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Comprehensive and Gamified Rehabilitation System for Upper-Limb Impairment Treatments

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1. Introduction

Upper limb (UL) motor impairments can be referred to as problems such as muscle weakness, loss of dexterous movement, and reduced sensation. Subsequent to a UL impairment, patients are often referred to physiotherapy for rehabilitation to improve range of movement, reduce pain, and regain function. Unfortunately, there are plenty of drawbacks and hindrances in the conventional rehabilitation process. Problems such as transportation difficulties for people with disabilities, expensive costs of treatment, the paucity of the workforce, and lack of motivation and repetitive practices in a rehabilitation process are challenges caused by conventional ways of treatment. Many studies have been conducted to show the effectiveness of gaming in the medical field. Gamification transforms a typically tedious task into something enjoyable that motivates users to participate in rehabilitation activities. In this article, a novel comprehensive rehabilitation system with a special focus on patients with UL impairment is presented. The main novelty lies under the comprehensive system capable of coping with various problems in conventional rehabilitation procedures, an efficient data acquisition system, appropriate and well-designed games completely compatible with physical rehabilitation exercises, and a software tool for tracking the patients' performances.

2. System Overview

i. Data Acquisition System (Hardware Design)

This sensor-based device is designed from scratch in order to collect and process propitious movement data. It includes a lithium battery and a battery charger module to supply the power of the system, an ESP8266 chip as a Microcontroller, and a Wi-Fi module for transferring data, an Inertia Measurement Unit (IMU), Regulator, one switch, and one status representer LED.

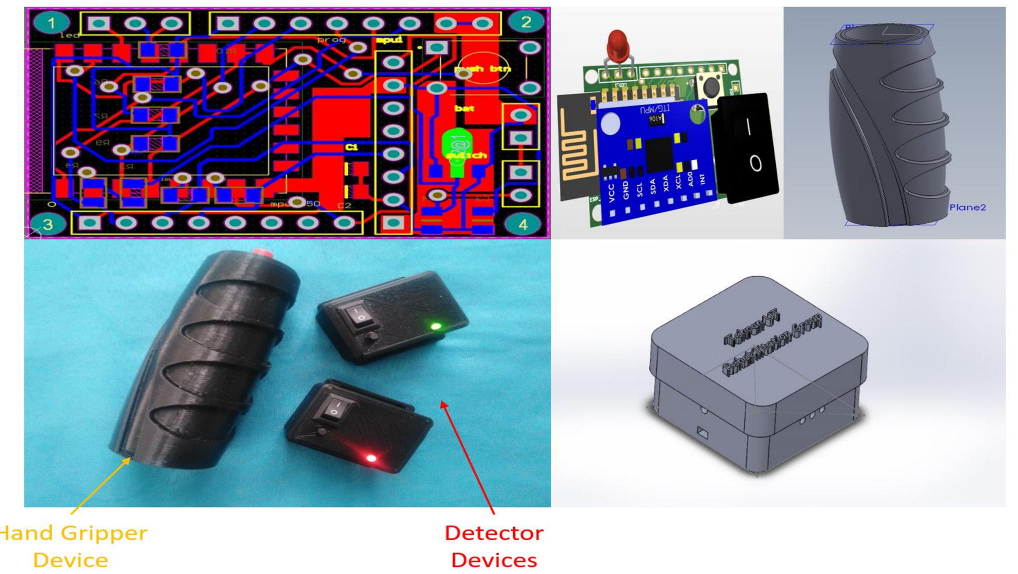

Fig. 1. Hardware structure from circuit and 3D design to final devices

ii. Graphic User Interface Design (Software Design)

The main software consists of a Graphic User Interface (GUI) and a controller in order to manage all the complexity behind the system. GUI is responsible for displaying pertinent diagrams and patients' information in order to track the improvement of individual patients and provide a complete and convenient environment for rehabilitation centers so that they can manage their clients properly. One of the important features of this software is that patients can use the system in their homes while stored data and favorable analyses are transferred to a server that is connected to the doctors' computer. So, they can supervise clients' practices remotely; this feature obviates transportation problems. Another salient problem related to the previous gamified systems is that they are not user-centered, as they are not compatible with every patient. However, in this system, users and experts can set appropriate goals for everyone according to their state of health and personal characteristics.

iii. Graphic User Interaction Design (Game Design)

Games in this system are designed in various forms and concepts in order to create good interaction and motivate patients to increase the movement domain of their impaired body parts. Every game is designed with respect to a group of related practices so that it just focuses on recovery instead of fantasy. Games are implemented by Unity, a game-developing platform with C# programming language. Achievements in these games get harder gradually at a reasonable pace so that patients do not get disappointed and stay enthusiastic during training.

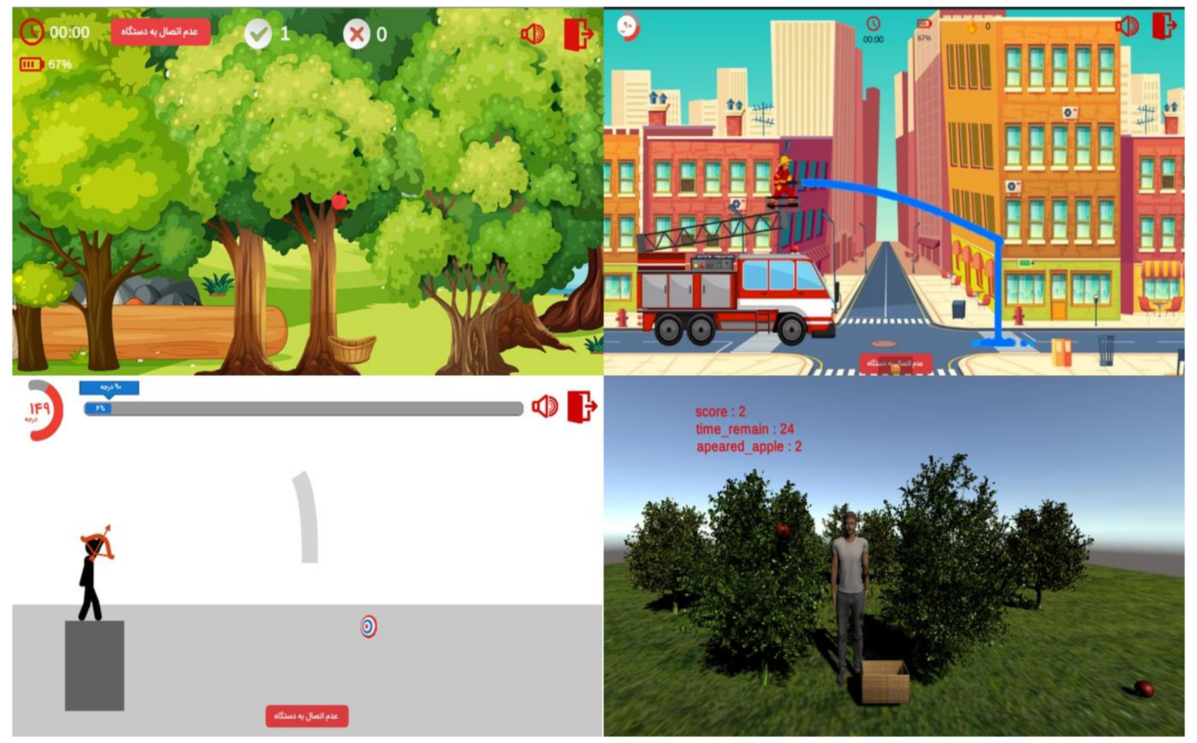

Fig. 2. Screenshots of the four games

3. Research Methodology

i. Participants

To assess our platform, we selected patients from a wide age range (youngest 15 years old and oldest 73 years old). In total, we selected twelve UL patients who voluntarily wanted to participate in our experiment. The subjects (45.3 ± 17.7 years old) consisted of 8 females and 4 males who were all diagnosed with UL impairments and were prescribed physiotherapy sessions. To evaluate all aspects of our platform, we tried to include all kinds of UL impairments (7 shoulder impairments, 2 elbow impairments, 2 wrist impairments, and 1 with both shoulder and elbow impairment) with various causes. Nine cases of UL impairments were caused by trauma, one by Diabetes, one by Stroke, and one due to Multiple Myeloma. Subjects were in different stages of their treatment (8 in the middle stages, 3 in the late stages, 1 in the early stages) and completed the experiment voluntarily.

ii. Experimental Setup and Study Protocol

In our experiment, Firstly, the sensing device was worn on the impaired part of the subject's UL using attached straps to the sides of the device. The subject was asked to move their impaired part as much as they could. By doing this, the range of motion of the patient's impaired part was recorded while they had no interaction with a computer. After that, the same subject was asked to play the corresponding games. As the subjects played the game, the movements of their impaired part were recorded. The subjects kept playing the games as long as they did not feel discomfort in their impaired part.

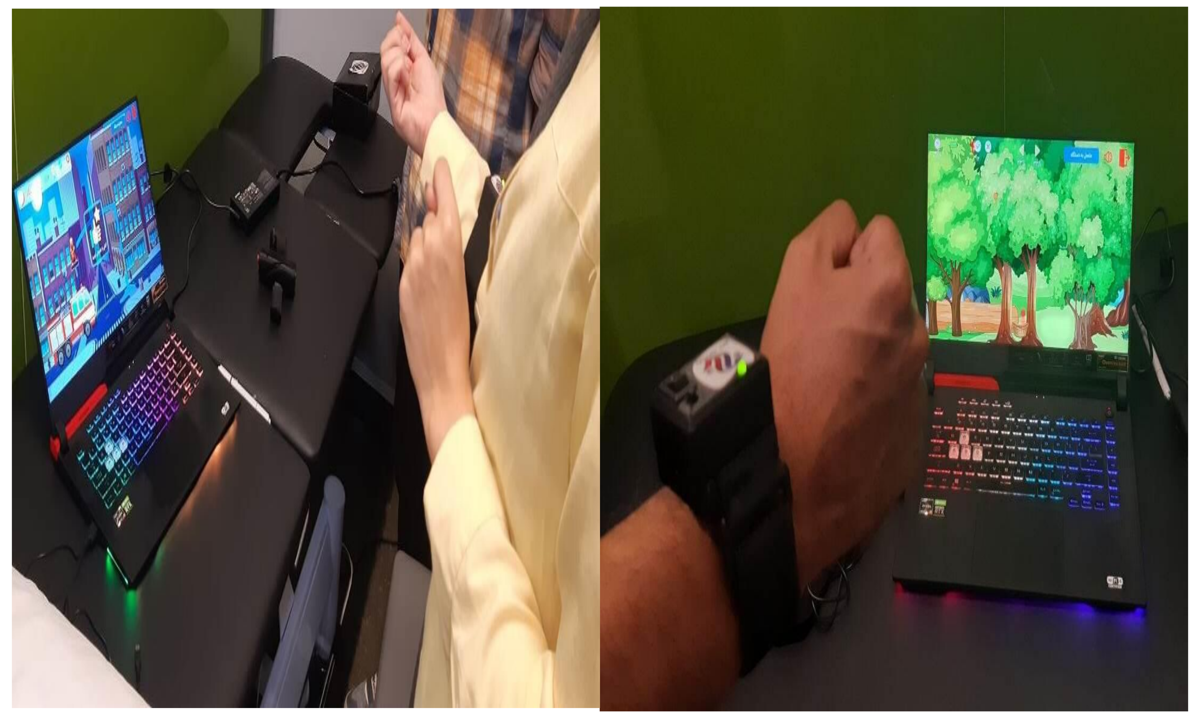

Fig. 3 Snapshots of subjects playing different games

4. Results

We designed a comprehensive questionnaire with consultations with medical experts. The participants scored the survey sheet qualitatively on a six-point scale from 0 to 5. The questionnaire is demonstrated in Table 1, and the results are shown in Table 2.

Table. 1. Questionnaire

Q1	How much do gamified practices help you to continue the exercises?
Q2	How much do you prefer this method of exercising over conventional methods?
Q3	How much did this method motivate you to increase your range of motion?
Q4	How much do you like to practice with this device in your home?
Q5	How convenient was the usage of this device?
Q6	How much do you think that this device would decrease the need for occupational therapists?
Q7	How satisfied are you with the increasing difficulties of the games?
Q8	How do you evaluate the overall difficulties of the games?

Table. 2. Questionnaire Assessment by Subjects

Patients		Questions							
ID	Specifications(S,A,L)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	M,O,E	5	5	5	5	5	3	5	5
2	F,M,M	3	5	5	5	5	5	2	3
3	M,M,E	5	5	5	5	5	5	5	5
4	F,O,M	5	5	5	3	5	4	4	5
5	F,O,M	4.5	5	5	4	5	5	4	5
6	F,T,E	3.5	4	4	4	4	4	3	3
7	F,O,M	5	5	5	4	5	5	5	5
8	F,Y,M	5	5	5	3	5	4	5	3.5
9	F,M,B	4	4	4	4	5	3	5	4
10	F,O,M	3.5	4	5	4	5	3	5	3
11	M,M,E	4	4	5	5	5	3	5	3
12	M,M,M	3	4	4	3	5	4	2	3
	Mean	4.21	4.58	4.75	4.08	4.92	4.00	4.17	3.96
	STD	0.81	0.51	0.45	0.79	0.29	0.85	1.19	0.96

Abbreviation: S:Sex(M-Male,F-Female), A-Age(O-Old,M-Middle-aged,T-Teenager,Y-Young), L-Level of Treatment(E-End, M-Middle, B-Beginning)

Furthermore, in order to evaluate the efficacy of our platform with a systematic and quantitative method, we compared the range of motion of the patient's impaired part while interacting with a computer and when doing conventional exercises without interaction. Surprisingly, working with this system increased the movement domain of patients' impaired body parts by 13.5 degrees on average in Abduction exercises and 9 degrees on average in Flexion exercises. The increase in the range of motion for each patient is depicted in Fig . 4.

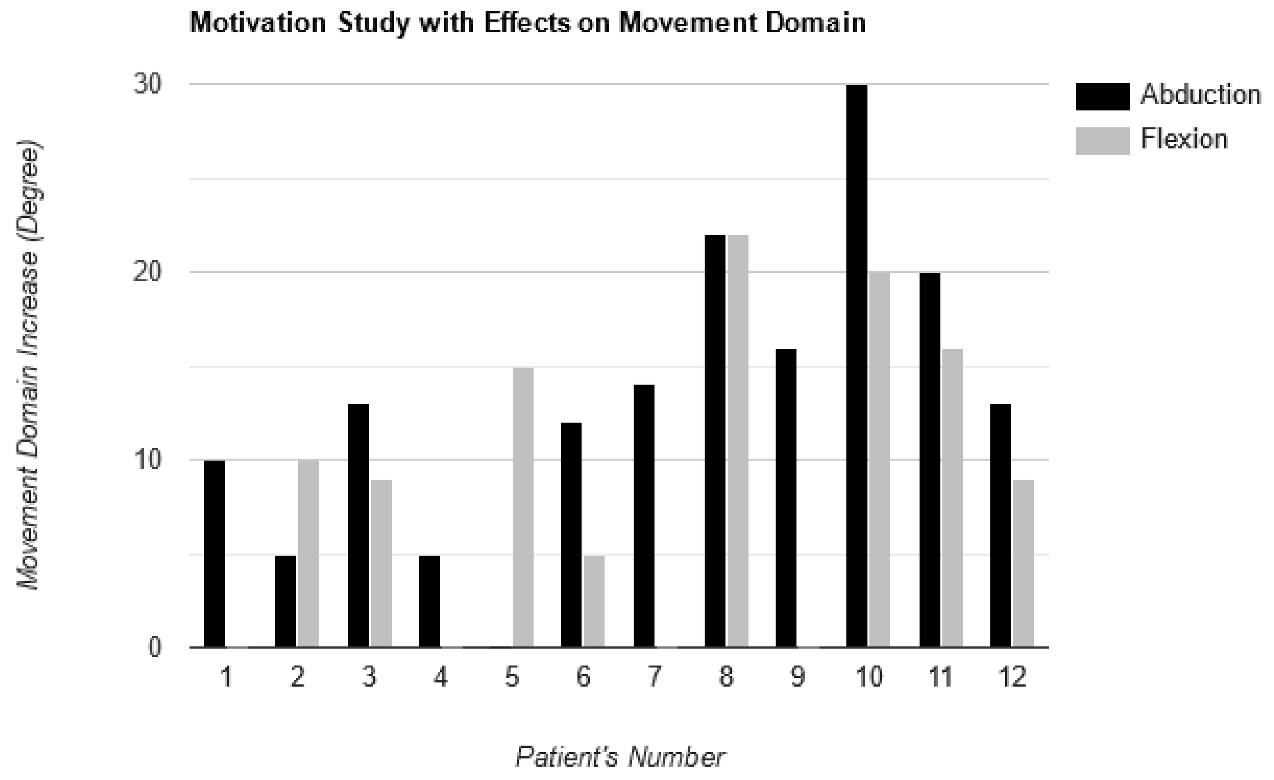

Fig. 4. Increased Range of Motion for Each Subject

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