Personalized Adaptive Serious Games for Elderly Care Through Context-Aware Robotic Interaction*

Antonio Blanco[0009-0003-8544-4662], Alicia Condón[0009-0007-3800-4831], Rosa Rina[0009-0005-8148-9315], Trinidad Rodríguez[0000-0001-7594-0011], and Pedro Núñez[0000-0002-3615-8833]1

All the authors are with RoboLab - Robotics and Artificial Vision at Universidad de Extremadura, Spain Corresponding author: pnuntru@unex.es

Abstract. Integrating robotics in elderly care has shown promise in improving cognitive, physical, and socio-emotional well-being through serious games. However, maintaining engagement and ensuring personalized experiences remains a challenge. This study explores adaptive robotic interaction that dynamically adjusts game content and conversational elements based on user preferences, performance, and difficulty level.
This study presents an adaptive robotic system for elderly care, leveraging real-time personalization in serious games through the EBO platform. The system dynamically adjusts game content, conversational elements, and difficulty levels based on user preferences and cognitive abilities. A key innovation is the integration of the CORTEX cognitive architecture with a Deep State Representation model, enabling both therapist-in-the-loop control and autonomous adaptation. The system was evaluated over two months in three elderly care facilities, involving 32 participants with mild to moderate cognitive impairment. Preliminary results indicate a significant improvement in user engagement (4.6/5 satisfaction), motivation (4.4/5), and perceived ease of interaction (4.5/5). These findings contribute to human-centric AI and Industry 5.0 by demonstrating the feasibility of scalable, personalized assistive technologies in real-world settings

Keywords: Serious games, human-robot interaction, adaptive systems

1 Introduction

The use of robotics in elderly care has gained significant attention to improve cognitive, physical and socioemotional well-being [1, 3]. Among various approaches, serious games have been widely recognized for their effectiveness in engaging elderly users in therapeutic activities [11, 2]. However, one of the key challenges is to ensure that these interventions are personalized and continuously adapted to the needs of individual users.

* This work has been partially funded by FEDER Project 0124_EUROAGE_MAS_4_E (2021-2027 POCTEP Program).

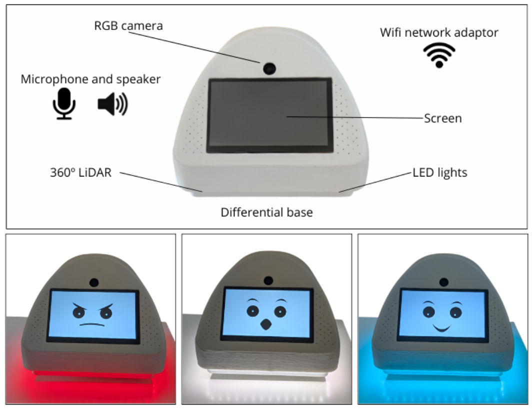

Fig. 1. The EBO robotic platform for delivering personalized adaptive serious games in elderly care facilities.

In this study, we propose a robotic system that dynamically adapts its game-based interactions and conversational elements to older users' specific preferences and cognitive abilities. The serious games developed include 'Simon Says', which involves a sequence of colors that change at adjustable speeds to challenge cognitive skills, and a storytelling-based game that serves as a conversational exercise related to activities of daily living. These games are designed to enhance engagement while providing personalized cognitive stimulation. Our research employs the EBO robotic platform (see Fig. 1), selected for several key advantages. EBO's non-intimidating, compact design with an expressive face display makes it particularly suitable for elderly users who might be apprehensive about technology. Additionally, its modular hardware architecture allows for the integration of low-cost peripherals essential for our adaptive game interactions, while its software flexibility enables seamless incorporation of our cognitive architecture. The affordability of EBO compared to humanoid alternatives also facilitates potential scalability in elderly care settings with limited budgets. The system is currently being studied in three elderly care facilities. At the two-month mark, we have collected preliminary data that provide initial insights into its impact on user engagement and therapy outcomes. Beyond standard interactive gaming, the robot is an adaptive conversational agent, integrating user-specific interests and difficulty adjustment mechanisms to optimize engagement.

A key innovation of our approach is integrating the robotic system within the CORTEX cognitive architecture [4], which incorporates a Deep State Representation (DSR) [4]. The DSR is a graph-based model that combines symbolic and geometric information, enabling the robot to maintain a unified internal representation of its environment, users, and ongoing interactions. This representation is crucial for our system as it allows for real-time adaptation of serious games by continuously adjusting game parameters, conversation topics, and levels of difficulty based on user interactions and their evolving cognitive state. The system operates in two primary modes: 1) therapist-in-the-loop, where caregivers can manually input user preferences and adjust parameters, and 2) autonomous adaptation, where the robot detects patterns in user behavior to refine the therapy experience dynamically. The DSR facilitates seamless transitions between these modes by maintaining context awareness across multiple therapy sessions.

This research contributes to the broader Human-Centric Artificial Intelligence (HCAI) field by focusing on adaptive interaction and personalized user experiences. The following sections detail related work in personalization and adaptive robotics (Section 2), describe our methodology, including the integration of the CORTEX cognitive architecture and adaptation mechanisms (Section 3), present our results, and discuss user engagement (Section 4), and conclude with key findings and future research directions (Section 5).

2 Related works

Research in adaptive serious games for elderly care has evolved significantly over the past decade. Several studies have explored the potential of personalized game mechanics in conjunction with robotics to enhance user engagement and cognitive stimulation [9]. Personalization in serious games is key to increasing engagement and adherence in elderly populations [7]. Various approaches have been proposed to tailor game experiences based on user preferences, cognitive abilities, and interaction history. For instance, previous studies have explored adaptive difficulty adjustment mechanisms in cognitive training games[5, 8], while other research has demonstrated that personalized content significantly improves motivation in elderly users [7, 6]. Our research extends these approaches by introducing a novel dual-mode adaptation system that dynamically integrates therapist input with autonomous adaptation mechanisms.

Adaptive systems in human-robot interaction focus on dynamically modifying robotic behavior based on user input and contextual data. Prior work has investigated the integration of user and robot modeling techniques to refine robot-assisted therapy sessions [12]. Additionally, reinforcement learning techniques have been applied to adjust robot interactions in response to real-time feedback from users [10]. The therapist-in-the-loop model has gained traction in assistive robotics, where human professionals are pivotal in guiding and optimizing interventions. Studies highlight the benefits of combining human expertise with AI-driven adaptation strategies to enhance therapy outcomes [13]. Recent advancements have focused on integrating therapist annotations and decision support systems within robotic frameworks to create more effective, personalized interventions [6]. Building upon these foundations, our work implements a multi-agent adaptive framework within the CORTEX cognitive architecture to achieve more nuanced personalization.

Cognitive architectures, such as CORTEX, have been employed to support adaptive interactions in robotics and serious games. CORTEX utilizes a distributed Deep State Representation to enable real-time adaptation of game parameters and conversation flows [4]. Previous research has demonstrated its ef-

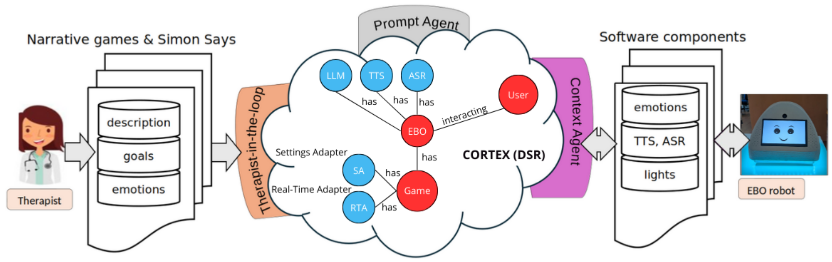

Fig. 2. System architecture for personalized adaptive serious games showing integration between EBO, CORTEX, and adaptation mechanisms.

fectiveness in social robotics and elderly care scenarios, where real-time data synchronization and modular adaptability are crucial. The following section details our methodology, including integrating the CORTEX cognitive architecture and the adaptive mechanisms implemented in our robotic system.

3 Methodology

The proposed system delivers personalized adaptive serious gaming experiences for older adults by integrating the EBO robotic platform with the CORTEX cognitive architecture. This integration enables dynamic adaptation of game content based on user's engagement, cognitive abilities, and preferences. The system operates in two modes: (i) therapist-in-the-loop, where healthcare professionals configure user-specific parameters, and (ii) autonomous adaptation, where the system refines therapy sessions based on observed behaviors. Figure 2 illustrates how our system's adaptive feedback loop integrates user interaction data, cognitive modeling, and therapist input to create a continuously personalized experience.

3.1 Personalized Game Adaptation Through CORTEX Cognitive Architecture

The adaptation process is orchestrated by a set of specialized software agents operating within CORTEX's distributed architecture. The agents include:

- *User State Estimation Agent:* Continuously monitors user responses, engagement levels, and performance metrics to dynamically assess capabilities and preferences. This agent updates the Deep State Representation in real time, ensuring an accurate model of the user's current state. Each serious game has its own dedicated estimation agent tailored to its specific interaction modalities.

- *Game Adaptation Agents:* Dynamically adjust game parameters including difficulty, speed, complexity, and feedback mechanisms to maintain an optimal balance between challenge and achievability. These agents operate at two levels: i) *Settings Adapter Agent,* which determines initial game configuration based on user profile data, ensuring a personalized starting point that aligns with the user's cognitive baseline; and ii) *Real-Time Adapter Agent*, which continuously modifies game parameters during gameplay in response to the user's evolving performance patterns and engagement indicators.
- *Conversational Adaptation Agent:* Personalizes dialogue elements by adjusting topics, linguistic complexity, and conversational pace based on user preferences, interaction history, and current engagement state.
- *Progress Monitoring Agent:* Tracks longitudinal performance data, identifying trends in cognitive abilities and compiling summarized insights for therapists to inform long-term intervention planning.

3.2 Dual-Mode Adaptation System

Our system integrates two complementary adaptation approaches to balance expert-driven customization with autonomous learning capabilities. On one hand, in the *Therapist-in-the-Loop Mode*, healthcare professionals actively guide the system's adaptation process through a specialized interface (Fig. 3), leveraging clinical expertise particularly valuable during initial assessment and for users with complex needs. This includes a configuration dashboard for specifying user preferences, real-time intervention controls for immediate session adjustments, and structured progress reports presenting aggregated performance data in clinically relevant formats. On the other hand, the *Autonomous Adaptation Mode* enables the system to independently optimize the therapeutic experience based on real-time behavioral analysis and historical performance data stored in the CORTEX architecture. Key autonomous operations include continuous performance monitoring of indicators like reaction time and task accuracy, Dynamic Difficulty Adjustment (DDA) algorithms that automatically calibrate game complexity, and context-aware conversational strategies that modify the robot's communication approach based on detected engagement levels.

4 Experimental Results

The proposed system is being evaluated in three elderly care facilities in Cáceres, Spain, to assess its impact on user engagement, acceptance, and adherence during therapy sessions. This paper presents preliminary results after two months of sessions, involving 32 older adults aged between 65 and 96 years (72% female, 28% male). Inclusion criteria required participants to have mild to moderate cognitive impairment according to the Mini-Mental State Examination (MMSE), be capable of interacting with a robotic system, and not suffer from advanced neurodegenerative conditions. The study protocol was approved by the Bioethical

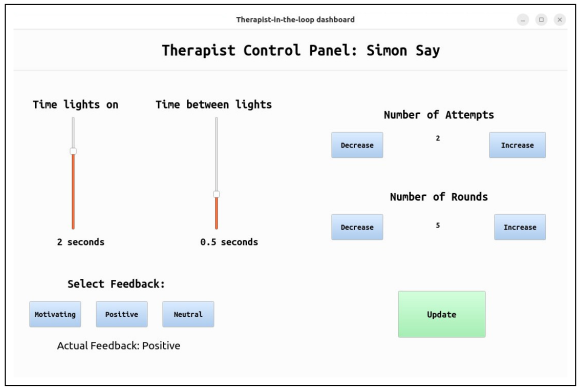

Fig. 3. Therapist-in-the-loop dashboard interface showing real-time monitoring and intervention controls.

Committee of Universidad de Extremadura (89_2024_CERT), and all participants provided written informed consent.

Each participant engaged in weekly sessions lasting approximately 10 minutes using the EBO robotic system. The sessions were structured around two primary serious games: *personalized storytelling* and *Simon Says*. Each session consisted of three phases: an initial phase featuring the personalized storytelling game, a second phase involving the Simon Says game, and a final reflection phase where participants answered questions about their emotions and opinions regarding the session. The games included the following components:

- *Simon Says*: A color-sequencing task with adjustable speed settings designed to enhance cognitive and motor skills.
- *Personalized Storytelling*: A narrative-based game where users make branching decisions related to daily life activities.

The EBO system was evaluated in three elderly care facilities in Cáceres, Spain, using a Likert scale (1-5) to measure user experience and perception (see Fig. 4). Table 1 presents the main findings and their relationship to the system's adaptive capabilities.

These results suggest that the EBO system's auto-adaptation capabilities allowed for a highly positive user experience. However, the presence of a therapist improved verbal communication, whereas the autonomous mode effectively maintained engagement through adaptive strategies. This indicates that while human supervision enhances some aspects of the interaction, the autonomous system remains a viable and effective tool for cognitive stimulation in older users. While the study provides promising results, several limitations must be acknowledged. The small sample size and wide age range suggest the need for more comprehensive future research. The predominance of female participants (72%) may introduce gender bias, potentially limiting result generalizability. Despite these constraints, the adaptive mechanisms demonstrated significant potential

Table 1. Evaluation metrics and relationship with auto-adaptation.

Evaluation Metric	Likert (1-5)	Relationship with Auto-Adaptation
Overall Satisfaction with EBO	4.6	Auto-adaptation maintained high satisfaction levels without human intervention.
Ease of Conversation with EBO	4.5	Adaptive language mechanisms ensured a smooth interaction experience.
Comprehension of EBO's Language	4.3	The system adjusted language complexity based on user responses, improving clarity.
Emotional Expressiveness of EBO	4.2	Adaptations in tone and expression contributed to user engagement.
Motivation Provided by EBO	4.4	The system dynamically adjusted game difficulty to maintain user interest.
Recommendation of EBO to Others	4.7	High adaptability led to a positive experience and strong user recommendations.
Perception of a Coherent Personality in EBO	4.1	The robot's behavior consistency was maintained through adaptive learning.
Impact of Interaction Mode (Therapist (T) vs. Autonomous (A))	T: 4.8 A: 4.2	Therapist supervision enhanced verbal interaction, while autonomous adaptation ensured content fluidity without manual intervention.

Fig. 4. Diverse interaction scenarios with the EBO robotic system in elderly care facilities. The images showcase participants engaging with the personalized storytelling and Simon Says games, highlighting the adaptive interactions between users and the robotic platform across different individual and group settings.

for personalized cognitive stimulation, indicating promising avenues for further investigation in robotic-assisted elderly care.

5 Conclusion

This research demonstrates that adaptive serious games improve engagement, cognitive stimulation, and emotional well-being in elderly users. The CORTEX-based robotic system dynamically adjusted gameplay and conversations, ensuring personalized user experiences. Both therapist-in-the-loop and autonomous adaptation modes positively influenced therapy outcomes, with therapist guidance leading to higher engagement and cognitive gains, while autonomous adaptation offered a scalable solution.

Future research should address limitations by expanding the sample size, integrating multimodal feedback (*e.g.*, physiological data), and exploring home-based implementations to support independent living. The findings contribute to Human-Centric AI and Industry 5.0, emphasizing intelligent and scalable interventions for cognitive health in aging populations.

References

1. Abdi, J., Al-Hindawi, A., Ng, T., Vizcaychipi, M.P.: Scoping review on the use of socially assistive robot technology in elderly care. BMJ Open **8**(2), e018815 (2018). https://doi.org/10.1136/bmjopen-2017-018815
2. Bleakley, C.M., Charles, D., Porter-Armstrong, A., McNeill, M.D., McDonough, S.M., McCormack, B.: Gaming for health: A systematic review of the physical and cognitive effects of interactive computer games in older adults. Journal of Applied Gerontology **34**(3), 166–189 (2015). https://doi.org/10.1177/0733464812470747
3. Broekens, J., Heerink, M., Rosendal, H.: Assistive social robots in elderly care: A review. Gerontechnology **8**(2), 94–103 (2009). https://doi.org/10.4017/gt.2009.08.02.002.00
4. Bustos, P., Manso, L.J., Bandera, A.J., Bandera, J.P., García-Varea, I., Martínez-Gómez, J.: The cortex cognitive robotics architecture: Use cases. Cognitive Systems Research **55**, 107–123 (2019). https://doi.org/10.1016/j.cogsys.2019.01.003
5. Chiotaki, D., Poulopoulos, V., Karpouzis, K.: Adaptive game-based learning in education: a systematic review. Frontiers in Computer Science **5** (06 2023). https://doi.org/10.3389/fcomp.2023.1062350
6. Clabaugh, C., Mahajan, K., Jain, S., Pakkar, R., Becerra, D., Shi, Z., Deng, E., Lee, R., Ragusa, G., Matarić, M.: Long-term personalization of an in-home socially assistive robot for children with autism spectrum disorders. Frontiers in Robotics and AI **6**, 110 (2019). https://doi.org/10.3389/frobt.2019.00110
7. Dartigues, J.F., Foubert-Samier, A., Le Goff, M., Viltard, M., Amieva, H., Orgogozo, J.M., Barberger-Gateau, P., Helmer, C.: Playing board games, cognitive decline and dementia: A french population-based cohort study. BMJ Open **3**(8), e002998 (2013). https://doi.org/10.1136/bmjopen-2013-002998
8. Konstantinidis, E.I., Billis, A.S., Mouzakidis, C.A., Zilidou, V.I., Antoniou, P.E., Bamidis, P.D.: Design, implementation, and wide pilot deployment of fitforall: An easy to use exergaming platform improving physical fitness and life quality of senior citizens. IEEE Journal of Biomedical and Health Informatics **20**(1), 189–200 (2016). https://doi.org/10.1109/JBHI.2014.2378814
9. Manca, M., Paternò, F., Santoro, C., Zedda, E., Braschi, C., Franco, R., Sale, A.: The impact of serious games with humanoid robots on mild cognitive impairment older adults. International Journal of Human-Computer Studies **145**, 102509 (2021). https://doi.org/https://doi.org/10.1016/j.ijhcs.2020.102509
10. Oliff, H., Liu, Y., Kumar, M., Williams, M., Ryan, M.: Reinforcement learning for facilitating human-robot-interaction in manufacturing. Journal of Manufacturing Systems **56**, 326–340 (07 2020). https://doi.org/10.1016/j.jmsy.2020.06.018
11. Robert, P., König, A., Amieva, H., Andrieu, S., Bremond, F., Bullock, R., Ceccaldi, M., Dubois, B., Gauthier, S., Kenigsberg, P.A., et al.: Recommendations for the use of serious games in people with alzheimer's disease, related disorders and frailty. Frontiers in Aging Neuroscience **6**, 54 (2014). https://doi.org/10.3389/fnagi.2014.00054
12. Stolarz, M., Mitrevski, A., Wasil, M., Plöger, P.G.: Learning-based personalisation of robot behaviour for robot-assisted therapy. Frontiers in Robotics and AI **11**, 1352152 (apr 2024). https://doi.org/10.3389/frobt.2024.1352152
13. Winkle, K., Caleb-Solly, P., Turton, A., Bremner, P.: Mutual shaping in the design of socially assistive robots: A case study on social robots for therapy. International Journal of Social Robotics **12**, 847–866 (2020). https://doi.org/10.1007/s12369-018-0510-7