PocketRehabv3: Gamified Android-Based Physical Rehabilitation Monitoring System with Bluetooth Wearable Sensors

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Abstract* — Addressing the challenges of traditional physical rehabilitation monitoring systems, PocketRehab emerges as an innovative Android-based solution that transforms the rehabilitation experience through gamification. The platform leverages Bluetooth-connected wearable sensors and introduces dynamic elements such as points systems, progress bars, auditory feedback, an interactive shop, and achievement systems to engage patients throughout their rehabilitation journey. Offering five essential exercises, PocketRehab turns routine tasks into enjoyable activities, fostering a sense of accomplishment. The task management system allows doctors to customize exercise parameters, including repetitions, intensity levels, schedules, and duration, ensuring personalized rehabilitation. Separate logins for doctors and patients, along with animated routines, real-time movement detection, and referral and appointment systems, enhance accessibility and convenience. Addressing the monotony of repetitive exercises, PocketRehab combines wireless wearable devices with an Android-based mobile application for remote monitoring. Accurate joint angle estimation and repetition tracking by Bluetooth-connected sensors showed system accuracy ranging from 91% to 99.5% and an angle joint estimation error of 1% to 3% in a study involving 30 patients with immobility issues. The gamified version yielded higher engagement scores, particularly among patients aged 51 to 59, with notable progress observed over six sessions in eight weeks. By offering a gamified experience, PocketRehab ensures improved patient engagement and more effective recovery outcomes compared to traditional non-gamified applications.

***Keywords*— gamified rehabilitation program, Android-based monitoring, Bluetooth wearable sensors, gamification, user engagement, rehabilitation outcomes, Arduino-Nano 33 BLE**

I. INTRODUCTION

Physical rehabilitation is a crucial component of recovery from various injuries and illnesses. Traditional rehabilitation often involves repetitive exercise routines performed in a clinical setting under the supervision of a therapist. While effective, these routines can become monotonous and lead to patient boredom, potentially hindering treatment adherence [1].

Gamification, denoting the integration of game-like attributes into non-game contexts, has gained considerable traction, particularly evident in the rising popularity of gamified mobile applications associated with heightened user engagement [2]. By incorporating game elements such as rewards, challenges, and progress monitoring into the realm of telerehabilitation, patients can experience heightened involvement in their rehabilitation programs, fostering increased motivation, adherence, and ultimately, improved rehabilitation outcomes.

Existing telerehabilitation system, such as PocketRehabV3, a pair of wearable devices that measures patients' range of motion during exercises, introduces gamified elements into the mobile application, accompanied by additional patient-centric features. These enhancements include shop system, unlockable achievements, progress bars, auditory feedback, and background music during routines, along with the integration of customizable scheduled tasks within the mobile application, aiming to enhance the overall rehabilitation experience for the user [3].

This research project endeavors to gamify telerehabilitation and develop an innovative physical rehabilitation monitoring system equipped with Bluetooth wearable sensors. The aim is to introduce an engaging element into the treatment process, yielding benefits for both patients and healthcare professionals through exploration and implementation of gamified approaches in the realm of telerehabilitation.

The goals of the study is to: (1) Develop a gamified mobile application utilizing Bluetooth wearable sensors to enhance patient engagement; (2) Evaluate the impact of gamification on telerehabilitation outcomes through systematic assessments.

II. METHODOLOGY

In this study, 30 adult participants were tested to evaluate the accuracy of movement detection and angle joint estimation using a gamified telerehabilitation system. The procedure involved participants using both non-gamified and gamified versions of a rehabilitation device across multiple sessions. Each participant's movements were tracked using sensors connected to a mobile application, which displayed the number of successful repetitions for various exercises. Additionally, participants wore a digital goniometer to measure joint angles, and these measurements were compared with the app's estimations to determine percentage error. Surveys were conducted to assess engagement levels and user satisfaction, ensuring the effectiveness of the gamified system. This comprehensive approach enabled the researchers to collect accurate data on movement detection and joint angle estimation, providing valuable insights into the system's efficacy.

A. System Flow

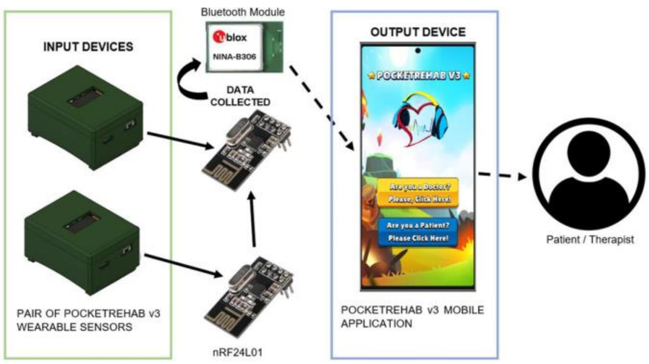

Fig 1. System Architecture

Figure 1 presents a detailed view of the overall system, outlining the integrated components designed to enhance the telerehabilitation experience. Positioned as the primary input devices are the pair of PocketRehab V3 devices, each equipped with an nRF24L01 transceiver in which captures and transmits data during rehabilitation sessions. The collected data undergoes a streamlined transmission process via Bluetooth, utilizing the embedded Bluetooth module within the Arduino Nano 33 BLE, As the data reaches the main device, the output is channeled into a gamified mobile application. This application stands as the user-facing interface, designed to process, analyze, and present the acquired data in an easily comprehensible format. Beyond conventional data representation, the gamified aspect introduces an engaging layer to the rehabilitation process.

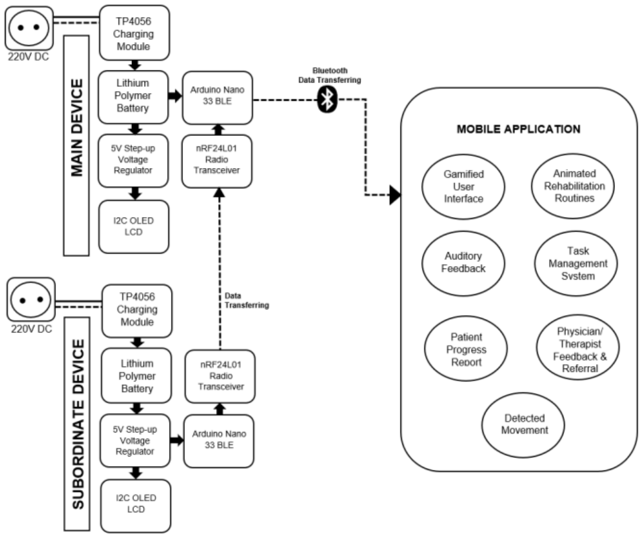

Fig 2. Block Diagram

The system comprises several components: a switch, battery management system (BMS), Arduino Nano BLE Sense, I2C OLED LCD, and nRF24L01. The Arduino Nano, LCD, and nRF24L01 are all powered by the BMS. The Arduino Nano 33 BLE Sense integrates an LSM9DSI 9-axis IMU and a NINA B306 Bluetooth module. The LSM9DSI includes an accelerometer, gyroscope, and magnetometer, which are utilized for measuring the range of motion (ROM) and angles between joints. Raw data collected from each device connected to the Arduino Nano is transmitted to the nRF24L01 transceiver and then processed through a calibration program. The calibrated data is transferred to an Android application via the NINA B306 Bluetooth module. The output of the LCD is for added visual indication. Added output for mobile application, it features gamified UI, animated routines, detected movement feedback, patient progress report, physician feedback and referral, task management system, and auditory feedback.

B. Design of the Device

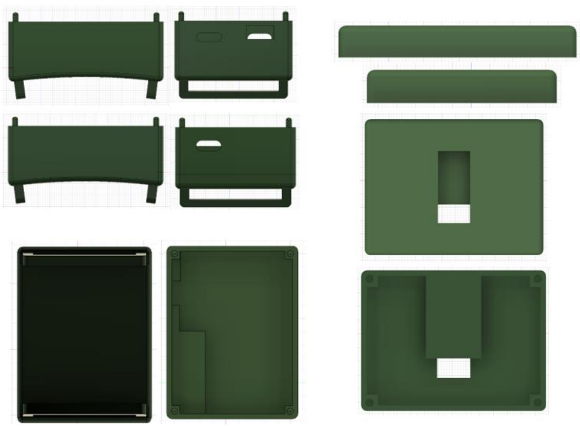

Fig 3. External Chassis Design

Figure 3 illustrates the external chassis with measured dimensions of: Length = 67 mm, Width = 51 mm, and Height of curvature = 24.083 mm, standard Height: 28.4; the chassis follows a slight bending of surface facing the user for an ergonomic usage, hence, having two heights. The chassis design incorporates specific holes to facilitate access to the switch, two ports, and an LCD display. The SPDT switch, located on the exterior of the chassis, can be toggled on or off. Additionally, there are two ports situated outside the casing: a Type-C charging port for device recharging and a Type-B micro-USB port for programming purposes. An LCD display is also positioned on the side of the chassis, providing additional visual indications to guide users during their sessions.

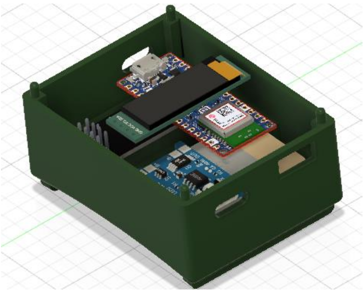

Fig 4. Internal Components

Figure 4 depicts the internal arrangement of the components utilized in the device. These components can be configured by opening the top lid of the device, a process carried out during hardware configuration and troubleshooting.

C. Design of the Application

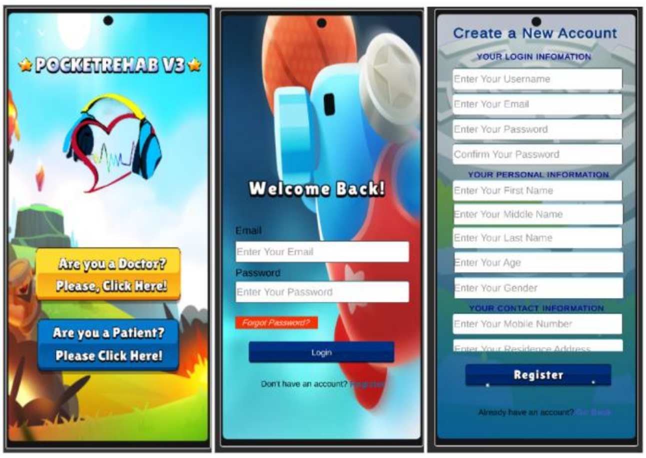

Fig 5. Login and Registration System UI

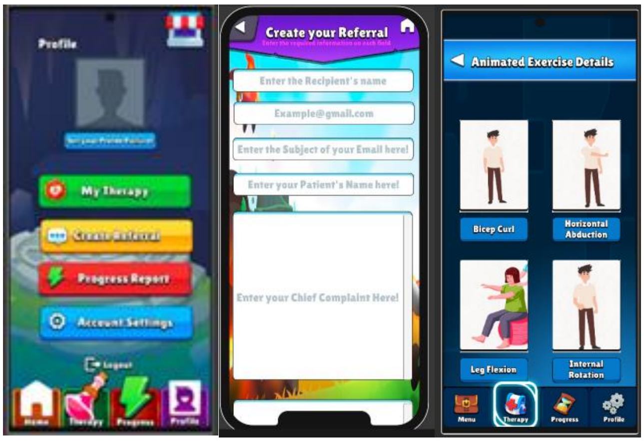

Fig 6. User Profile, Doctor Referral Sytem and Exercise Details UI

Figure 5 showcases the user interfaces for patients' and doctors' profiles, illustrating the design for a seamless login and registration process. The login section features input fields for existing users to enter their username and password, along with a "Login" button to submit their credentials. While Figure 6 shows the user interfaces for patients' and doctors' profiles. In the doctor's interface, physicians can recommend their patients to other physical rehabilitation practitioners. Additionally, the figure presents five exercises for the patient to choose from: Bicep Curl, Horizontal Abduction, Leg Flexion, Internal Rotation, and Shoulder Flexion.

Fig 7. Integrated Games UI

This figure shows the integrated mini-games that provide motivational exercises to patients. Patients can choose from five different game types, each corresponding to a specific exercise type from the exercise details. The difficulty level of the games is based on the doctor's prescribed task, which includes the game's intensity and the required number of successful repetitions, each calibrated to achieve a specific angle.

D. Functionality

Fig 8. Testing of Device and Application

Figure 8 shows a patient wearing the PocketRehab kit attached to her arms while performing an exercise. Before starting, the patient connects the application to the wearable device using Bluetooth. Once paired, the patient selects the appropriate exercise and its equivalent game, with levels and repetitions set by the doctor. The device sends information needed to determine the angles and repetitions for each exercise, displaying real-time angles in the application. When the prescribed angle is reached, the application records a game score until the required score, or repetitions are achieved. Patients can see their progress and success rate for each exercise, and the results can be viewed by the physician. Before deploying the device to patients with mobility issues, it was tested on five individuals without physical mobility impairments.

EXERCISES	TESTED ANGLES				
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
SHOULDER FLEXION	90^{0}-109^{0}	110^{0}-129^{0}	130^{0}-149^{0}	150^{0}-169^{0}	170^{0}-180^{0}
HORIZONTAL ABDUCTION	60^{0}-74^{0}	75^{0}-89^{0}	90^{0}-104^{0}	105^{0}-119^{0}	120^{0}-180^{0}
INTERNAL ROTATION	90^{0}-104^{0}	105^{0}-119^{0}	120^{0}-134^{0}	135^{0}-149^{0}	150^{0}-180^{0}
BICEP CURL	90^{0}-104^{0}	105^{0}-119^{0}	120^{0}-134^{0}	135^{0}-149^{0}	150^{0}-180^{0}
LEG FLEXION	45^{0}-54^{0}	55^{0}-64^{0}	65^{0}-74^{0}	75^{0}-84^{0}	85^{0}-180^{0}

Table 1. Corresponding Angle Ranges for each Exercise and Their Levels

Table 1 shows the corresponding range of angles for each exercise and their levels. Patients are required to reach these range of angles in order to count the repetion for each exercise.

E. Accuracy Testing

Movement Detection Accuracy

The accuracy of movement detection was evaluated by comparing the actual number of repetitions performed by the patients to the successful repetitions detected and displayed by the PocketRehab mobile application (detected movements). For this analysis, the contained movements were set at 15 repetitions per exercise for one set. Patients were allowed to complete as many sets as they desired. The total number of repetitions per session was summed to obtain the actual number of repetitions. The mean accuracy for each exercise was calculated using the formula:

$$Accuracy\ (\%) = \left(\frac{Detected\ Repetitions}{Actual\ Repetitions}\right) \times 100$$

Angle Joint Estimation Percent Error

The percentage error in angle joint estimation was assessed by comparing the angle measurements displayed by the PocketRehab mobile application to the actual angles measured by a goniometer. The percent error was calculated for each exercise at different difficulty levels. The percent error for each angle measurement was calculated using the formula:

$$Percent\ Error = \left(\frac{V_{observed} - V_{true}}{V_{true}}\right)$$

III. RESULTS

A. Functionality Testing Results

EXERCISES	ACCURACY (IN %)									
	LEVEL 1		LEVEL 2		LEVEL 3		LEVEL 4		LEVEL 5	
	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
BICEP CURL	100	100	93.33	100	86.67	100	100	100	93.33	100
SHOULDER FLEXION	100	100	93.33	100	100	100	93.33	100	86.67	100
HORIZONTAL ABDCUTION	100	100	86.67	100	93.33	100	93.33	100	80.00	100
INTERNAL ROTATION	100	100	100	100	93.33	100	93.33	100	93.33	100
LEG FLEXION	100	100	93.33	100	100	100	86.66	100	100	100

Table 2. Accuracy of Movement Detection for Random Testing

Table 2 displays the highest and lowest reach accuracies for each type of exercise across all available levels in the game. Remarkably, the table highlights that the interval between the lowest and highest accuracies is almost negligible in most cases. The accuracy percentages are calculated based on 15 repetitions of each exercise. For instance, if out of 15 actual repetitions, the device detected 13 movements correctly, the accuracy would be 86.67% (13/15). This method ensures a consistent reference point for understanding the detection accuracy across different exercises and levels.

EXERCISES	PERCENT ERROR (%)				
	LEVEL 1	LEVEL2	LEVEL 3	LEVEL 4	LEVEL 5
BICEP CURL	0.63	0.75	0.8	0.84	1.97
SHOULDER FLEXION	1.63	0.66	1.68	1.43	2.59
HORIZONTAL ABDUCTION	4.32	1.75	2.04	2.70	3.85
INTERNAL ROTATION	1.09	1.21	0.80	0.92	2.51
LEG FLEXION	3.82	2.24	1.49	1.44	1.09

Table 3. Accuracy of Angle Joint Estimation for Random Testing

Table 3 presents the percent error of Angle Joint Estimation for each exercise across different levels. These results were collected from the same ten random individuals.

B. Deployment Results

EXERCISES	ACCURACY (in %)									
	LEVEL 1		LEVEL 2		LEVEL 3		LEVEL 4		LEVEL 5	
	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
BICEP CURL	86.67	100	86.67	100	76.67	100	86.67	100	86.67	100
SHOULDER FLEXION	93.33	100	86.67	100	80	100	73.33	100	76.67	100
HORIZONTAL ABDUCTION	85.19	100	86.67	100	73.33	100	83.33	100	83.33	100
INTERNAL ROTATION	90	100	90	100	73.33	100	88.89	100	90	100
LEG FLEXION	93.33	100	86.67	100	86.67	100	96.67	100	91.11	100

Table 4. Accuracy of Movement Detection for Deployment

Table 4 shows the high and low accuracy of detected movement from the deployment results. The accumulated findings from the onsite and house-to-house deployment were the data in this table.

EXERCISES	ACCURACY (in %)				
	LEVEL 1	LEVEL2	LEVEL 3	LEVEL 4	LEVEL 5
BICEP CURL	98.26	98.08	94.56	91.31	93.34
SHOULDER FLEXION	98.79	98.19	94.91	92.09	92.22
HORIZONTAL ABDUCTION	96.67	96.55	95.44	93.49	91.67
INTERNAL ROTATION	97.95	97.83	95.67	93.88	94.44
LEG FLEXION	99.5	98.49	98	98.89	95.93

Table 5. Overall Accuracy of Detected Movement

Table 5 presents the overall accuracy of detected movement across various exercises at different levels. The data, derived from the average results of patients' exercises, reveal an inverse relationship between exercise level and accuracy. Specifically, as the exercise level increases, accuracy tends to decrease. This trend is observed in exercises such as bicep curls, shoulder flexion, horizontal abduction, internal rotation, and leg flexion. This inverse relationship is likely due to patients' difficulties in achieving the required range of motion (ROM) at higher levels because of their mobility limitations. Consequently, higher accuracy at advanced levels indicates that the patient can move the affected body part through a broader range.

EXERCISES	PERCENT ERROR (%)
BICEP CURL	1.85
SHOULDER FLEXION	1.78
HORIZONTAL ABDUCTION	2.27
INTERNAL ROTATION	2.19
LEG FLEXION	1.95

Table 6. Overall Percent Error of Angle Joint Estimation

Table 13 displays the overall percent error for both on-site and house-to house deployments. The data indicate that exercises involving vertical movements, such as Bicep Curl, Shoulder Flexion, and Leg Flexion, exhibit lower percent errors compared to exercises involving vertical movements. This pattern is consistent with the inevitability of errors in manual angle measurement.

EXERCISES	VERSION 2 PERCENT ERROR (%)	VERSION 3 PERCENT ERROR (%)	ERROR DIFFERENCE	REMARKS
BICEP CURL	6.40	1.85	-4.55	Significant Improvement
SHOULDER FLEXION	2.75	1.78	-0.97	Minor Improvement
HORIZONTAL ABDUCTION	1.67	2.27	0.60	Slight Increase
INTERNAL ROTATION	6.53	2.19	-4.34	Significant Improvement
LEG FLEXION	7.68	1.95	-5.73	Major Improvement

Table 7. Overall Error Difference of Angle Joint Estimation

Table 7 displays the error difference between two different versions of telerehabilitation device. Version two ranges from two percent to eight percent error in angle joint estimation. The data in version three exhibit a lower percent error, indicating a higher accuracy percentage compared to version two. The error differences indicate significant improvements in most exercises with the new version, except for a slight increase in the percent error for horizontal abduction. Overall, the newer version shows a marked reduction in errors, demonstrating enhanced accuracy and effectiveness in the exercises.

IV. CONCLUSION

The research successfully met its objectives, demonstrating the system's effectiveness and reliability. The study developed advanced wireless wearable devices featuring a Lithium-ion Battery Management System and Arduino Nano 33 BLE, achieving exceptional accuracy in movement detection and joint angle estimation. The programming of the Arduino Nano 33 BLE facilitated high accuracy levels, with a notable reduction in percent error compared to previous versions, and effective data transfer via the Bluetooth module (NINA B306). The PocketRehab V3 device demonstrated superior reliability and precision in angle estimations and movement detection, making it highly suitable for rehabilitation purposes. The gamified mobile application further enhanced user engagement, and survey results confirmed significant differences in engagement levels between the gamified and non-gamified versions. Overall, patient progress improved notably over six rehabilitation sessions, particularly during gamified sessions.

V. RECOMMENDATIONS

To enhance the effectiveness and usability of PocketRehab V3, several key recommendations are proposed. First, expand the variety of exercises to cover a broader range of muscle groups and joint movements, ensuring the system can adapt to diverse rehabilitation needs. Second, refine existing features and introduce new game types, challenges, and rewards to sustain and boost patient engagement and motivation throughout their rehabilitation journey. Finally, develop versions of the application compatible with iOS to increase accessibility and reach a wider audience, thereby maximizing the impact and benefits of telerehabilitation for a larger population of patients.

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