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ORIGINAL

A novel IoT system for remote monitoring in geriatric rehabilitation

Un novedoso sistema IoT para la monitorización remota en la rehabilitación geriátrica

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ABSTRACT

This paper presents the design, development, and implementation of a geriatric rehabilitation kit consisting of four dynamic stations, aimed at improving the physical and cognitive well-being of older adults through the use of emerging technologies. The system employs specialized sensors, computer vision, interactive games, a web-based video game, and MQTT communication. It operates on an architecture of ESP32 development boards, sensors, and a VPS server for real-time data storage and analysis. Each geriatric station was designed to stimulate specific abilities: motor activity with a pedal board and video game, agility and memory through a cognitive panel, gait cycle rehabilitation with artificial vision, and balance improvement with the stairs and slope monitored by sensors. The results obtained from experimental tests conducted with geriatric patients at a senior care center demonstrated significant improvements in their physical and cognitive performance, as evidenced by the collected metrics and historical chart analysis. The combination of different sensors and their programming facilitates key data collection, optimizing physical therapy processes and promoting active aging. Furthermore, high acceptance was observed among patients and healthcare professionals, who highlighted the motivation the kit generates and the usefulness of remote monitoring. It is concluded that the kit not only promotes active aging but also represents a viable, scalable, and low-cost solution for physical therapy centers.

Keywords: EMQX; ESP32; IoT; Remote Monitoring; MQTT; Geriatric Rehabilitation; VPS.

RESUMEN

En este trabajo se presenta el diseño, desarrollo e implementación de un kit de rehabilitación geriátrica conformado por cuatro estaciones dinámicas, orientadas a mejorar el bienestar físico y cognitivo de adultos mayores mediante el uso de tecnologías emergentes. El sistema emplea sensores especializados, visión artificial, juegos interactivos, videojuego en la web y una comunicación mediante el protocolo MQTT, operando sobre una arquitectura de tarjetas de desarrollo ESP32, sensores y un servidor VPS para almacenamiento y análisis de datos en tiempo real. Cada estación geriátrica fue diseñada para estimular capacidades específicas: actividad motriz con pedalera y videojuego, agilidad y memoria mediante un panel cognitivo, rehabilitación del ciclo de la marcha con visión artificial, y mejora del equilibrio con la escalera y pendiente monitorizadas por sensores. Los resultados obtenidos en las pruebas experimentales realizadas con pacientes geriátricos pertenecientes a un centro de atención al adulto mayor demostraron mejoras significativas en la evolución física y cognitiva de los pacientes, según lo evidenciado por las métricas recopiladas y el análisis de gráficos históricos. La combinación de los diferentes sensores y su programación facilita la recopilación

clave, optimizando los procesos de fisioterapia y favoreciendo el envejecimiento activo. Además, se reflejó una alta aceptación por parte de pacientes y profesionales de la salud, quienes destacaron la motivación que el kit genera y la utilidad del monitoreo remoto. Se concluye que el kit no solo favorece un envejecimiento activo, sino que también representa una solución viable, escalable y de bajo costo para centros de fisioterapia.

Palabras clave: EMQX; ESP32; IoT; Monitoreo Remoto; MQTT; Rehabilitación Geriátrica; VPS.

INTRODUCTION

Geriatric rehabilitation faces numerous challenges due to the lack of technological tools that allow efficient monitoring and continuous motivation of patients.[1] As the population ages, the need for innovative solutions that facilitate the recovery of older adults, promoting their independence and quality of life, becomes increasingly evident.[2] In this context, the application of emerging technologies such as the internet of things (iot) and the mqtt communication protocol emerges as a viable strategy to optimize real-time data collection and analysis, allowing healthcare staff to track patient progress more accurately.

The geriatric rehabilitation kit comprises four training stations designed to address different aspects of mobility and cognitive function in patients. Each station includes sensors that collect information about the patient's performance and send it in real-time for analysis. Station 1 integrates a pedal exerciser linked to a video game to enhance motor activity, promoting patient coordination and motivation.

Station 2 focuses on cognitive and agility exercises using an interactive panel, promoting mental stimulation and quick decision-making. Station 3 is designed for gait cycle rehabilitation using parallel bars, facilitating the recovery of mobility in patients with walking difficulties. Finally, station 4 incorporates stair monitoring and a rehabilitation ramp, allowing patients to improve their confidence and balance while facing daily mobility challenges.

The mqtt protocol has stood out in iot environments for its efficiency in data transmission,[3] as it operates under a publish-subscribe model that reduces bandwidth consumption and minimizes latency. Its application in geriatric rehabilitation allows the integration of sensors into exercise stations, enabling the monitoring of key parameters such as strength, mobility, and coordination. Connecting these sensors to the esp32 development board sends data to a central server via an mqtt intermediary such as emqx,[4] confirming stable and scalable communication in medical environments. Data collection from the sensors integrated into each station has facilitated the generation of detailed reports in graphs and tables, providing a complete picture of the patient's performance during rehabilitation sessions.

This optimizes physiotherapy processes and promotes active aging by engaging patients in dynamic activities that combine technology and movement. In addition to the technical and therapeutic impact, the kit's reception by both patients and medical staff has been very positive.

Patients have highlighted the interactive design of the stations and their ability to motivate them to continue with rehabilitation. At the same time, health professionals have emphasized the system's usefulness for centralizing information and integrating technology into medical practice. These opinions support the viability of the kit as an innovative tool for improving geriatric rehabilitation. The integration of the geriatric rehabilitation kit represents a significant advance in the application of iot technologies for monitoring and optimizing physiotherapy in older adults.

The ability to transmit data in real-time with low power consumption and bandwidth makes mqtt the ideal choice for this type of application. The results obtained from experimental tests with geriatric patients have demonstrated the system's effectiveness in rehabilitation, allowing continuous monitoring of the patient's evolution. This technological approach optimizes geriatric rehabilitation and opens up new possibilities for developing innovative medical tools in digital health.

System architecture

The geriatric rehabilitation kit is designed to address various motor and cognitive aspects to assist patients in maintaining and/or regaining personal autonomy. The physiotherapist can freely choose between stations according to his professional criteria. Each patient has an assigned rfid card, ensuring all data collected at each station is stored under the corresponding patient id (id000#). Each station can be used independently and simultaneously, ensuring data is distributed correctly without interference between stations.

All collected data is displayed on the kit's dedicated vps server, allowing healthcare professionals and family members to monitor each patient's progress through charts and graphs.

Station 1 pedalboard for increased motor activity

The first station (figure 1) focuses on the physical work of the patient's lower and upper limbs[5] to progressively

activate the motor part, seeking to strengthen the muscles of the joints, recovering and/or maintaining the range of motion of the joint.[6] Therefore, the muscular activity developed during pedaling makes it advisable in certain physical medicine and rehabilitation programs.[7]

Figure 1. Pedal exerciser accompanied by a video game

In the video game fly in the jungle (figure 2), developed in unity (software for video game creation),[8] the player controls an avatar that must avoid obstacles while flying through an immersive environment. If the player stops pedaling, the avatar falls due to the effects of gravity.

The game has two pedaling options (hands or feet) and three levels of difficulty (fundamental, medium, and expert), which differ in the speed of pedaling and the speed at which obstacles appear. The game is designed to work with constant communication between the game and the pedelec; the data from the pedelec to the game is in real-time and responds fluidly to every player's movement with a stable internet connection. When the patient loses the game by touching an obstacle, the data obtained will be sent, which can be later visualized on the patient's page with their respective progress graph.

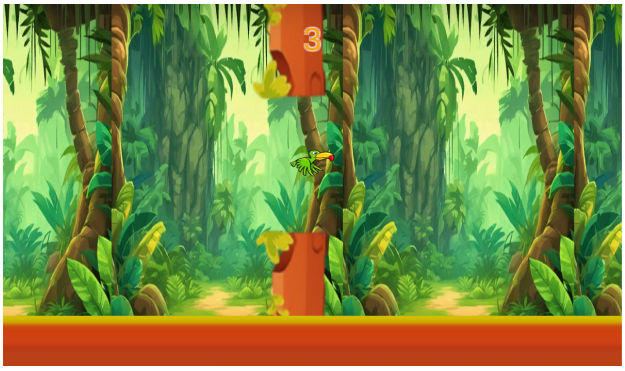


Figure 2. Video game 'fly in the jungle'

Station 2: cognitive and agility work panel

Figure 3. Working panel

The second station focuses on working on the cognitive level of the patient (figure 3.), offering visual, auditory, and mental stimuli. This approach strengthens brain connections and improves hand-eye coordination through cognitive stimulation. It has three games (visual memory, auditory memory, and agility). The first two games require attention, memory, responsiveness, and the maintenance and improvement of cognitive functions. According to a study by [9], memory and attention games can delay the progression of cognitive decline. Incorporating an agility game helps older adults in their motor coordination and reflexes. This is essential to prevent falls and maintain physical independence.[10] emphasize the importance of physical activity and coordination in the quality of life of older adults.

Station 3: gait cycle rehabilitation

The third station (figure 4) aims to strengthen the gait cycle,[11] using artificial vision to obtain data on knee elevation and distance traveled. Physiotherapists will be able to perform a gait cycle analysis with the data obtained, and the patient will work on joint and muscle activation, which will benefit balance re-education, gait cycle rehabilitation, and improved motor control and coordination.

Figure 4. Work panel

It is composed of a box where the patient's card is read, and the artificial vision software part is accompanied by libraries such as opencv and mediapipe to capture video in real-time,[12] detect poses, and analyze movements. Two exercises are available:

Walking exercise, where its main objective is to obtain the average distance between steps, the patient will walk along the bar, and when he/she reaches the end, the corresponding data will be obtained.

Knee elevation exercise counts the number of knee elevations performed in a given time. When the patient completes the set time, the data obtained is sent.

Station 4 rehabilitation stair/slope

The fourth station (figure 5) Aims to rehabilitate the patient's motor skills, balance, and autonomy. It will have distance sensors on the staircase that will count the steps up and down the patient and an infrared sensor that will help determine if the patient has finished crossing the ramp. Its purpose is to monitor the stairs/slope, where the patient must complete the entire sequence on the furniture without skipping any steps. The patient starts by climbing the stairs, and as they go up, there will be a visual stimulation on the stairs to be climbed to motivate the patient. Once they have finished climbing all the stairs, they must go down the ramp and reach the end, repeating the procedure until completing the three assigned sequences.

Figure 5. Staircase/ pending rehabilitation

Implementation of the mqtt protocol

Mqtt is a publish-subscribe protocol.[13] A client can publish a message for a specific topic, and other clients

subscribed to the topic will receive the published messages via the broker.

The geriatric rehabilitation kit uses the emqx broker with quality of service zero. Each station has a dedicated topic, which allows data to be transmitted in an organized manner and enables independent operation of each station. As illustrated in figure 6, the system includes the mqtt protocol with the emqx broker, and the topic and data obtained from each station are indicated.

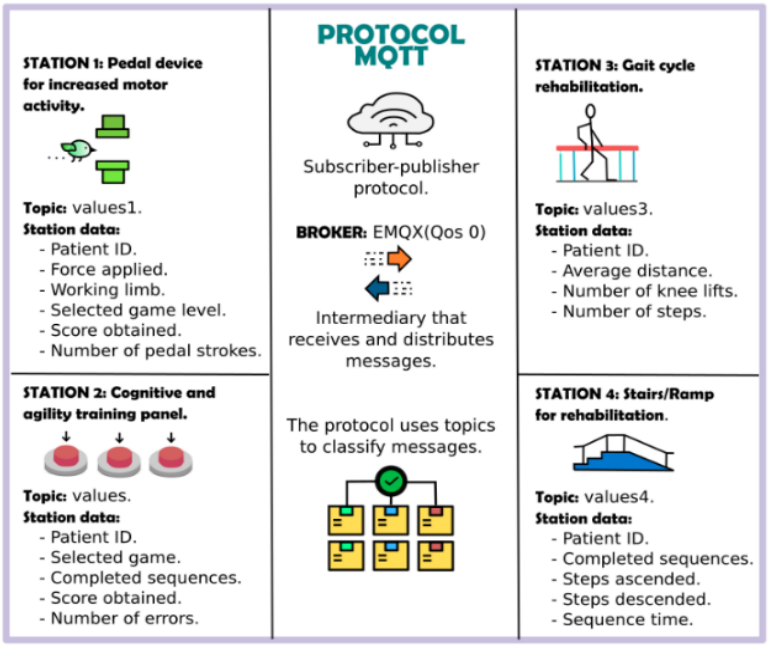


Figure 6. Mqtt stations and protocol

RESULTS

The experimental results validate its effectiveness and highlight the potential for future improvements, such as the incorporation of artificial intelligence for personalized therapy and the integration of new communication protocols to extend the connectivity and functionality of the system, which would allow identifying improvements in motor skills, mobility, and cognitive development. This outcome analysis facilitates the evaluation of the kit's effectiveness and potential contribution to geriatric rehabilitation.

Station 1: pedalboard for increased motor activity

Fecha y Hora de registro	Parte trabajada	Nivel Juego	Puntaje	Cantidad de Pedaleadas	Fuerza pedal Derecho [Newtons]	Fuerza pedal Izquierdo [Newtons]
2024-12-02 10:42:27	Manos	basico	0	2	2.23	2.33
2024-12-02 10:42:46	Manos	basico	1	8	2.23	2.33
2024-12-02 10:43:01	Manos	basico	1	4	2.23	2.33
2024-12-02 10:44:47	Manos	basico	1	0	2.23	2.33
2024-12-02 11:01:55	Manos	basico	0	1	2.08	1.08
2024-12-02 11:02:11	Manos	basico	0	3	2.08	1.08
2024-12-02 11:02:24	Manos	basico	0	4	2.08	1.08
2024-12-02 11:03:13	Manos	basico	6	11	2.08	1.08

Figure 7. Station data 1 patient freddy

The analysis below pertains to the 73-year-old patient freddy. The observed patterns can be visualised in figure 7.

Number of pedal strokes: the values obtained oscillate per session, showing variability between attempts. This reflects differences in the level of effort and time spent, which are influenced by his physical condition, level of fatigue, and understanding of the game.

Applied force: the values recorded for the right and left pedal remain constant between 2,08 and 2,33 n, with minor differences indicating balance in the effort applied by both hands.

Score: in most of the sessions, a score of 1 was recorded, which shows that in the first attempts, the patient was not able to coordinate the visual part with the motor part. This is why there is a big difference between the score and the number of pedal strokes, as the patient was constantly pedaling without looking at the game. After continuous explanations, he was able to have greater coordination and obtain a score of 6 at the end. The patient trends can be observed in figure 8, and a breakdown can be seen.

The number of pedal strokes shows high peaks in specific items, which is related to the optimal performance of the user at those times. In contrast, a lower number of pedal strokes is observed in other sessions, which may be attributed to fatigue or shorter usage time.

The applied forces (right and left) are consistent, with stable lines that reinforce the idea of a uniform level of resistance on the pedalboard, suitable for the basic level.

The score shows stability and remains positive, confirming that the sessions were able to deliver efficiently.

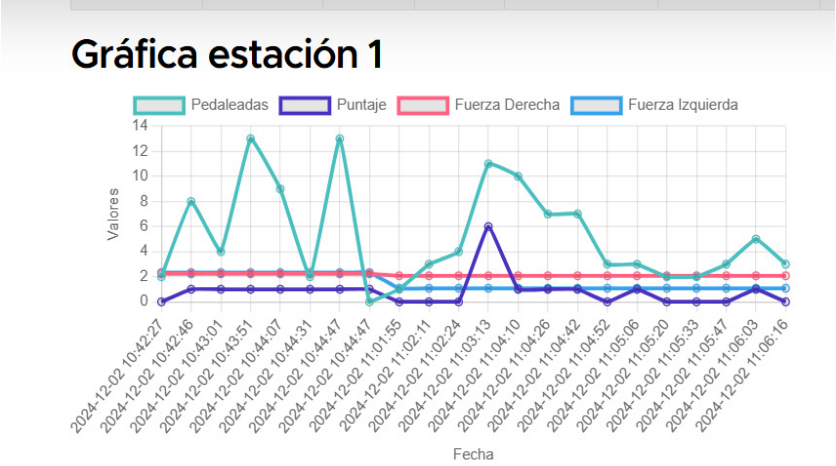


Figure 8. Graph of station 1 patient freddy

Station 2: cognitive and agility work panel

Datos Estación 2: Panel de trabajo

Fecha y Hora de registro	Juego Seleccionado	Secuencias Correctas	Errores	Puntaje
2024-11-27 14:58:56	Juego Agilidad	3	0	30
2024-11-27 15:00:15	Juego Agilidad	3	0	30
2024-11-27 15:05:39	Juego Visual	3	25	-95
2024-11-27 15:06:18	Juego Agilidad	3	25	-95
2024-11-27 15:07:21	Juego Agilidad	3	0	30
2024-11-27 15:07:51	Juego Agilidad	3	0	30
2024-11-27 15:08:22	Juego Agilidad	3	0	30
2024-11-29 11:00:49	Juego Agilidad	3	1	25
2024-11-29 11:01:24	Juego Agilidad	3	1	25
2024-11-29 11:02:16	Juego Agilidad	3	2	20
2024-11-29 11:03:45	Juego Visual	3	3	15
2024-11-29 11:05:06	Juego Visual	3	5	5

Figure 9. Data from station 2 patient olga

The analysis shown belongs to the 86-year-old patient olga; the patterns observed can be seen in figure 9.

Correct sequences: the patient completed all three correct sequences in all sessions, regardless of the number of errors made. This shows that the patient managed to understand and fulfill the station's basic objectives.

Errors: errors show significant variability, ranging from 0 to 25, reflecting different levels of accuracy and difficulty of each game.

Scoring: scores ranged from positive (30) to negative (-95) values. Negative scores are related to sessions with many errors, mainly in the 'visual game,' due to the patient's understanding and level of attention. The patient's trends can be observed in figure 10.

Score: the score shows abrupt drops during the sessions with visual games, where errors reached maximum values. Subsequently, it stabilises in a positive range, suggesting an improvement in accuracy.

Errors: there is a general decrease in errors over time, except in specific sessions. This is due to the level of attention that the patient has, due to her mental condition (mild dementia) she tends to lose focus and again the game is explained and she is encouraged.

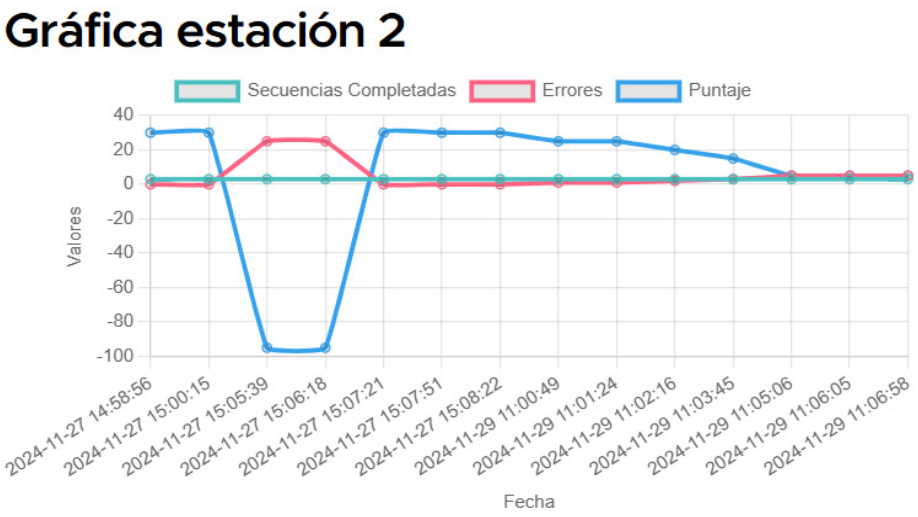


Figure 10. Graph of station 2 patient Olga

Station 3: gait cycle rehabilitation

Datos Estación 3: Paralelas

Fecha y Hora de registro	Distancia de pasos Promedio [cm]	Cantidad de pasos total
2024-12-03 11:05:31	37	4
2024-12-03 11:05:31	37	4
2024-12-03 11:05:45	37	4
2024-12-03 11:05:46	37	4
2024-12-03 11:05:56	25	6
2024-12-17 11:46:33	37	4
2024-12-17 11:46:46	37	4

Fecha y Hora de registro	Elevaciones de Rodilla
2024-12-03 11:05:31	9
2024-12-03 11:05:31	14

Figure 11. Data from station 3 patient alberto

The analysis pertains to patient alberto aged 82 years, the patterns observed can be seen in figure 11.

Average step distance: it is constant in the majority, registering a value of 37 cm in most cases. However, in a single record a decrease of 25 cm is observed, indicating:

- Variations in physical ability (fatigue or decreased strength).
- Changes in technique or posture during the activity.

Total number of steps: shows uniform values of 4 steps in most measurements, with an occasional increase of 6 steps, which could be related to a momentary improvement.

Knee raises: 9 and 14 knee raises were recorded in two consecutive sessions. This difference indicates a progression in the patient's ability. The modality obtained in this exercise is to perform 10 lifts per side for 1 minute. The patient trends can be observed in figure 12.

Step distance: a stable line is observed, which reinforces the uniformity in the average distance achieved by the patient. The slight point decrease could be related to less stability or fatigue.[14]

Number of steps: total step values show stability in consecutive sessions, with slight variations reflecting the physical performance of the patient.

Knee lifts: the graph shows a clear difference in the sessions evaluated, only two were performed due to the patient's knee bending complaint.

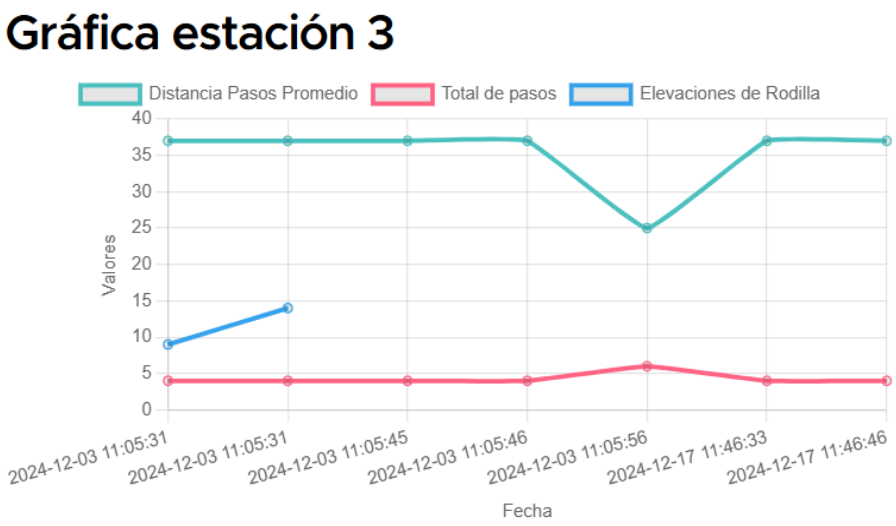


Figure 12. Data from station 3 patient alberto

Station 4 rehabilitation stair/slope

The analysis shown pertains to 86-year-old olga; the patterns observed can be seen in figure 13.

Complete sequences: in both sessions, three complete sequences were completed, reflecting consistency in the patient's performance in achieving the activity. This result is evidence of a controlled level of effort appropriate for a geriatric setting.

Step-ups and step-downs: in the first and second sessions, nine and nine step-downs were recorded, demonstrating a balance of metrics and a symmetrical approach to exercise design.

Total time: the total time required to complete the sequences decreased from 89 seconds in the first session to 79 seconds in the second session. This reduction of 10 seconds indicates an improvement in patient efficiency due to increased confidence, technique, and familiarity with the exercise station.

Datos Estación 4: Rampa/Gradas

Fecha y Hora de registro	Secuecuencias Completas	Gradas Subidas	Gradas Bajadas	Tiempo Total de secuencias
2024-11-29 11:45:18	3	9	9	89
2024-11-29 11:46:54	3	9	9	79

Figure 13. Data station 4, patient olga

The patient trends can be observed in figure 14, the graph shows a consistency in the number of complete sequences and steps up/down. However, there is a decrease in total time, suggesting a positive progression in the user's performance.

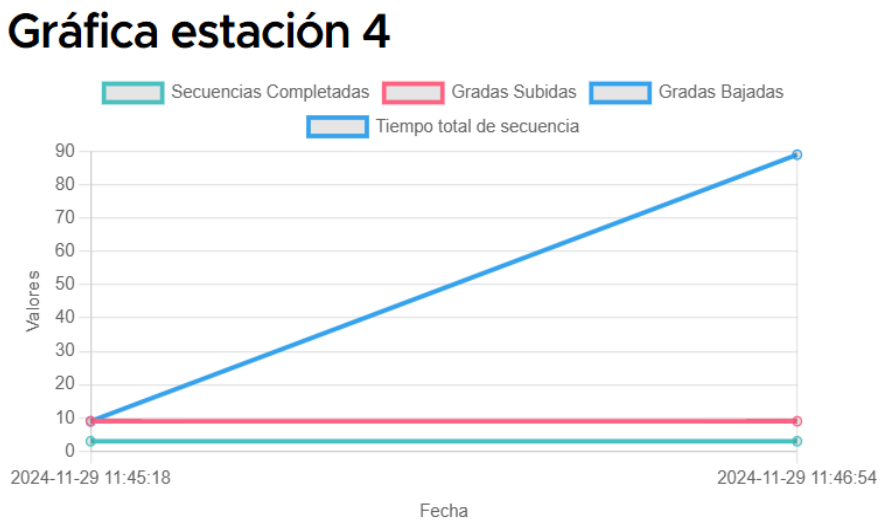


Figure 14. Graph station 4, patient olga

Impact on geriatric rehabilitation

Technology integration in geriatric rehabilitation has transformed patient care by providing innovative solutions that improve quality of life.[15] The rehabilitation kit's design reflects a balance between technology and functionality through the careful selection of electronic components and the incorporation of emerging technologies.

The four dynamic stations address motor and cognitive rehabilitation, offering an innovative and engaging experience. These stations stand out for their ability to operate independently, promoting patients' physical and mental engagement while allowing medical staff to monitor progress efficiently in real-time.

All stakeholders highlighted the kit's positive impact, as seen in the satisfaction survey results. Patients praised the dynamic design of each station and how it motivated them to continue, while medical staff emphasized its usefulness in centralizing information and merging technology with medicine.

Figure 15. Geriatric centre validation process. A) station 1. B) station 2. C) station 3. D) station 4

The satisfaction survey was designed to assess the perception and satisfaction of patients and medical staff regarding the use and functionality of the geriatric rehabilitation stations. This instrument was structured with specific questions covering various aspects such as ease of use, comfort during exercise, perceived physical improvement, and usefulness of the device for rehabilitation. The survey seeks to collect quantitative data to validate the effectiveness of the design and operation of the stations and identify possible areas for improvement in implementation.

Patients: six patients, five male and one female, were surveyed. The majority are between 80 and 89 years of age.

The survey results reflected a high level of user satisfaction with the geriatric rehabilitation stations (figure 16). The majority of participants rated the ease of use and comfort during exercise sessions positively, indicating that the equipment's design meets the necessary standards for the geriatric population. Also, a significant percentage of respondents reported a perception of physical improvement and alertness after using the stations, validating their effectiveness as a therapeutic tool.

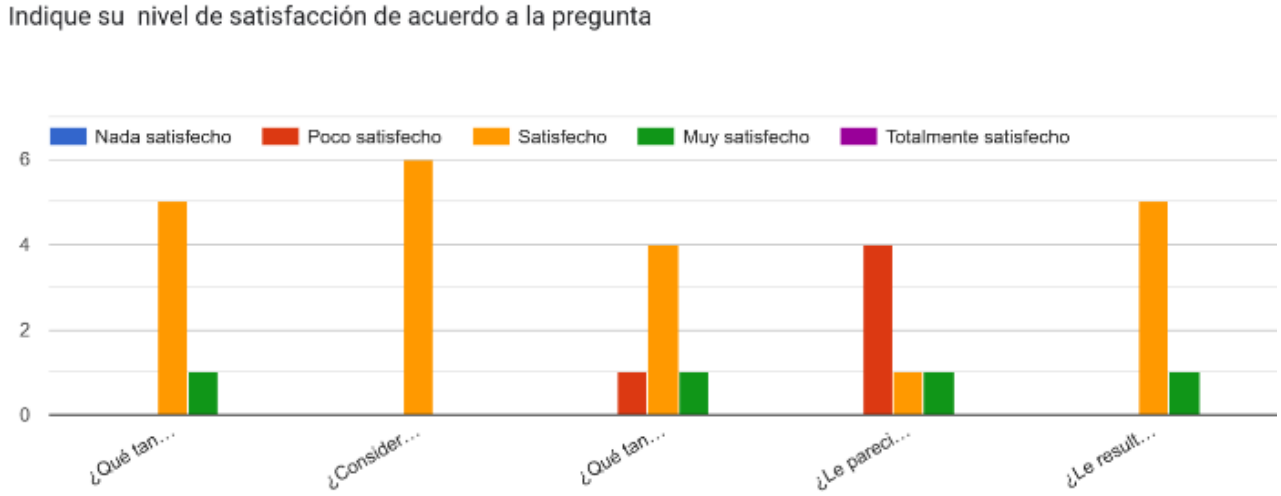
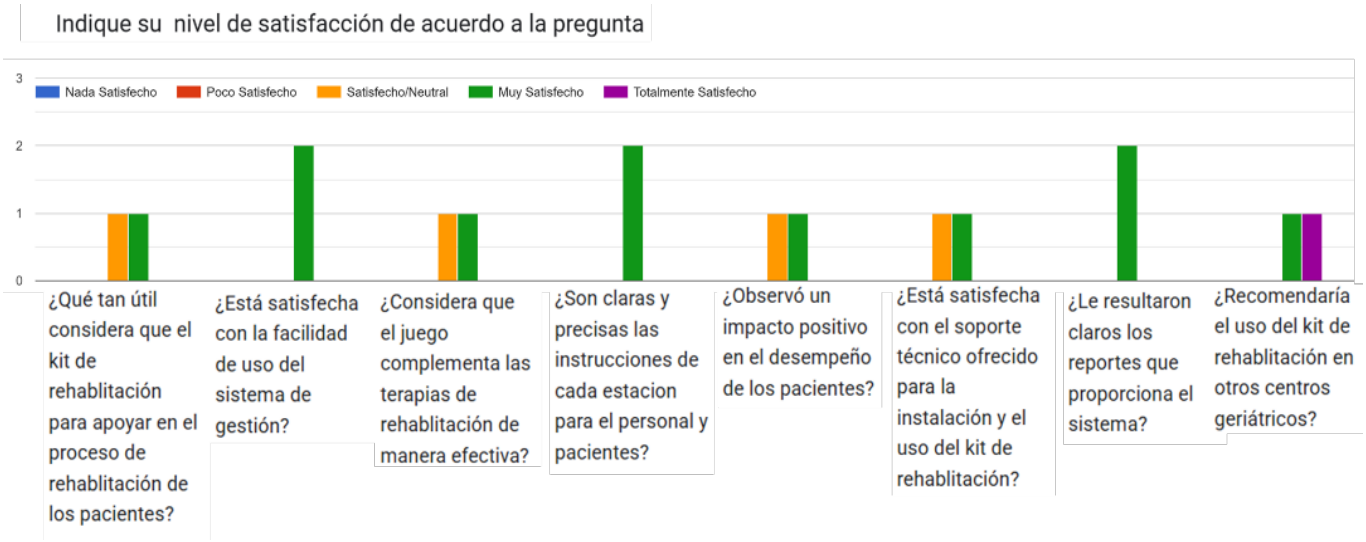


Figure 16. Patient satisfaction survey graph

Medical staff: two health staff users were surveyed, including a doctor specializing in general medicine and a physiotherapist.

The analysis of the responses indicates high levels of satisfaction, with outstanding scores in questions related to the perception of physical improvement and the stations' adaptability to the patients' individual capabilities (figure 17).



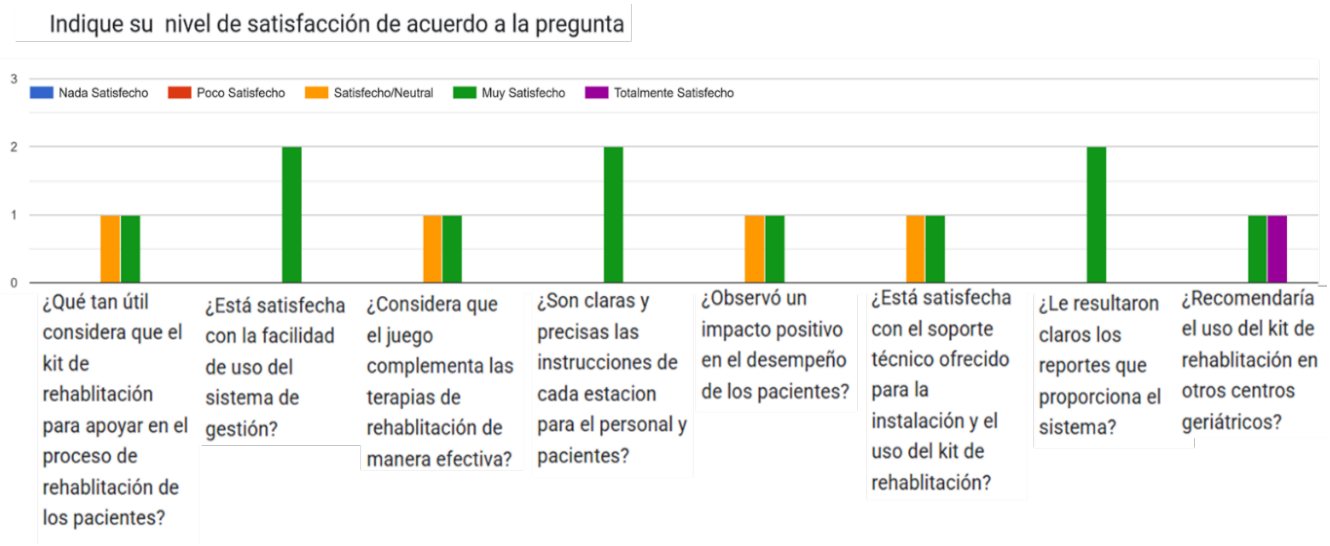


Figure 17. Medical staff satisfaction survey graph

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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