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Rehabilytec: Adaptive Video Games with Natural Interfaces for Children's Motor Neuro-Rehabilitation

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Abstract. The article reports on the first phase of the Rehabilytec project developed in collaboration with CRIT Michoacán, México. The central purpose of the project is to develop adaptive video games that, in addition to facilitating the physical rehabilitation of children, offer an entertainment experience that allows them to temporarily distance themselves from the medical environment, which is often related to therapies involving pain. The video games developed allow monitoring of upper body movements, which are detected by advanced sensors integrated into the Orbbec Astra camera. These sensors accurately record the patient's range of joint movement, allowing the system to automatically adjust the video game parameters based on the degree of mobility detected, thus optimizing the interaction and the rehabilitation process. The system includes a web platform for therapists, where they can configure and customize the video games for each patient, as well as track their progress through graphs and statistics. The Game-Scrum methodology and a programming environment with Unity and C# were used in the development of the video games. This article shows that the implementation of serious video games can contribute significantly to physical rehabilitation therapies, being well received both by therapists, who can personalize them and track the track patients progress, and by children, who do their therapies with greater motivation.

Keywords. Adaptative videogame, neurorehabilitation, interfaces.

1 Introduction

In recent years, there has been an attempt to combine technological advances with important areas of health, such as neuroscience and rehabilitation, resulting in applications such as adaptive video games that seek not only to motivate patients and involve them in recreational activities, but also to contribute to improving motor control, coordination, and neurological recovery.

According to Strüder, Weicker and Winkelmann [1], neurorehabilitation "refers to efforts to improve the brain's ability to control and regulate cognitive, emotional and motor functions through the application of specific therapeutic techniques. "Neurorehabilitation can include a variety of approaches, such as physical therapy, occupational therapy, speech and language therapy, cognitive and psychological therapy, and can be a long and complex process that requires long-term care and monitoring, so having the intervention of technological applications is a factor that has been decisive in improving the "patients treatment".

Direct collaboration with specialized therapists from CRIT (Telethon Children's Rehabilitation Center) has provided the medical knowledge that underpins the innovation made in the development of adaptive video games with natural interfaces for motor neurorehabilitation. This represents a significant advance in the treatment of children with motor difficulties, using video games with natural interfaces such as motion sensors and cameras, to enable a more intuitive and natural interaction.

On the other hand, by having a personal scan according to the individual capabilities of the patients, video games offer a more efficient and attractive rehabilitation experience, improving

Fig. 1. Project Collaborators (Medical Director and Therapist at CRIT Michoacán)

motivation and therapeutic performance. This approach not only optimizes the rehabilitation process, but also facilitates more accurate monitoring of progress, contributing to a faster and more effective recovery.

These video games are designed to adapt to the specific capabilities and needs of each child, adjusting the difficulty and offering feedback in real time. Constant and personalized interaction helps optimize of therapeutic results, making the rehabilitation process more accessible and effective.

1.1 Motivation

Physicians and physical therapists from CRIT (Teletón Children's Rehabilitation Center) in Michoacán, Mexico, collaborated on the development of this project. It was developed to support rehabilitation therapies for children with motor disabilities. It is expected to be used by 450 children who may have brain or neurological injuries that limit motor control of their upper and lower extremities to varying degrees (cerebral palsy, spastic diparesis, spastic hemiparesis, muscular dystrophy, limb-girdle dystrophy, brachial plexus injury, etc.) and who are currently receiving treatment at the CRIT facilities.

Direct contact with therapists and patients has enhanced the importance of this work, as data were collected both before and after the intervention, allowing observation of the impact of therapies performed through movements that usually cause pain. When these movements are carried out within the context of the video game, children are able to move their limbs with less pain, as their attention is focused on scoring points in the game rather than physical discomfort.

The project plans to continue developing more video games, under the guidance of therapists working in the rehabilitation of various physical disabilities.

2 Related Work

This section presents various investigations into how video games and new technologies have contributed to and benefited rehabilitation. This implies that these video games and applied technologies (such as robotics) have been designed and developed under the supervision of specialized therapists. In a more specific context, two of the most widely used therapy systems are Tyromotion's PABLO system and Microsoft's Kinect peripheral [2].

Although they have very different purposes and/or approaches, they are among the most widely different, as one (PABLO) is primarily a robotic tool to facilitate therapies, while the other, Kinect has always been used as an entertainment device for video games.

In the case of the PABLO® system [3], it is a robotic system developed to perform therapies for the hands, torso, head, and lower body. However, it is also limited in that many of the exercises presented may or may not reliably benefit certain diagnoses. PABLO works thanks to a manual sensor and small motion sensors; the former is firmly attached to the hand targeted for therapy and provides relevant information to the software, such as position, tilt, applied pressure, among others [3].

Focusing the research to video game applications for rehabilitation, the following

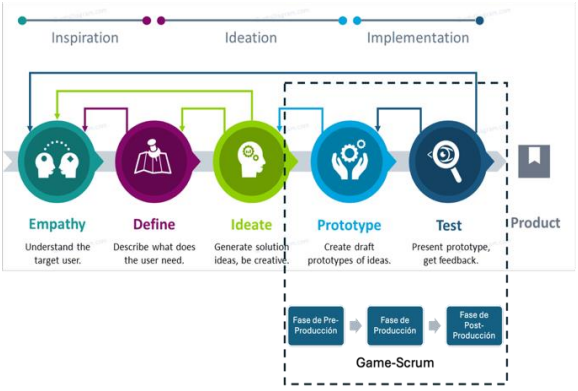

Fig. 2. Design Thinking and Game-Scrum methodologies applied in the project

applications use natural user interfaces to support rehabilitation:

1. Rehametrics. This is a cognitive rehabilitation software used in the medical field to help patients with acquired brain injury or neurodegenerative diseases recover their cognitive abilities. It is only available in Spain [4].

2. Evolrehab. EvolvRehab Body is a set of therapy modules for upper and lower extremity rehabilitation. It is used worldwide in inpatient, outpatient, and home settings. The system has been designed to include content for a wide range of skills for different neurological conditions. Evolrehab has received medical certification as a rehabilitation method [5].

3. General Kinect games. Such as Kinect Sports [6], are recreational games with no rehabilitation purpose but that involve repeated exercises are used in some rehabilitation centers. These games are not customizable to the patient's range of motion.

Finally, it is important to mention one of the most significant and nearly unique initiatives in the development of video games for rehabilitation in Mexico: the IFC at UNAM.

According to an article published in UNAM's Gaceta [7], the Institute of Cellular Physiology (IFC) at UNAM is developing video games associated with position and movement sensors, as well as devices for the rehabilitation of patients with neurological damage caused by a cerebrovascular event (stroke). Their goal is not to replace conventional physical therapy for patients who have survived a heart attack or stroke, but rather to complement it.

The same article specifies that the multidisciplinary team at LANR has developed 10 video game-type applications, four of which were tested in 2019 in a pilot project with patients from the National Institute of Neurology and Neurosurgery in Mexico City, with encouraging results.

To conclude this section, it is relevant to mention a documentary research that carried out a systematic review of works published between 2015 and 2020, where the use of video games and motion capture systems for the physical rehabilitation of upper limbs is explored, and technologies, diagnoses and possible challenges are identified. Using the PRISMA method, 19 articles were selected from databases such as Scopus, Pubmed, IEEE Xplore and Web Science, and it was concluded that the most relevant factor of the projects was developing systems that included precise motion capture, being adaptive video games and having monitoring platforms [8].

3 Proposed Work

The work presented in this article has been designed, developed, implemented, and tested in the field of pediatric physical therapy rehabilitation, using various tools, technologies, and work methodologies, which are detailed below.

3.1 Proposed Methodology

The project's underlying methodology is a blend of Design Thinking, as it is user-centered and distinguished by two essential characteristics in this type of proposal: Innovation and empathy; and Game Scrum, which is proposed solely for the development and prototyping of video games [9]. The combination of these two methodologies applied in the project can be seen in Fig. 2.

The objective of the Design Thinking methodology is to understand user needs and meet them with the most suitable, feasible, and viable solutions. This methodology was selected because it goes beyond developing a product and keeps the user in mind from the beginning of the project. This was essential given the empathy that must be

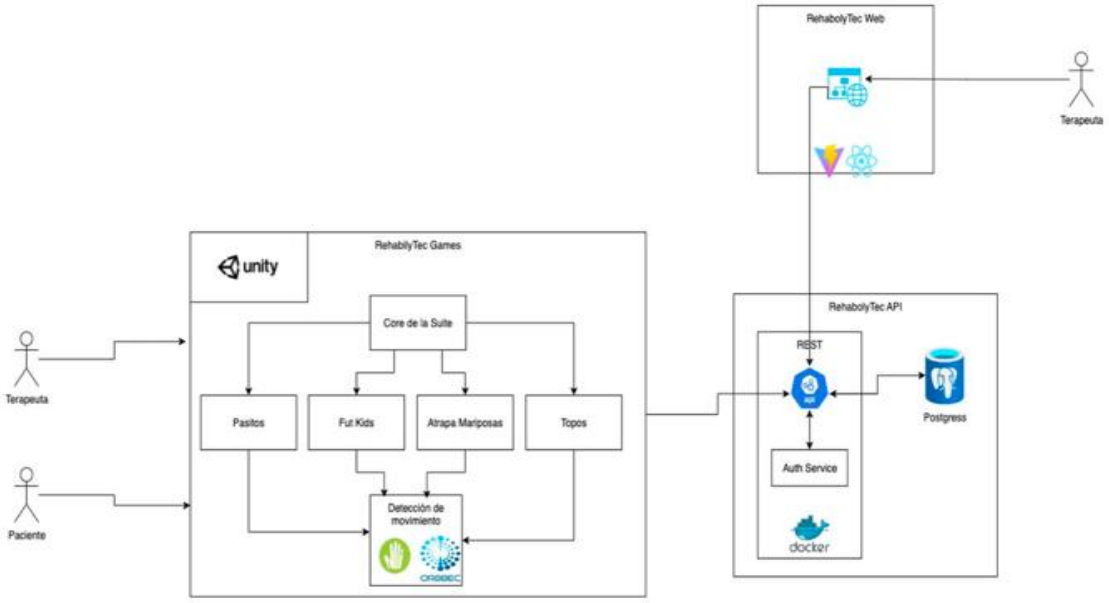

Fig. 3. Project Architecture of RehabilyTec (Source: Own)

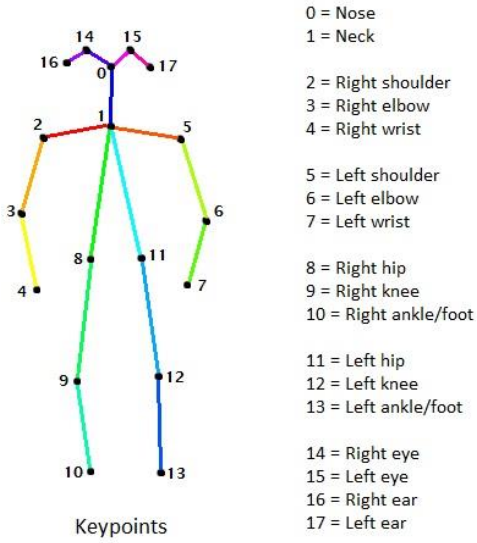

Fig. 4. Body tracking format with its 18 key points following the representation of the skeleton

shown toward the patients for whom the project is intended.

The phases of this methodology are: Empathize, Define, Ideate, Prototype, and Test. In the Prototyping phase, the Game-Scrum methodology was used to carry out the development of the video games.

Although video games are located within the software category, there is no development methodology that is a standard and that ensures

the quality of the development and its processes in this area of video games, so the Game-Scrum methodology was chosen proposed by Godoy and Barbosa [10] which is based on the SCRUM and XP methodologies dividing the development process into three phases, pre-production, production and post-production. This methodology is also proposed by other authors such as Rollings and Adams, Callele, Neufeld and Schneider and Bethke [11,12,13].

3.2 Project Architecture

This section presents the general architecture of the RehabilyTec project, showing users, tools, and communication between applications. Figure 3 shows the users of this video game suite, as well as the elements interconnected with the database.

It is important to highlight the role of the therapist in the architecture. They can use a web application to view the time and movements performed by each patient during their video game sessions. These results are stored in the database and can be consulted at any time via a website, allowing patients' progress and results to be reviewed.

Also, as can be seen in the architecture of Fig. 3, the patient is sensed through the infrared of the Orbbec camera, which measures the patient's length ranges and angles of movement, to configure the video game parameters so that they adapt to the patient´s physical abilities. Once configured, it will be displayed on the monitor or screen in front of the patient.

3.3 Body Tracking

The body tracking module focuses on detecting and tracking a person's bones. A detected bone is represented by its two endpoints, known as key points. The ZED camera can provide 2D and 3D information about each detected key point. In addition, it produces local rotation between adjacent bones [14].

The body tracking module also uses a neural network for key point detection and then uses the SDK's depth and position tracking to obtain the final 3D position of each key point. The ZED SDK supports multiple body shapes [14].

Fig. 5. Gaming Suite Login

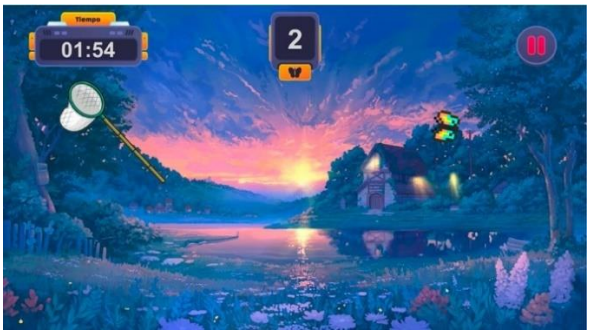

Fig. 6. Butterfly Catcher video game interface

3.4 Design of Games

The Video Game Suite currently includes two video games designed to contribute to upper motor rehabilitation therapies, and one for lower motor rehabilitation.

The development of each video game was carefully guided by the expertise of physicians and therapists from CRIT, who provided ongoing input into the design of the specific movements that the games would encourage in players.

3.4.1 Butterfly Catcher Video Game

Its main objective is to contribute to the therapies of patients with upper motor disabilities by performing arm movements within the range of amplitude detected by the camera sensor at the start of the video game.

This video game consists of catching a series of butterflies that appear on the player's screen, taking into account that to start the game they must assign them a series of basic configurations, such as the

game time in seconds, the number of butterflies that will appear during the game, which cannot exceed the game time with the ratio 1 to 1, one butterfly per second; There is also a section of enemies, in this case bees, which cannot exceed the number of butterflies between two, with the ratio of 1 to 2, one bee for every two butterflies; and most importantly, the movement limit configuration.

After completing the initial setup, the patient accesses the game's home screen. There, they must move their selected hand (right or left, depending on the previous setup) to catch as many butterflies as possible, avoiding bees if they have been added as enemies. This process supports the rehabilitation of arm extension and promotes improved overall mobility.

At the end of the game, a summary of the patient's results is presented.

3.4.2 Space Adventure Video Game

Its main objective is to contribute to the balance and motor mobility of the upper body of patients, enabling lateral movements of the body without losing stability.

This video game aims to help children maintain balance and improve their ability to maintain an upright posture, thus resulting in improvements in their spine. The Space Adventure game involves dodging a series of meteorites falling from the screen, and using their torso to move the rocket so it doesn't get destroyed.

The configuration of the Space Adventure video game encompasses settings for both the speed and quantity of meteorites that descend during gameplay. If the player's rocket is destroyed and the game is lost, encouraging visual and auditory messages are provided to the player. The goal is to prevent frustration and to support a positive experience, even when success is not achieved. Based on therapist recommendations, each game session is limited to a maximum duration of three minutes.

3.4.3 FutKids Video Game

The main objective of this video game is to contribute to the rehabilitation therapies of children with motor disabilities in their lower and upper limbs, through the simulation of stopping balls in a goal, using their feet (lower limbs) or their hands (upper limbs).

Fig. 7. Space Adventure video game interface

Fig. 8. Initial interface of the Futkids video game

Fig. 9. Setting parameters for the video game (performed by therapists)

This video game unfolds within a two-dimensional environment, where the child takes on the role of a fictional goalkeeper. Throughout the session, the game generates a specific number of

balls at configurable intervals, ensuring each round is tailored for therapeutic engagement.

The player's primary objective, in their role as goalkeeper, will be to intercept these balls with any part of their body before the established time expires for a goal to be scored.

The video game must be able to collect key metrics, such as the number of saves made and the number of goals conceded, organized into categories by top, middle, and bottom. It must also be able to record the total time elapsed during the game session. These data must be presented in a concise and structured manner at the end of the game, allowing for a clear evaluation of the player's performance based on the previously established parameters.

The game ends after three minutes by displaying on screen the data and results obtained during the game.

3.5 Patient Control and Monitoring

To ensure effective progress tracking in rehabilitation therapies, a dedicated web platform has been developed for managing and monitoring sessions. This system streamlines therapist registration, allowing practitioners to easily set up their accounts and add patients to the network for ongoing therapy oversight.

Once registered, therapists can access each patient's history, view key metrics obtained during gaming sessions, and analyze performance over time. This structured approach enables efficient information management, aiding in therapeutic decision-making and personalizing rehabilitation treatments. Figures 10 and 11 show the therapist and patient registration webpages.

The results displayed after each patient played one of the video games during their therapy (always under the supervision of the therapist who created the session) included: type of game used, difficulty level, points achieved, time taken, flexion angles, extension levels, and the limb used. This summary is displayed upon completion of the video game and is also stored in the patient's file so the therapist can review it later.

Results are reviewed in two stages: upon completion of the game, the patient's statistics can be viewed, or at an unspecified time when the

Fig. 10. Therapist Administration Page

Fig. 11. Patient Administration Page

Fig. 12. Patient results at the end of the game

Fig. 13. Sensing the limits of a patient's upper and lower limbs

therapist wishes to review each patient's records or history.

4 Experimentation and Preliminary Results

4.1 Preparing for the Testing Phase

At the end of the development phase, the created video games were prepared for evaluation in a real-world environment. The video game was installed on a laptop, which was then taken to the testing area within the CRIT facilities. In this space, both the Astra camera and the screen used to display the video games were connected.

Before beginning the testing, the medical team and therapists received a training session. During this training, the procedure for using the video games was detailed, including the calibration of the motion sensors, the configuration of specific therapy parameters for each patient, and the process for recording and reviewing the results of each session.

4.2 Beginning of Experimentation

Due to the confidentiality of underage patients, we were only allowed to show some photos of the tests performed on patients and a sample of the data collected during the tests.

Usability and acceptance tests were conducted by therapists and a group of patients who were likely to be users of the video games. Functional tests were performed by physical therapists from the development phase. They tested the sensing limits for limb movement, sounds, alerts, speed of video game elements, timing, and difficulty settings to ensure that the sensing and movement configuration were correct.

Figure 13 shows the detection of a patient's limbs movements during the pilot tests conducted to collect preliminary results.

Likewise, in figures 14 and 15 you can see the patient using the video game Butterflies at different times and with different degrees of difficulty.

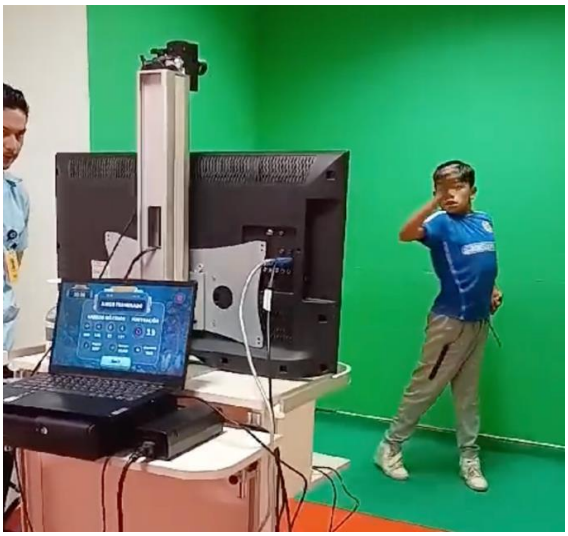

Fig. 14. Patient using the Butterfly Catcher video game

Fig. 15. Patient using the Butterfly Catcher video game with a higher level of complexity

Table 1. Total number of patients who have used video games

Videogame	#Total Use	Lower Motor	Upper Motor
Butterfly Catch	123	123	0
Space Adventure	59	59	0
FutKids	96	43	53

Tabla 2. Data from a patient with hemiparesis using the Butterfly Catcher video game for 4 weeks

IdPaciente	puntuacion	idExtremidad	anguloMaximo	derechoMaximo	izquierdoMaximo	arribaMaximo	abajoMaximo
10102	20	2	178.851227	183.270691	167.412811	119.138947	145.346527
10102	21	2	179.635757	171.427414	174.700333	94.1943741	151.813171
10102	14	1	180	173.6530151	160.307709	74.6177	136.348969
10102	15	2	178.215347	135.415527	70.91051	46.2454453	133.7229
10102	11	2	179.886353	27.113289	126.11409	71.761449	132.82016
10102	11	2	179.903076	162.767914	103.410545	83.354744	129.998688
10102	26	2	179.947647	119.968	94.07158	77.9381256	133.994034
10102	14	2	179.865829	111.533409	157.4947	108.8507	139.219345

Tabla 3. Data from a patient with Cerebral Palsy using the Butterfly Catcher video game for 1 week

idPaciente	idExtremidad	anguloMaximo	derechoMaximo	izquierdoMaximo	arribaMaximo	abajoMaximo
5394	1	179.6231	125.551636	83.92084	55.95958	193.321808
5394	1	180	78.27907	62.85899	88.48686	193.321823
5394	1	180	91.9377747	70.00899	81.9474	144.871582
5394	1	180	89.02498	137.114075	110.868347	193.321808
5394	1	180	124.808815	124.338074	94.56961	144.0153

4.3 Preliminary Results

The video games were developed to support rehabilitation therapies for children with motor disabilities. They are expected to be used by at least 450 children at the CRIT in Michoacán who may have neurological or brain injuries that limit motor control of their upper and lower extremities to varying degrees and who are currently receiving treatment at the CRIT's rehabilitation facilities.

The Butterflies Catch videogame has been the most widely used because it was the first to be developed and released for pilot testing. However, the FutKids video game is gaining wider application because it can exercise both the upper and lower motor systems.

Table 1 shows the use of the video games, already installed and running, over a 3-month period with different patients.

As can be seen in Table 1, although the butterfly video game has been used more, the Futkids video game has a greater range of use among patients with upper and lower motor disabilities.

Some of the parameters recorded in the video games, in addition to their general data, are: Gameplay, difficulty, limb used (left or right), maximum angle of movement, maximum right, maximum left, maximum down, maximum up, time, score, average playing time.

Each patient is scheduled for two weekly visits to the CRIT virtual room, resulting in eight sessions per month. Table 2 presents the data from a patient diagnosed with hemiparesis, whose rehabilitation therapy included the Atrapa Mariposas video game for one month.

As can be seen in Table 2, the maximum ranges recorded in the patient's body sensing were always exceeded by the maximum angle reached in the

video game, except for the first time he used it. This was independent of the limb used (1 left, 2 right).

A preliminary observation could be that patients "forget" their movement limitations when playing and concentrate on scoring points (or catching butterflies). Thus, their ranges of motion are expanded while playing.

The angles of each limb differ in each patient, depending on the diagnosis established by the therapist, however, the maximum angles recorded during the video game have always been higher.

Table 3 shows that the patient with cerebral palsy, whose physical rehabilitation is based on the assessment of motor skills, muscle tone, reflexes, and posture to identify delays in motor development, also showed progress in his angles of movement when using the Butterfly Catcher video game.

The following graph in Figure 17 shows the results obtained during 5 sessions with an 8-year-old girl with cerebral palsy

One observation made by the therapists was that patients look forward to this part of their therapy because it involves less pain when performing the movements. This is not because they avoid doing them, but because they are not fully aware of performing them while focusing on earning points in the video game. They even achieve a greater range of motion without being aware of it.

It should be noted that this assessment is subjective and reflects the therapists' perception based on their experience with patients who have been receiving treatment at CRIT for some time. However, preliminary numerical data results confirm this for now.

Fig. 16. Graph showing the maximum angles recorded during sensing and those reached during the video game

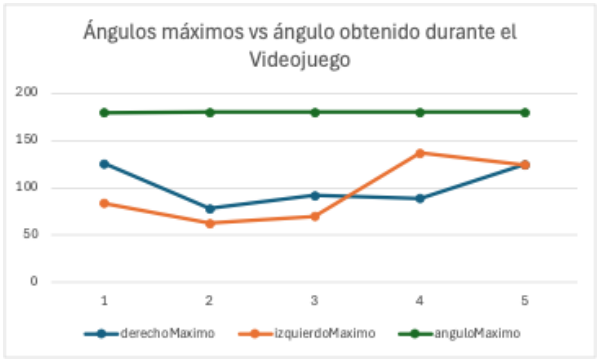

Fig. 17. Graph showing the maximum angles recorded during sensing and those reached during the video game of a girl with cerebral palsy

5 Conclusion and Future Work

The preliminary results presented here are a small sample of the data still being collected. Further research has begun on the impact of video games as a support tool for motor rehabilitation therapies for pediatric patients.

In Mexico, there are 24 Teletón Children's Rehabilitation and Inclusion Centers (CRIT). These centers are distributed throughout the country and offer rehabilitation services to children and young people with neuromusculoskeletal disabilities. In addition to the 22 CRITs, there is also the Teletón Children's Oncology Hospital (HITO) and the Teletón Autism Center (CAT) [15].

The proposal under discussion is to use two CRIT institutions to evaluate the progress of patients with and without the support of video games, while also aiming to continue developing more projects of this type for other conditions that cause disabilities in children and young people.

The FutKids video game is currently being tested on a group of patients with both upper and lower motor disabilities. At the same time, another group of patients with the same diagnoses will be receiving therapy without the support of these video games. Therefore, short-term results are expected to help guide future research and the development of video games.

Finally, the possibility of making these video games accessible in patients' homes was considered, providing greater support for therapy and avoiding travel to the CRIT facilities, given that many families are low-income and it is difficult to transport patients with them. Since the video games record movements, scores, times, and relevant progress data, therapists can monitor their patients even without being present at the CRIT.

The project is already deployed in the cloud, so if this proposal is approved, families will have immediate access.

Acknowledgments

This work has had the collaboration of doctors and physical therapists from the Teletón Children's Rehabilitation Center (CRIT) in the state of Michoacán, as well as graduate and engineering students.

We greatly appreciate the advice, work, and dedication of everyone involved in the project. We share the same vision: "May science and technology be a light for those who need it most and hope where others see limits.".

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