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ORIGINAL

Development of Intelligent Therapeutic Devices: Integration of New Technologies for the Care of Elderly Adults in Cuenca: ARTRI Phase 2

Desarrollo de Dispositivos Terapéuticos Inteligentes: Integración de Nuevas Tecnologías para el Cuidado de Adultos Mayores en Cuenca: ARTRI Fase 2

Galo Hurtado Crespo[1], Gina Pamela Novillo[1], Ana C. Umaquinga-Criollo[2], Juan Marcelo Pérez[1]

[1]Instituto Tecnológico Particular Sudamericano de Cuenca, Software. Cuenca, Ecuador.
[2]Universidad Técnica del Norte, Facultad de Ingeniería en Ciencias Aplicadas, Ibarra-Ecuador.

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Corresponding author: Galo Hurtado Crespo

ABSTRACT

Population aging and the increasing prevalence of osteoarthritis pose a significant challenge for geriatric care. According to the VIII Population and Housing Census of Ecuador (2023), older adults constitute 9 % of the national population, highlighting the need to implement innovative technologies for rehabilitation. Cuenca, Ecuador, is internationally recognized as one of the preferred cities for foreign older adults as a place of residence. Additionally, according to the National Institute of Statistics and Censuses (INEC), it has a high life expectancy of 79 years, making it an ideal environment for implementing technological solutions in geriatric rehabilitation. This study presents the evolution of ARTRI, an intelligent therapeutic device designed for motor stimulation in older adults with osteoarthritis. The new version incorporates an optimized electronic board with ESP32, improving processing capacity, connectivity, and energy efficiency. Additionally, a digital lock was implemented for code protection, and an acrylic structure was designed to enhance durability and ergonomics. The software has been upgraded with structured databases, cloud storage, and real-time monitoring, enabling efficient therapy supervision. The SCRUM methodology ensured an iterative and agile development process, while a demographic heat map facilitated the strategic distribution of the device in key institutions such as the University of Older Adults in Cuenca. The results demonstrate significant improvements in effectiveness, security, and user acceptance, establishing ARTRI as a scalable and innovative solution in digital health and geriatric rehabilitation.

Keywords: Intelligent Therapeutic Devices; Integrated Technologies for Osteoarthritis Prevention and Treatment; Geriatric Rehabilitation; Older Adults; ESP32.

RESUMEN

El envejecimiento poblacional y la prevalencia creciente de la artrosis representan un desafío importante en la atención geriátrica. Según el VIII Censo de Población y Vivienda del Ecuador en el año 2023, los adultos mayores constituyen el 9 % de la población nacional, lo que subraya la necesidad de implementar tecnologías innovadoras para su rehabilitación. Cuenca-Ecuador, es reconocida internacionalmente como una de las ciudades preferidas por adultos mayores extranjeros como zona de residencia. Además, según el Instituto Nacional de Estadísticas y Censos (INEC), presenta una alta esperanza de vida de 79 años lo que la convierte en un entorno propicio para la implementación de soluciones tecnológicas en rehabilitación geriátrica para el adulto mayor. Este estudio presenta la evolución de ARTRI, un dispositivo terapéutico inteligente diseñado para la estimulación motora en adultos mayores con artrosis incorpora una placa electrónica optimizada

con ESP32, mejorando la capacidad de procesamiento, conectividad y eficiencia energética. Además, se implementó un candado digital para la protección del código y una estructura en acrílico que optimiza la durabilidad y ergonomía del dispositivo. El software ha sido actualizado con bases de datos estructuradas, almacenamiento en la nube y monitoreo en tiempo real, permitiendo una supervisión eficiente de la terapia. La metodología SCRUM garantizó un desarrollo iterativo y ágil, mientras que un mapa de calor demográfico facilitó la distribución estratégica del dispositivo en instituciones clave como la Universidad del Adulto Mayor de Cuenca. Los resultados muestran mejoras significativas en la eficacia, seguridad y aceptación del dispositivo, consolidándolo como una solución escalable e innovadora en salud digital y rehabilitación geriátrica.

Palabras clave: Dispositivos Terapéuticos Inteligentes; Tecnologías Integradas Para Prevención y Tratamiento de Artrosis; Rehabilitación Geriátrica; Adultos Mayores; ESP32.

INTRODUCTION

As the years go by and due to the activities carried out throughout life, muscle strength is compromised by degenerative diseases, which cause musculoskeletal alterations associated with the progressive wear and tear of cartilage, tendons, and ligaments in the joints.[1] Osteoarthritis is a degenerative disease that affects the joints, generally those that bear weight, such as the spine, hips, knees, and hands. It is estimated that approximately 302 million people worldwide suffer from this condition, making it a significant public health problem. This disease causes wear and tear of the cartilage in the joints, causing pain, stiffness, and difficulty in movement.[2] These conditions significantly impact the mobility and functionality of older adults, increasing the prevalence of chronic diseases such as hand osteoarthritis.

In Ecuador, people over the age of 65 are considered older adults and are more predisposed to developing musculoskeletal disorders that affect their quality of life. Among these conditions, osteoarthritis stands out as a degenerative and progressive disease that compromises joint functionality and the independence of this population. In response to this problem, various research studies have developed strategies to mitigate the effects of osteoarthritis and improve the quality of life of older adults, focusing on maintaining autonomy and well-being.[3,4,5]

As part of these efforts, the research [6] proposes designing and implementing a system of adapted kitchen utensils to facilitate food preparation and prevent injuries in older adults, thus promoting their independence in activities of daily living. On the other hand, physical activity has been widely documented as a key factor in the prevention and treatment of osteoarthritis, as it contributes to the preservation of joint mobility and the reduction of musculoskeletal deterioration.[7,8] In line with this, a study carried out by [9] evaluated the therapeutic effects of physical exercises in the aquatic environment, concluding that using natural agents represents an effective strategy for managing hand osteoarthritis, as it reduces pain and improves joint functionality.

From a predominantly technological perspective, innovative devices are being developed to rehabilitate people with osteoarthritis. In Cotopaxi, Ecuador, a board with assisted technology is being implemented for physiotherapeutic rehabilitation, contributing to a 10 % reduction in muscle pain in older adults. In addition to being portable, this device incorporates a data storage system, facilitating clinical monitoring and continuous evaluation of therapeutic progress.[10]

Likewise,[11] describes the development of an intelligent application for the integral management of knee osteoarthritis aimed at promoting self-management of health, personalized physical activity, and patient education. The collection of qualitative data on individuals with this condition showed that the combination of digital interventions and social support strategies significantly improves therapeutic adherence and quality of life in older adults.[12,13,14]

Meanwhile,[15] proposes an interactive system based on a controller and a gamified web platform, ARTRI, designed to optimize motor rehabilitation in older adults with hand osteoarthritis. Through an experimental and explanatory approach, its effectiveness was evaluated using a LIKERT questionnaire applied to experts, demonstrating its contribution to non-pharmacological therapy and the use of ICT in geriatric rehabilitation.

Within the framework of this research, the present phase focuses on the optimization and expansion of the technological and therapeutic capabilities of ARTRI.[15] This study introduces improvements in the intelligent therapeutic device, integrating emerging technologies such as web platforms and gamification, to enhance the effectiveness of the treatment and improve therapeutic adherence. The implemented updates expand the system's functionalities and strengthen motor and cognitive stimulation, consolidating an interdisciplinary and innovative approach to geriatric care. Additionally, the study incorporates Ecuadorian music as a motivational element, enriching the patient's experience, strengthening their cultural identity, and improving adherence to therapy. This convergence between technology and culture optimizes the treatment's effectiveness and favors

a more personalized approach to rehabilitation, adapting to the specific needs of the elderly population in Cuenca. This advance represents a significant step in applying digital technologies in rehabilitation, contributing to designing more accessible and personalized therapeutic strategies for the elderly population.

METHOD

The study adopts a qualitative approach with an experimental, transversal, and explanatory methodology. Qualitative research allows us to understand complex phenomena based on the participants' experiences, generating knowledge based on their perceptions and experiences.

The methodology used (see figure 1) is structured in sequential stages, aligned with the proposals of various authors on the methodological research process. These phases guarantee a systematic design that allows for analyzing the effectiveness and applicability of the improvements implemented in ARTRI-Phase2, ensuring a comprehensive approach to motor rehabilitation of older adults with hand osteoarthritis.

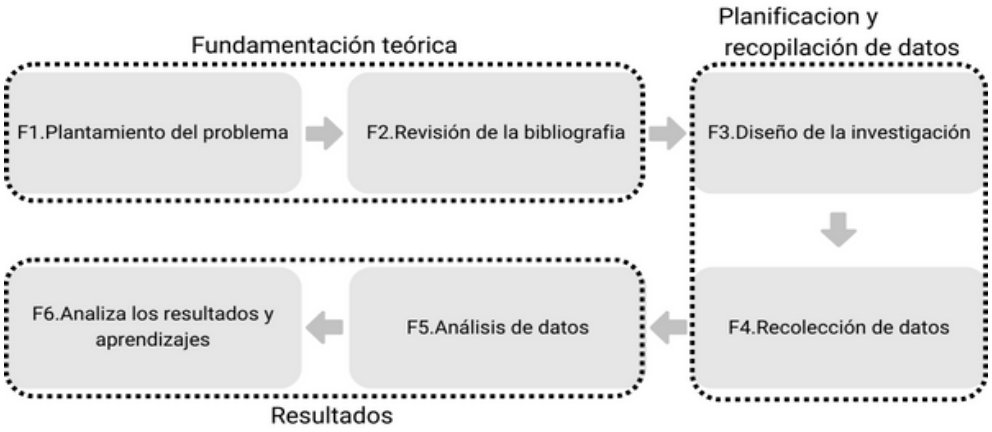

Figure 1. Methodological design

The present study is classified as qualitative and experimental to evaluate the effectiveness of gamification in the motor stimulation of joints in adults over 60 years of age in Cuenca. The research follows a cross-sectional experimental design that includes a test session lasting less than 20 minutes, during which participants interact with an electronic device complemented by specific software. This approach allows for comparing responses from different groups of subjects in the study environment. The main objective of experimental research is to establish causal relationships between variables, using controlled manipulation and measurement of the effects, making it a relevant explanatory approach within scientific research.

DEVELOPMENT

Based on the initial tests on the ARTRI prototype, published in [15], the need to delve deeper into the clinical stages of the osteoarthritis patient has been identified, allowing for a more precise adaptation of the system to their therapeutic requirements. These stages, represented in Figure 2, establish a frame of reference for the patient's evolution and treatment, facilitating the implementation of personalized therapeutic strategies:

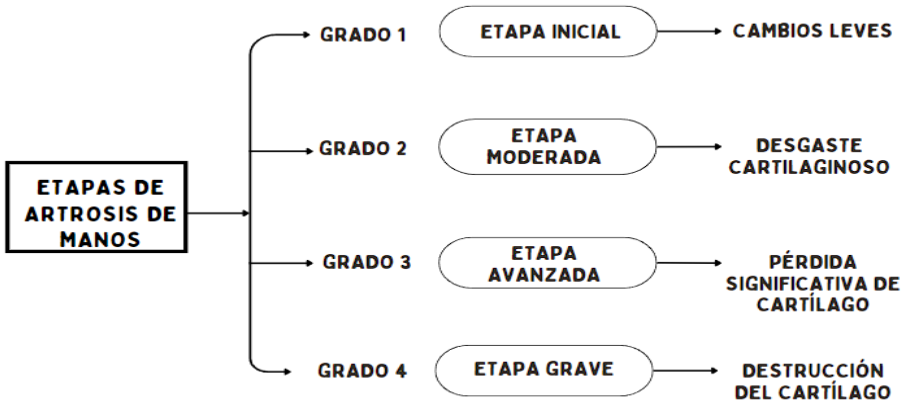

Figure 2. Stages of osteoarthritis of the hands

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As a therapeutic tool, the device contributes significantly to treating patients with grade 2 or lower osteoarthritis (see figure 2) by facilitating mobility and strengthening exercises. Targeted physiotherapy strengthens the muscles surrounding the affected areas, improving joint stability and helping to reduce the progression of the disease.

In the second version of the prototype, key technological improvements have been implemented, including the industrial-scale production of electronic boards and the integration of an electronic lock designed to increase the security of the device's code. This mechanism allows efficient control over security parameters, ensuring the protection of sensitive information both in the development phase and in the system's execution.

In addition, a Docker-based platform was implemented, which facilitates user interaction with the device through an intuitive and accessible user interface. The platform not only guarantees the system's modularity and scalability but also optimizes resource management and virtualization of development and deployment environments. The device's data is securely stored in an ElephantSQL database, which is deployed on the servers of the Instituto Tecnológico Sudamericano de Cuenca. This infrastructure allows for robust and accessible data storage, guaranteeing its integrity and availability for further analysis.

The agile SCRUM methodology is adopted for project management and organization. This methodology allows for a clear distribution of roles and a structured planning of processes within the work team. Its application facilitates adaptation to changes, guaranteeing a progressive implementation of improvements and optimizing both iterative development and continuous integration of the system (See figure 3).

Figure 3. Design of the project outline with connection to the database

As for the methodological process applied to the development of the electronic device, the agile SCRUM methodology is adopted, which is structured in the following stages:

The initial circuit design [15] is taken as the starting point, and based on the results obtained, an improvement plan is implemented aimed at optimizing the system's performance and production. As part of this phase, a production model of 15 devices is established, which will be distributed according to the agreements that the institute currently maintains. See figure 4.

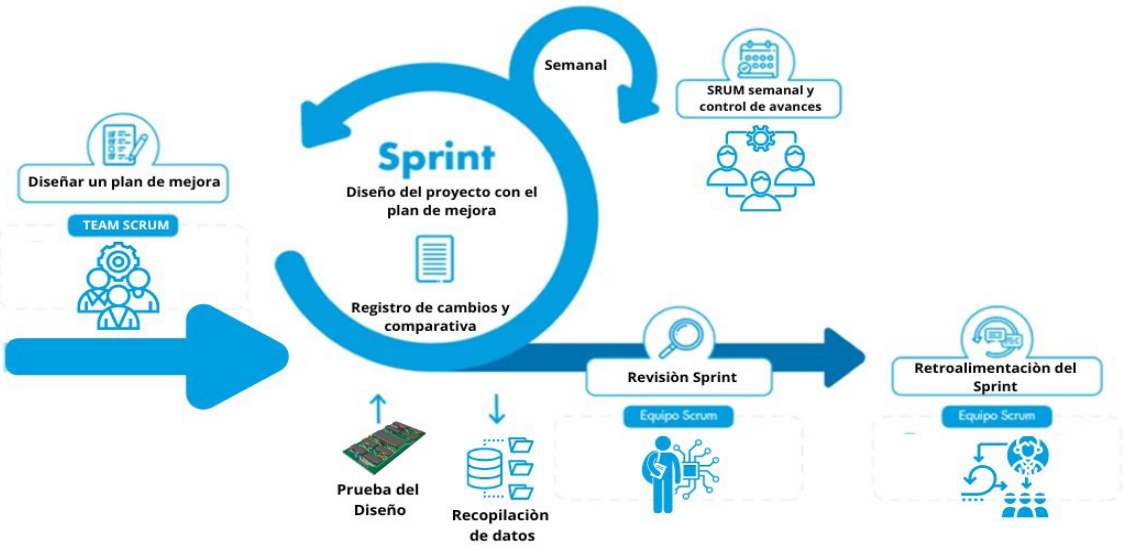

Figure 4. Design of the SCRUM methodology applied to the development and optimization of the ARTRI electronic device Phase 2

To monitor the improvements of the project, it is planned to implement a SCRUM methodology; the weekly checks will allow us to determine the significant progress of the project through the feedback that, in turn, will

enable us to experiment,[12] learn quickly and adapt the product to the need that it is intended to solve. The significant improvements are presented below:

Printing of PCB boards: the design of the board circuit was done in Eagle software, then using the Gerber files requested by the manufacturer, it was sent to a foreign company for layout; once the boards were imported again, we proceeded to work on the soldering, which was done manually due to the number of devices that are 15once each of the electronic components had been assembled on the boards, a visual inspection is carried out with the help of a multimeter to verify that there are no short circuits, checking the continuity of the tracks and measuring the voltage at the relevant points on the board.

In addition, an electronic security board was designed to protect the code implemented in the circuit. The code was developed in C++ (Arduino) and executed in an ESP32 microcontroller, using various specialized libraries to integrate with the hardware. To guarantee adequate interaction between the software and the hardware, it is necessary to verify the correct configuration of the input and output (I/O) ports, as well as the adequate power supply of the system. The electronic security board acts as an intermediary between the ARTRI board and the computer, establishing a restriction mechanism that prevents any unauthorized modification of the programming code:

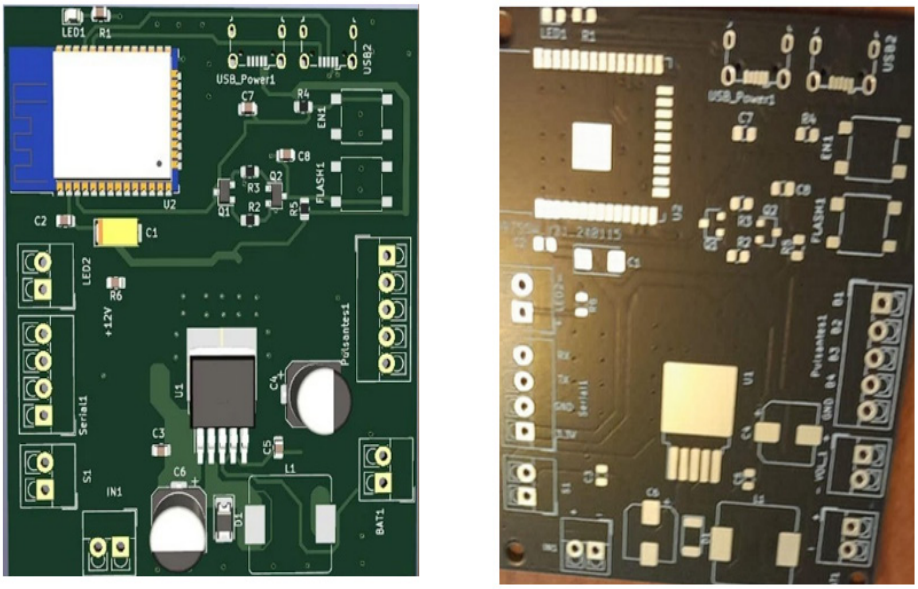

Figure 5. Design and production of PCB boards

Databases: The database stores and manages the information generated during the user's interaction with the device, allowing for a quantitative analysis of therapeutic performance. The records include the number of correct answers per session, which facilitates evaluating the effectiveness of the treatment and monitoring the patient's progress in rehabilitating hand osteoarthritis.

Interaction with the device uses polystyrene balls commonly used in motor rehabilitation therapies. To optimize the user experience, color theory is incorporated, based on the research [13] carried out in 2017, which establishes that a chromatic strategy based on warm colors (red, yellow, and orange) improves the perception and response of older adults. To validate the chromatic trend, a cold color (blue) is integrated as a control variable, allowing us to analyze its influence on the user's interaction with the system.

This implementation allows us to evaluate the impact of color perception on therapy and validate previous studies, which contributes to the development of more effective therapeutic strategies adapted to the individual needs of the patients.

The database is implemented on an ElephantSQL server, a cloud database service (DBaaS) based on PostgreSQL that provides scalability and optimization in data management. This architecture allows multimedia content, particularly the music tracks used in the therapy, to be stored and expanded, guaranteeing efficient resource management.

To promote a significant cultural rescue, a selection of Ecuadorian musical genres is incorporated, based on the classification established in 2009 by Juan Mullo Sandoval[14], who identifies the pasillo, albazo, yaraví, sanjuanito, bomba del Chota, marimba esmeraldeña and danzante as representative expressions of Ecuadorian music. To curate the repertoire, a survey was conducted of 80 older adults in the city of Cuenca, using a Google Forms questionnaire, to determine the most relevant song within each genre. As a result, 70 % of these genres are represented in the database, ensuring a cultural connection with the target population.

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Given that the research will be extended for another year, new musical pieces are foreseen as the analysis of the collected data progresses. This will allow for a progressive enrichment of the repertoire and a continuous evaluation of the impact of music on therapeutic adherence. See table 1.

Table 1. Playback of Ecuadorian music on digital platforms

Gender	Number of views	Years
Pasillo	151 millones	6
Albazo	18 millones	10
San Juanito	4,7 millones	17
Yaraví	3,7 millones	8
Danzante	2,5 millones	6

To validate the songs and to relate them to the surveys carried out, YouTube was also searched for the songs with the most plays, as detailed below: El Pasillo Ecuatoriano with Julio Jaramillo is in first place with more than 151 million plays in the last 6 years, El Albazo ecuatoriano is in second place with 18 million plays, in third place El San Juanito with 4,7 million plays in 17 years on the platform, El Yaraví has a total of 3. 7 million plays and finally the danzante, which is a genre widely listened to, especially in the northern part of the country, has a total of 2,5 million plays. Ecuadorian music has a long history of promoting the culture and traditions of ancestral peoples, and this type of project aims to integrate new technologies with medicine and generate the added value of rescuing Ecuadorian culture.

RESULTS

As part of the optimization process, the platform is restructured to improve its functionality, efficiency and responsiveness, integrating new technological components that strengthen its stability and performance (see figure 6).

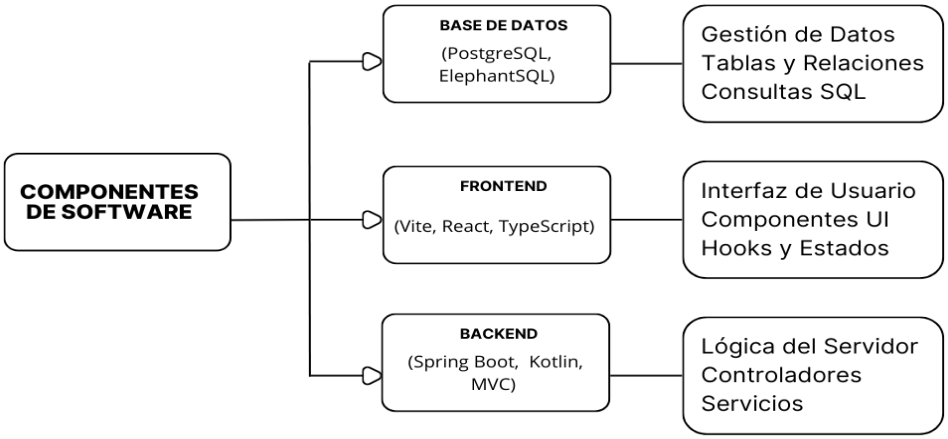

Figure 6. Architecture and components of the software platform development

The conceptual map shows:
Backend: Responsible for server logic, APIs, authentication, etc.
Frontend: Responsible for the user interface (UI) using HTML, CSS, and JavaScript technologies.
Database: Manages the storage and retrieval of information with SQL or NoSQL technologies

Figure 7 describes the representation of the components used for the project's development and the integration of new technologies. For the electronic part, an ESP32 microcontroller is used, taking advantage of the fact that they are affordable devices that integrate components such as Bluetooth and WIFI modules.

As for the domain, https://artri.sudamericano.edu.ec/ is stored on a Google server, allowing real-time access and presenting an interface with five entities divided into 1. The user, 2. The microcontroller (ESP32), 3. Data collected (sensors), 4. Level reached (number of attempts), 5. Musical genre (Ecuadorian music), resulting in the following entity-relationship model:

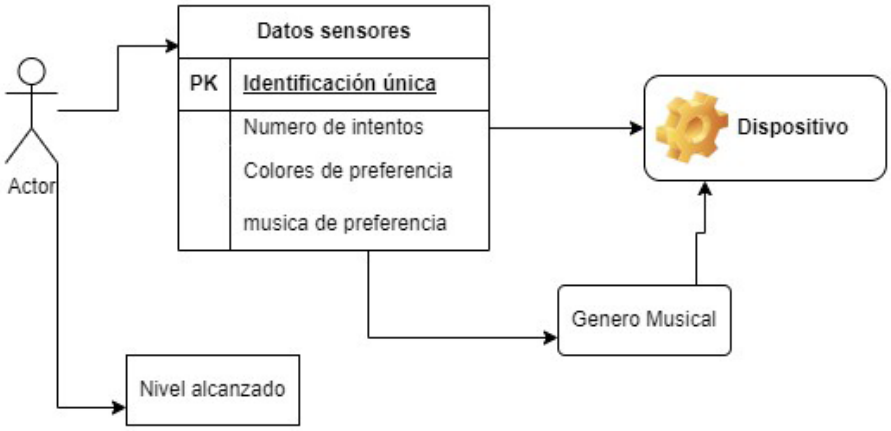

Figure 7. Entity-relationship model of the database

Frequency statistics are used to analyze the data obtained from the opinions of experts and users. These allow us to measure the level of acceptance achieved by the project and its demonstrated effectiveness. The results obtained are based on the agreements that have been made for the applicability of the devices distributed as follows, as described in table 2:

Table 2. Distribution of electronic devices

Gender	Project	Years
Ibarra Technological Institute (ITSI)	Integral Care for the Elderly Degree Course	4
TEC Sudamericano Cuenca (Software)	Care for the Elderly	2
UAM (University of the Elderly)	University of the Elderly Cuenca	3
Nursing degree at TEC	Links with society	3
Social Security	Elderly Campaign	3

The device's hardware incorporates significant improvements, optimizing its performance and durability. These improvements are detailed in figure 8, which shows the evolution of the design and the integration of new components that strengthen its stability and functionality.

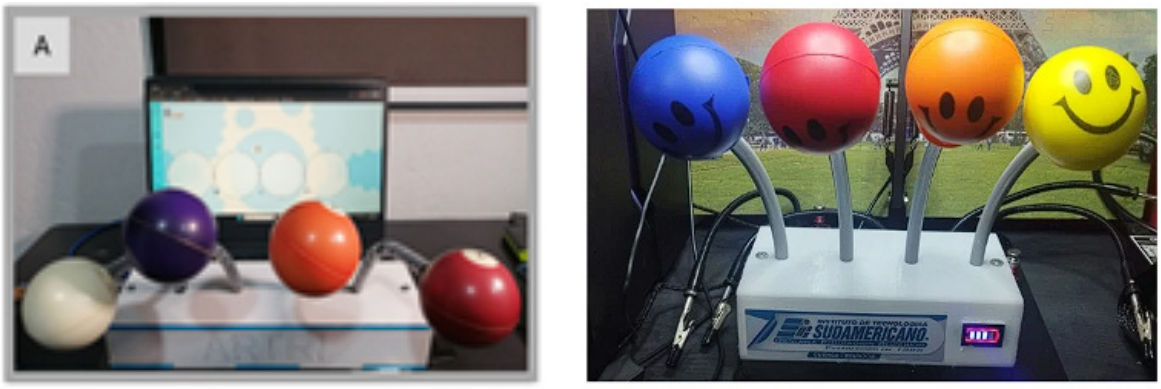

Figure 8. Improvement in the device's hardware

DISCUSSION

Based on the tests carried out with the initial device, the evaluation included a sample of 20 participants. However, the new device version expanded the sample to 80 older adults, allowing for a more representative analysis of its impact on rehabilitation. Based on this expansion, a comparative table is established with the data obtained in the previous study. This comparison allows the percentage of improvement to be calculated, providing a quantitative reference for evaluating the progress made concerning the initial research.

The findings obtained reflect the following significant improvements described in figure 9:

Indicador	Valor Inicial (MAX 20)	% de mejora DE (80 participantes)	Nuevo Resultado
Accesibilidad	15	↑ 90	28.5
Aplicabilidad	16	↑ 65%	26.4
Compatibilidad	16	↑ 5%	16.8
Dinamica del Juego	18	↑ 100%	36
Experiencia de usuario	18	↓ 60%	28.8
Funcionalidad	19	↑ 95%	31.35
Novedad Tecnològica	14	↓ 76%	24.64

Figure 9. Table of results of an analysis of 80 older adults

Comparative analysis between the initial and most recent research provides a clear view of the device's evolution and impact on the rehabilitation of older adults. Figure 10 shows the results obtained in the study's first phase, in which 20 older adults evaluated the initial device, considering key aspects such as applicability, technological novelty, user experience, functionality, game dynamics, accessibility, and compatibility.

The results show that functionality achieved the highest score,[19] followed by user experience and game dynamics,[18] indicating that the device was effective in its therapeutic purpose. However, technological innovation obtained the lowest rating,[14] highlighting the need for improvements. Likewise, accessibility, with a score of 15, suggests that some users experienced difficulties interacting with the interface or the hardware.

When comparing this data with the evaluation of the new device, which has been tested on 80 elderly adults, there is evidence of a significant improvement in the system's functionality, acceptance, and effectiveness. The expansion of the sample and the collection of a greater volume of data reinforce the validity of the findings, highlighting the viability of implementing the device in public institutions and entities that could benefit from its use in geriatric rehabilitation programs.

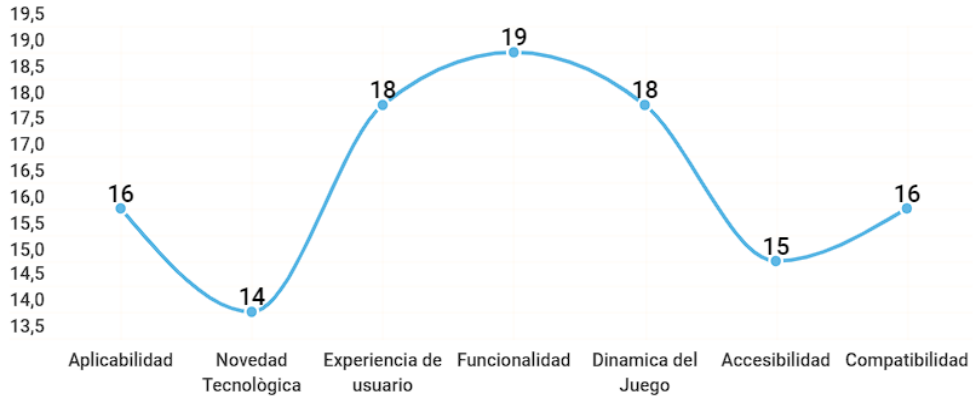

Figure 10. Evaluation of the performance of ARTRI Phase 1 in a sample of 20 older adults

Figure 11 represents the evaluation of ARTRI Phase 2, in which data was collected from 80 older adults in Cuenca. Compared to the previous phase, there is evidence of a significant increase in all the aspects evaluated, which confirms the effectiveness of the improvements implemented in the device.

The highest scores were observed in terms of the game's functionality and dynamics, reaching 95 % and 100 %, respectively. This indicates that the new device has optimized the user experience and the therapeutic impact on motor rehabilitation.

Meanwhile, the user experience also shows a substantial improvement, reaching 28 points compared to 18 in the previous phase, reflecting greater acceptance and comfort of users with the device. On the other hand, technological innovation and accessibility have undergone notable improvements, increasing by 76 % and 90 %, respectively, which suggests that the update of the hardware and software has facilitated its use in a real rehabilitation environment.

A key aspect to highlight is compatibility, which has increased by 25 %. This indicates that the device has been optimized to integrate with different platforms and therapeutic needs, expanding its applicability in

clinical and community settings.

In general, these results demonstrate that ARTRI Phase 2 improves the user experience and functionality and responds more effectively to the needs of older adults, consolidating its viability for implementation in healthcare institutions and geriatric rehabilitation centers.

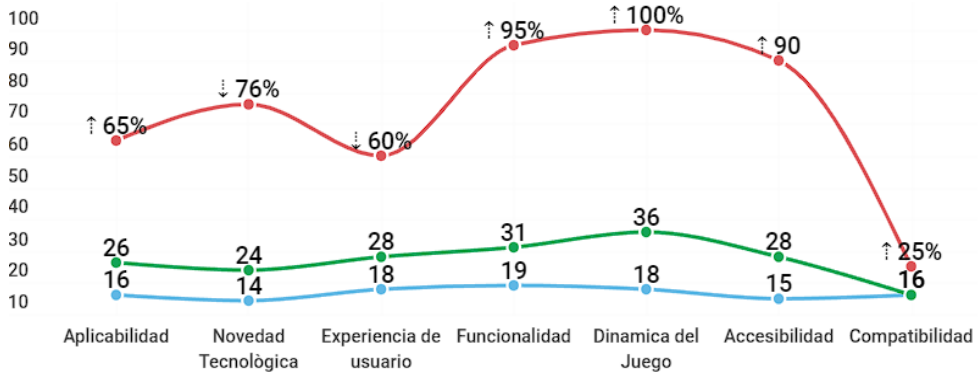

Figure 11. Comparative analysis between 20 and 80 older adults ARTRI Phase 2

CONCLUSIONS

The present study provides solid evidence of the impact of technological innovation on health, highlighting the effectiveness of web tools and electronic devices that integrate gamification principles. These approaches have been shown to significantly increase the attention and motivation of older adults, facilitating their participation in recreational activities that promote cognitive and motor stimulation.

Substantial improvements have been observed in various aspects of geriatric health, which supports the viability of implementing interactive technologies in rehabilitation programs. In the city of Cuenca, where approximately 1 520 590 people over 65 reside, representing nearly 9 % of the country's total population, adopting these types of devices is particularly important for improving this population group's quality of life and autonomy.

Complementary therapies implemented in this context have proven effective in promoting comprehensive treatment, encompassing physical and psychological dimensions. This approach has been efficient in pain management, contributing to the perception of control over the disease and improving patients' general well-being.

The research culminated in developing a prototype backed by a structured and defined framework. Expert evaluations reflect a high level of impact, which allows the integration of academic initiatives with the social sector, benefiting a sample of 80 elderly adults with hand osteoarthritis. Data management was carried out using databases in ElephantSQL, supported by entity-relationship models that facilitated the organization and analysis of the information collected.

A significant project component is the revival of Ecuadorian music, which has been incorporated as a motivational element in the interventions, enriching the user experience and fostering cultural identity. The participation of older adults in the project trials provides a robust empirical basis for evaluating the effectiveness and acceptance of these innovations in the community.

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CONFLICT OF INTEREST

None.

CONTRIBUTION OF AUTHORSHIP

Conceptualization: Galo Hurtado Crespo.
Data curation: Galo Hurtado Crespo.
Formal analysis: Pamela Novillo, Ana Umaquinga, Galo Hurtado.
Acquisition of funds: Juan Pérez.
Research: Galo Hurtado.
Methodology: Ana Umaquinga.

Project administration: Galo Hurtado.
Resources: Juan Pérez.
Supervision: Galo Hurtado.
Writing - original draft: Galo Hurtado.
Writing - review and editing: Galo Hurtado, Ana Umaquinga.

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