Demo Abstract: BIGHand - A Bilateral, Integrated, and Gamified Handgrip Stroke Rehabilitation System for Independent at-Home Exercise

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ABSTRACT

Effective home rehabilitation is important for recovery of hand grip ability in post-stroke individuals. This paper presents BIGHand, a bilateral, integrated, and gamified handgrip stroke rehabilitation system for independent at-home exercise. BIGHand consists of affordable sensor-integrated hardware (Vernier hand dynamometers, Arduino Uno, interface shield) used to obtain real-time grip force data, and a set of exergames designed as parts of an interactive structural rehabilitation program. This program pairs targeted difficulty progression with user-ability scaled controls to create an adaptive, challenging, and enticing rehabilitation environment. This training prepares users for the many activities of daily living (ADLs) by targeting strength, bilateral coordination, hand-eye coordination, speed, endurance, precision, and dynamic grip force adjustment. Multiple measures are taken to engage, motivate, and guide users through the at-home rehabilitation process, including "smart" post-game feedback and in-game goals. A demo video is available at https://youtu.be/zrLVkZZ4Ukc.

KEYWORDS

Rehabilitation, Stroke, Smart Health, Sensor System, Exergame

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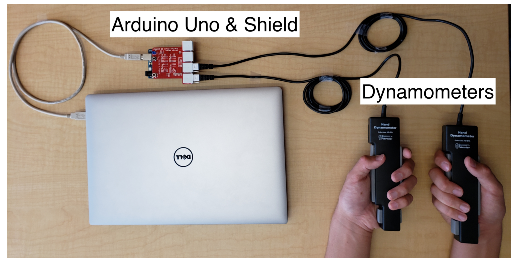

Figure 1: Setup of hardware sensor system.

1 INTRODUCTION

Stroke affects 800,000 Americans per year [4]. Post-stroke individuals commonly experience paresis of the hand, losing dexterity and speed in functional gripping movements [10]; grip strength is also decreased post-stroke [8]. This impairment makes activities of daily living (ADLs) [3] especially difficult for post-stroke individuals. Affected activities include using a steering wheel, squeezing toothpaste tubes, and holding silverware. Thus, it is important to effectively rehabilitate hand grip ability post-stroke.

Modern therapy systems attempt to provide home rehabilitation for upper extremities, including grip ability, in the absence of a rehabilitation professional [5–7, 9]. Systems such as MusicGlove [2] use sensor-equipped gloves for exergames involving functional gripping movements. However, this approach did not target grip strength or bilateral coordination; additionally, it lacked adaptive difficulty progression of exercises. Although other systems had adaptive difficulty and post-game performance analysis, their exergames focused on gross upper extremity training, neglecting dynamic fine motor training of hands [1].

To address these limitations, we propose BIGHand, a bilateral, integrated, gamified hand grip stroke rehabilitation system for independent at-home exercise. BIGHand features a structural rehabilitation program which includes a comprehensive set of interactive exergames. These exergames target a wide range of hand grip abilities that are applicable to ADLs, including strength, bilateral coordination, hand-eye coordination, speed, and more. Two hand dynamometers are used to accurately obtain real-time grip force data from each hand, allowing for high-precision fine motor training in these exergames. Difficulty is automatically scaled to the user's current maximum grip force, which is measured at the beginning of each exergaming session. To engage and motivate patients, each exergame has built-in goals with real-time quantitative positive feedback (e.g., more stars and higher numerical scores for improved motor performance), and interesting visuals. Furthermore, our system provides post-game qualitative "smart" feedback directly to users, analyzing areas where user performance could improve; this gives guidance and structure to the program.

2 BIGHAND DESIGN

Our system consists of sensor integrated hardware, exergame software, and data maintenance and analysis.

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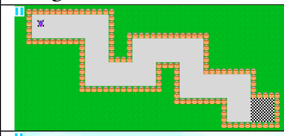
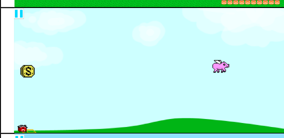
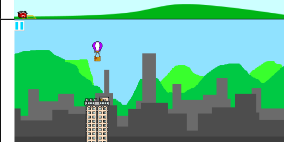
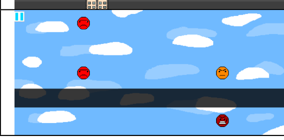
Game	Controls	Game Goals	Rehab Goals	Relevant ADLs	Images
Maze	One hand controls rotation; other hand controls forward velocity; controls switch halfway	Reach the end of the maze	Bilateral coordination, fine precision	Using a computer, climbing a ladder	
When Pigs Fly	Left and right hand force proportional to y and x position	Stay as close to the moving coin as possible	Bilateral coordination, precision, adjustment, endurance, strength	Pouring a drink, screwing on bottle cap	
Balloon Ride	One hand controls height; controls switch halfway through	Fly over buildings coming from right of screen	Strength, endurance, reaction time	Holding heavy objects, squeezing toothpaste	
Happy Times	Grip-and-release to activate corresponding side of bar	Activate bar only as targets pass through	Speed, reaction time, bilateral coordination	Using a remote control, catching falling objects	

Table 1: Descriptions of exergames.

2.1 System Hardware

Two Vernier HD-BTA (hand dynamometers) obtain the real-time grip force exerted by the patient (Figure 1). HD-BTA, a strain-gauge based isometric force sensor, collects precise forces from 0-850N, then converts force input to voltage . We connect the HD-BTAs to the Vernier Arduino Interface Shield and Arduino Uno for rapid Analog-to-Digital conversion; this allows force input to be continuously read by the computer running the exergame software.

We use this hardware setup because the high-precision, real-time force feedback allows for a variety of interactive exergames which train skills needed for ADLs. Also, the sensors are affordable and compatible with different laptop and PC models, as per our tests on MacBook Air (MacOS) and Dell (Windows 10) PCs; this increases accessibility, which is important for home-based rehabilitation.

2.2 Exergame Software

The exergame software, implemented in C# with Unity, is designed to rehabilitate various areas of hand grip ability. It takes real-time grip force input from the sensor system through USB connection, enabling users to interact with the exergame software using their hand grip abilities.

First, each exergaming session begins with a calibration period. Users squeeze the left and right dynamometers with their maximal grip forces (N), which are saved by the software. The forces required in each exergame are then scaled proportionally to the maximums for each hand, making difficulty adaptive to user ability.

Following calibration, the exergames become available, each with objectives and controls tailored to train certain grip abilities (Table 1). To encourage progression as users improve, each exergame has multiple difficulty levels, each stratified by stages with progressive difficulty. This, alongside pregame force calibration, fosters challenging yet attainable exergaming for users of all abilities.

2.3 Data Maintenance and Analysis

Each user has a personalized account. During each game, quantitative data pertaining to the user's grip performance is gathered. This data is displayed at the conclusion of each game. To make the data more meaningful, accessible, and encouraging to users, it is converted to and displayed alongside a composite "gold star" score. This data is then stored in the user's profile, and can be displayed alongside previously collected data, creating a historical record of the user's progress for each game. This gives a sense of progression, and provides motivation for the user to improve. Patterns in the current session's data are also used to generate "Smart Tips" which give users specific information on bad habits and suggestions for active improvement. This allows the users to take responsibility and control over their home rehabilitation process.

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