Conversely, robots designed with a more friendly, non-humanoid appearance tend to avoid the eerie feeling associated with the Uncanny Valley and are more readily accepted by users. Our original EBO robot addressed the Uncanny Valley phenomenon by adopting a non-humanoid, friendly design [13]. This approach helps avoid the Uncanny Valley and promotes a sense of comfort and control among users. By prioritizing a mascot-like appearance, EBO enhanced its effectiveness in interacting with humans, particularly in therapeutic contexts. In this paper, the new EBOv2 design ensures that the robot can provide emotional support and companionship without eliciting discomfort, making it more suitable for use in occupational therapy, assistance for older adults, and managing neurodegenerative diseases.

The appearance of social robots plays a critical role in user engagement. In [5], the authors highlight that social robots' embodiment and physical design significantly influence user experience and engagement. Their findings suggest that incorporating expressive gestures and a user-friendly interface enhances the quality of interaction between humans and robots. The authors in [8] demonstrate that the robot's appearance plays a crucial role in therapy protocols, indicating that user engagement and therapeutic outcomes are significantly influenced by the robot's design. In the work presented in [10], the authors affirm that social robots can be categorized into several types: socially evocative, socially situated, sociable, socially intelligent, and socially interactive. The level of development of each one of them directly influences user engagement. Therefore, EBOv2 falls under the socially intelligent robots, designed to exhibit human-like social intelligence through advanced human cognition and social competence models. The redesign of EBOv2 focuses on enhancing user engagement by incorporating a larger screen for expressive emotional display, which is particularly beneficial for older adults. This feature, combined with speakers and microphones to facilitate personalized affective interaction, further improves the robot's usability and acceptance.

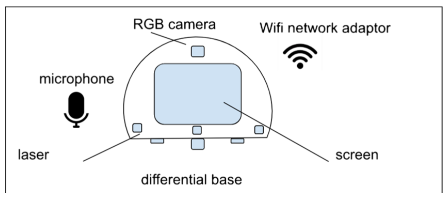
Finally, social robots should possess the capabilities to interact with affection and empathy during therapy, including understanding and responding to users' emotional states. In the work [12], the author demonstrates that simple emotional gestures in socially assistive robots can significantly increase user engagement and reduce anxiety in medical settings. Similarly, in [4], the authors explore how robot posture and idle motion affect emotional contagion during human-robot interactions, highlighting the importance of affective design in user perception. The EBOv2 redesign incorporates these advanced interaction capabilities at the hardware level, combined with the CORTEX architecture agents [6], ensuring that this robot can meet the diverse emotional and cognitive needs of older adults in various therapeutic settings.

3 EBO: a social robot for therapy with older adults

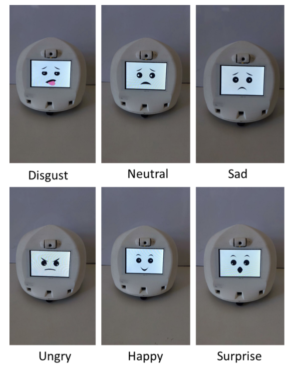
This section provides a comprehensive overview of the EBO platform, a social-care robot designed by the RoboLab research group at the University of Extremadura. It builds upon its predecessor, the LearnBot, which was initially developed by the same group in 2005 and serves as a foundational model in educational robotics. The original LearnBot, depicted in Figure 1a, operates on the Odroid-C1 hardware platform and has various sensors and actuators. These include four ultrasonic sensors, a fixed camera, and a differential base, all integral to its functionality.

Figure 1c presents a schematic diagram alongside various real images of the EBO robot, showcasing its design and visual characteristics. These images illustrate how the EBO robot displays different emotions on its screen, highlighting its interactive capabilities.

(a) The LearnBot, predecessor of the EBO social robot



(b) EBO sensors and actuators.



(c) The EBO social-care robot with device schematic and facial expressions for basic emotions.

Fig. 1: LearnBot and original EBO.

3.1 Hardware components

The original EBO robot was carefully designed on a differential platform, integrating various devices to facilitate environmental perception and expressive capabilities. These features include emotional expressions, image displays on its screen, and physical attributes such as shape, voice modulation, and facial expressions. To ensure that the robot meets the needs and preferences of its intended users—older adults and healthcare professionals—their feedback was actively solicited during the development process. Collaborative meetings and working sessions were conducted to integrate their valuable insights and preferences.

To optimize user acceptance, the external structure of the EBO social-care robot was designed using a prototyping approach. This iterative process enabled continuous refinement based on user feedback. Consequently, the original EBO robot features a sleek, visually appealing design, as shown in Figure 1, where its plastic shape is highlighted. With a diameter of less than 15 cm and a weight of under one kilogram, the EBO robot is compact and lightweight, enhancing its portability and usability.

The EBO robot incorporated hardware components in its original version, specifically focused on therapeutic applications with older adults.

3.2 Software Components: CORTEX architecture

The EBO robot's control software comprises several integral agents that enhance its functionality and interaction capabilities. These software elements manage the physical devices, generate emotional expressions, facilitate human-robot interaction, and display visual information on the robot's screen. In its original version, EBO uses the CORTEX cognitive architecture [6].

– The *Navigation agent* regulates the robot's forward and rotational movements. It processes commands corresponding to different emotions, allowing the robot to display unique movement patterns that reflect each emotional state. This feature enhances the robot's expressiveness and enables it to adapt its behavior during therapy sessions.
– The *Laser agent* interprets data from the laser sensors to detect potential obstacles and ensure safe navigation. The robot can move safely and reliably by continuously monitoring its environment, fostering a secure interaction setting.
– The *RGB Camera agent* manages the servomotor of the camera and employs facial detection algorithms to track users' faces and capture their expressions during therapy. This capability allows the robot to respond effectively to users' emotional cues, promoting a more engaging and personalized experience.
– The *Facial Expression agent* is vital for generating the robot's emotional expressions. Utilizing various algorithms and models, this component enables the EBO robot to display basic emotions, enhancing its ability to convey empathy and form emotional connections with users.
– The *HRI (Human-Robot Interaction) agent* enables communication between the EBO robot and its users. It employs Automatic Speech Recognition (ASR) and Text-to-Speech (TTS) algorithms to facilitate speech-based interactions throughout therapy sessions, improving the robot's communication capabilities and ensuring appropriate audio responses.

Upon activation, the EBO robot establishes a local WiFi network that connects it with other interaction components. While designed for autonomous operation, the robot supports teleoperation via an intuitive interface. The EboTalk tool implements a predefined protocol to ensure seamless communication, but it is crucial that the dialogue flow can be modified during supervision. The interface must also support the transmission of emotions and subtle movements, enriching the dialogue with emotional elements.

4 EBOv2: a redesign of a social robot

The redesign of EBOv2 aims to enhance the functionality, usability, and user experience of the original EBO robot. This new iteration addresses today's needs by incorporating advanced hardware components and a user-friendly design. The goal is to create a more effective and versatile robot that can be widely used in occupational therapy, assistance for older adults, and management of neurodegenerative diseases.

The development process of EBOv2 involved two co-creation sessions with both engineers and occupational therapists from the research team as well as various senior centers. These sessions were pivotal in identifying key requirements and ensuring the robot's design met the specific needs of its intended users. The engineers focused on integrating state-of-the-art hardware, while the occupational therapists provided their expertise on the practical applications of the robot and the interaction needs required for it.

EBOv2 was presented in workshops with older adults and occupational therapists to refine the design further[1]. These sessions provided feedback on the robot's appearance, functionality, and overall user experience. Participants interacted with various prototypes and provided their opinions on the physical design, including the casings' shape, size, and aesthetic appeal.

These workshops and co-creation stages revealed preferences and suggestions from the end-users, which were then incorporated into the final design. The feedback highlighted several key aspects: the importance of a compact and lightweight form factor, a larger high-resolution screen to display emotions better and facilitate interaction, enhanced microphones and speakers to improve communication and interaction quality, and the need for a user-friendly interface that older adults could easily navigate, preferably through voice commands.

4.1 Hardware components

This section will define four types of elements: controller, actuators, sensors, and power supply, which are described below.

Controller EBOv2 has an Jetson Xavier NX as a controller due to its AI and machine learning capabilities and energy efficiency, essential for real-time image processing, emotion detection, and extended operational time. Its GPIO ports provide flexibility for integrating various sensors and actuators, facilitating seamless communication between components. Additionally, the robust development ecosystem from NVIDIA supports rapid implementation and optimization of AI applications. The scalable architecture of the Jetson Xavier NX allows for future upgrades, ensuring the long-term viability and adaptability of the EBOv2 robot.

Actuators Among the actuators that will enable human-robot interaction are:

- The differential wheels ensure smooth and fluid movement of the robot.
- LED lights, model WS2812B, this type of LED allows for individual RGB interaction, enabling the display of complex and dynamic patterns or interactions to express emotions or actions.

[1] Generación Silver: Avances en Robótica Asistencial e Inteligencia Artificial, Cáceres, Spain, may-2024

- 7-inch touch screen with speaker, the increased screen size facilitates viewing items or substitutes in case of hearing difficulties, adding the complement of touch interaction.

Sensors The sensors for observing the external word are:

- Lidar VL6180X, with 5-200 millimeters, this sensor helps the robot avoid obstacles.
- RGB sensor TCS34725, located at the bottom of the robot, to carry out exercises in educational robotics, such as line following or color differentiation.
- RGB camera with 130 degrees FOV on the front, to human and object recognition.
- Microphone omnidirectional array XVF-3000 to speech recognition.

Power supply The electrical requirements for EBOv2 include ensuring an effective autonomy of at least 4 hours and powering the hardware elements of the robot, which have an average consumption of 35W and a peak consumption of up to 60W. To meet these demands, the system is equipped with one 5V power bus for the LEDs and one 9V power bus for the motors and the controller, as the controller operates within a range of 9-19V. The controller's power supply is connected to the 9V source, reducing material costs and saving space. Considering these requirements, the following components have been selected to fulfill these needs:

- 144 Watts, 24 volts Li-ion battery. This battery provides the necessary power for the robot's operations.
- 5 Amperes fuse to ensure safety by protecting the electrical components from overcurrent.
- Converter 24 volts to 9 volts and 5 volts to adapt the voltage from the battery to the required levels for different robot components.

This ensures that the electrical demands are met and allows for the implementation of modern systems without concerns about the power supply.

Appendix A shows the electrical schematic developed for this purpose.

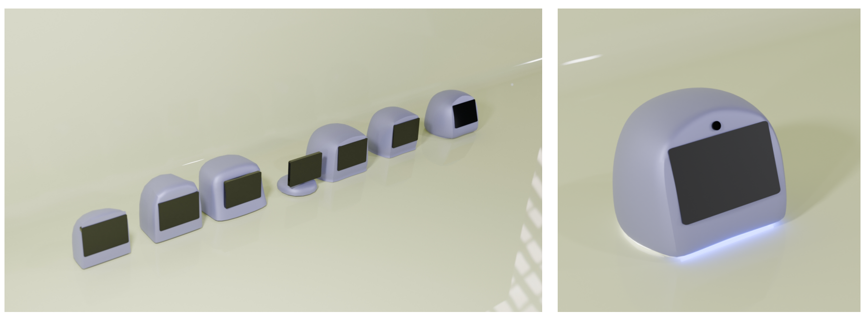
4.2 Software Components

The software components of the EBOv2 robot remain largely unchanged, as the existing software developed for the CORTEX architecture is fully compatible with this new version. This continuity ensures that all previously developed functionalities and interaction capabilities are preserved and optimized for the EBOv2 platform.

4.3 Body Design

The design philosophy of EBOv2 focuses on creating a functional and emotionally engaging robot. The robot's appearance is crucial in its acceptance and effectiveness, particularly in therapeutic and educational settings. The body design process incorporates several key elements to achieve this balance:

Prototyping Process Initially, rapid prototyping was conducted to explore and refine key concepts for the robot's body design. This phase involved creating multiple prototype versions to visualize different design ideas and assess their feasibility. As shown in Fig. 2, the initial prototypes (Fig. 2a) facilitated the iterative process of experimenting with various shapes and forms. Feedback from these iterations gathered through co-creation sessions with engineers, occupational therapists, and older adults was instrumental in refining the design. The final prototype (Fig. 2b) was selected based on its adherence to the original design's friendly and approachable appearance, aesthetic suitability, ease of use, and overall user acceptance. This collaborative and iterative design process ensured that the EBOv2 met technical specifications and addressed its intended users' practical needs and preferences.



(a) Shapes Iteration (b) Final prototype

Fig. 2: Prototypical versions of the new EBO design

Figure 3 shows two versions of the new EBO robot from different views. These two versions have been evaluated in the Results section.

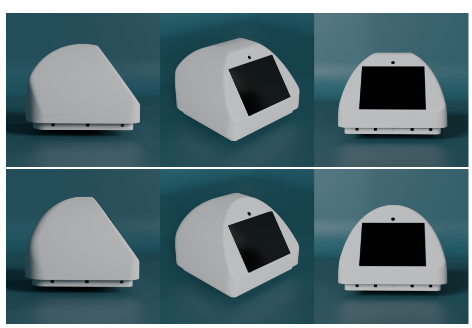


Fig. 3: Possible final versions of EBOv2 design

5 Evualuating the EBOv2 social robot

The final design was chosen based on its ability to meet all necessary design requirements while closely adhering to the structure of the original EBO robot. This version ensures that the new EBO remains recognizable and retains the qualities that made the original design successful.

In this phase of the design process, we sought to validate the new design by surveying occupational therapists. Forty occupational therapists working with older adults were selected for the survey. A Likert-type questionnaire encompassed various aspects such as the robot's general appearance, shape, color, and usability in their therapies. The results are presented in Figures 4 and 5.

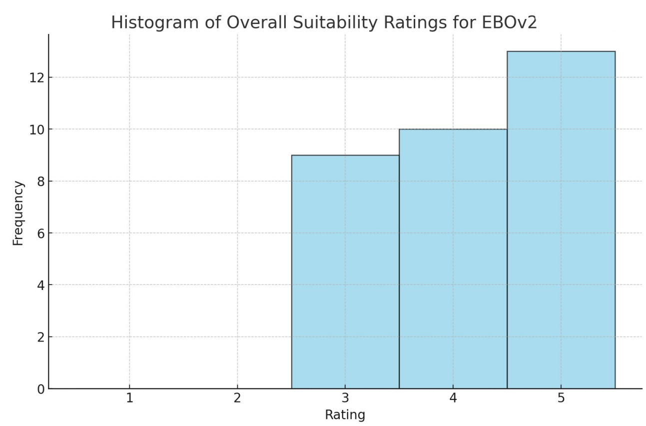


Fig. 4: Survey results validating EBOv2 design

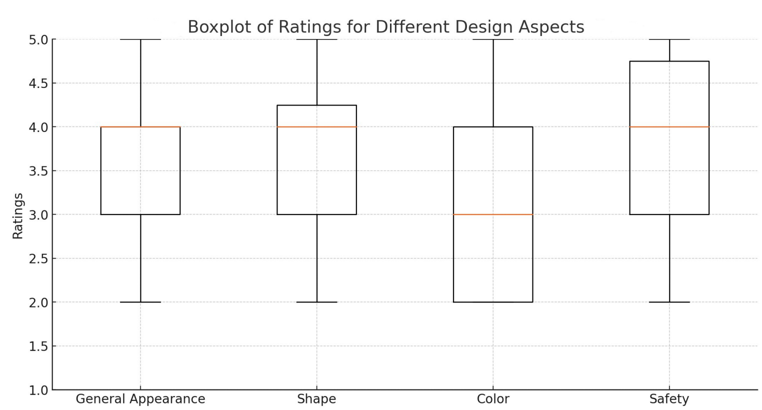


Fig. 5: Points for improvement highlighted by therapists

The survey analysis indicated strong therapist validation, as shown in Figure 4. Therapists particularly appreciated the robot's familiar and approachable design, essential for user acceptance. Additionally, specific points for improvement were highlighted, as shown in Figure 5, providing valuable insights for further refinement of the robot. This feedback underscores the importance of user-centered design and continuous iteration to ensure the robot meets its users' practical needs and preferences.

Therapists' evaluations of specific aspects of the EBOv2 design showed that while the general appearance, shape, and sense of security were positively received, the chosen color received neutral feedback.

5.1 Comparison

The evolution of the EBO robot, as illustrated in Table 1, highlights significant advancements in technology and design from the original LearnBot to the new EBOv2.

Aspect	**LearnBot**	**EBO Original**	**EBOv2**
Controller	Odroid-C1	Raspberry PI 3	Jetson Xavier NX
Sensors	4 ultrasonic sensors	4 single-point LiDAR and Microphone	10 single-point LiDAR and Microphone Array
Movement	Differential base	Differential base	Differential base
Vision	Fixed camera	Mobile camera	Fixed wide-angle camera
HRI	Movement	Movement, sound and 3" screen	Movement, sound, 7" screen and LED lights
Programming Interface	Robocomp	Robocomp and LearnBlock	Robocomp and LearnBlock
Simulation Support	No	RCIS	Webots with Robocomp framework
Materials and Manufacture	3D printed using PLA	3D printed using PLA	3D printed using Recicled PLA

Table 1: Comparison between LearnBot, EBO Original, and New EBO

One of the most notable upgrades is in the controller. The transition from the Odroid-C1 in LearnBot to the Raspberry PI 3 in the original EBO and finally to the Jetson Xavier NX in EBOv2 reflects a substantial increase in computational power and capabilities. This progression allows EBOv2 to perform more complex tasks, including advanced AI and machine-learning applications for human-robot interaction during therapies.

In terms of sensory capabilities, EBOv2 demonstrates a marked improvement. The original LearnBot's reliance on four ultrasonic sensors has been replaced by a more sophisticated array of sensors in the later models. The original EBO incorporated four single-point LiDAR sensors and a microphone, while EBOv2 features an enhanced setup with ten single-point LiDAR sensors and a microphone array. This significant upgrade enhances the robot's environmental perception and interaction quality, making it more adept at navigating complex environments and understanding auditory cues.

Furthermore, the human-robot interaction capabilities have been expanded. While the LearnBot was limited to basic movement, the original EBO included movement, sound, and a 3" screen; the EBOv2 included a 7" screen, and LED lights on the bottom of the robot. These additions significantly enhance the robot's ability to convey emotions and information, providing a richer, more engaging user experience. Additionally, EBOv2's vision system now includes a fixed wide-angle camera, improving its ability to capture and process visual information compared to the mobile camera of the original EBO.

The programming interface and simulation support have also seen advancements. The consistent use of Robocomp and LearnBlock provides a robust platform for developing and testing new applications. However, transitioning from RCIS to Webots with the Robocomp framework for simulation support in EBOv2 offers more advanced and realistic simulation capabilities, facilitating better preparation and testing of the robot's functions before deployment.

Finally, EBOv2's commitment to sustainability is reflected in its use of recycled PLA for 3D printing, compared to the PLA used in earlier models. This reduces environmental impact and aligns with growing trends in eco-friendly manufacturing practices.

6 Conclusions

In this work, we have explored the iterative design process of the EBO robot, highlighting its evolution from the LearnBot to the original EBO and finally to the new EBOv2. Our primary objective was to maintain the core principles and design features that contributed to the success of the original EBO while incorporating necessary advancements to meet current user needs and technological standards.

The process began with rapid prototyping to visualize and assess various design ideas. This phase allowed us to quickly iterate and refine the robot's body design, ensuring it remained friendly and approachable. By engaging occupational therapists in the evaluation process, we obtained valuable feedback on the design's applicability and effectiveness within its intended deployment context. The feedback validated the new design while pointing out improvement areas and guiding our final adjustments.

Through the comprehensive comparison of LearnBot, the original EBO, and the new EBOv2, we demonstrated significant improvements in hardware, programming interface, simulation support, and HRI. EBOv2 not only builds upon the strengths of its predecessors but also introduces enhanced accessibility and aesthetic features, which are crucial for its role as a socially intelligent robot. In this way, EBOv2 represents a balanced blend of innovation and tradition. It respects the validated design of its predecessor while addressing modern requirements and user expectations. This thoughtful evolution ensures that EBO continues to be an effective and engaging tool in educational and therapeutic settings, fostering positive human-robot interactions and enhancing the overall user experience.

The successful integration of feedback and iterative design has resulted in a functional, practical, appealing, user-friendly robot. As we continue to develop and refine social robots like EBO, the insights gained from this project will inform future innovations and contribute to the growing field of human-robot interaction.

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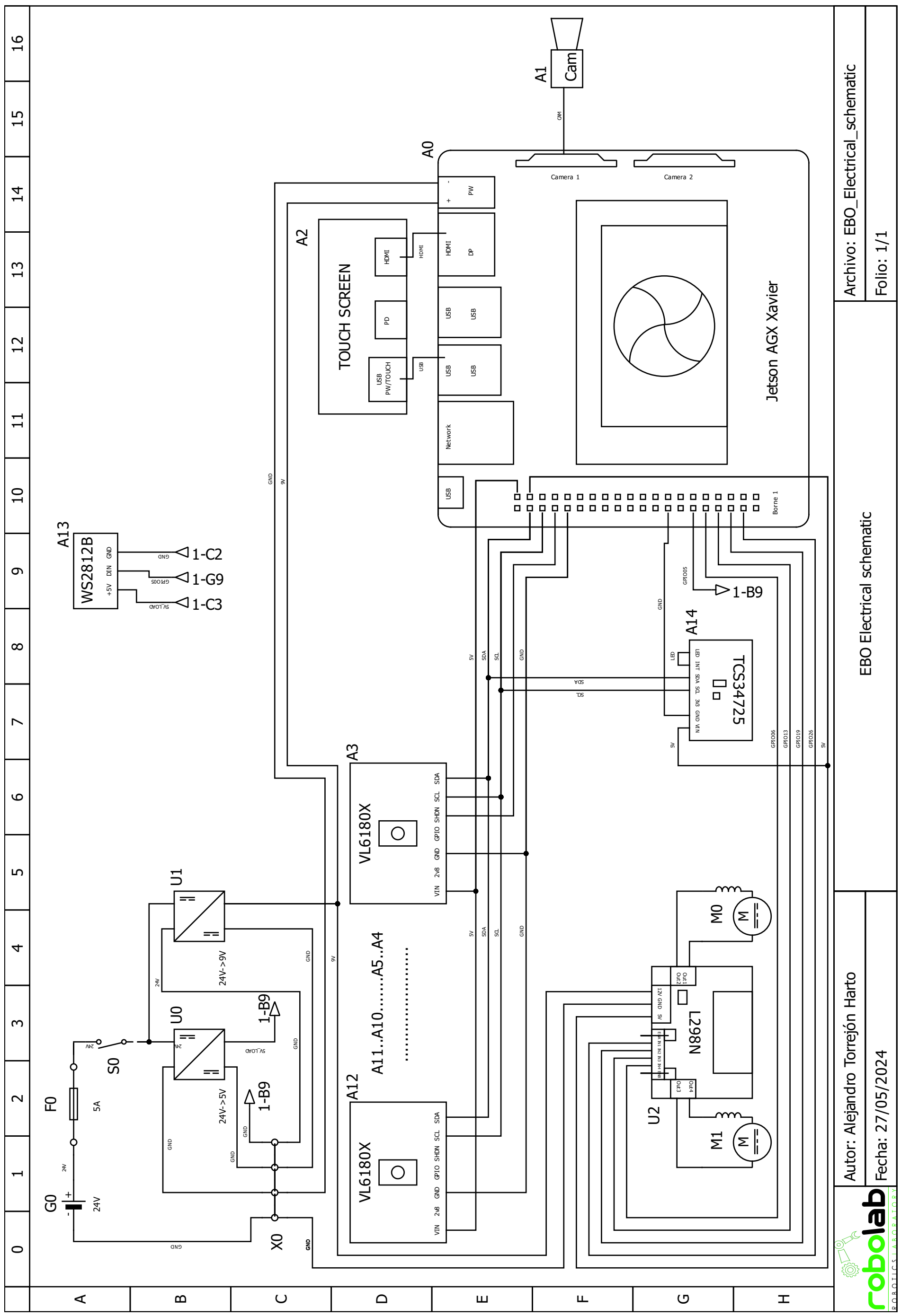
A EBOv2: Electrical Schematic


EBO Electrical schematic
Archivo: EBO_Electrical_schematic
Folio: 1/1
Autor: Alejandro Torrejón Harto
Fecha: 27/05/2024
robolab
Jetson AGX Xavier
A0
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A2
TOUCH SCREEN
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Network
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