Child-Centric Interactive Exercise Devices (CCIED) and System for Conductive Education Therapy

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ABSTRACT

Cerebral palsy (CP) is a group of permanent movement disorders that appear in early childhood. Often, symptoms include poor coordination, stiff muscles, weak muscles, and tremors. Often babies with cerebral palsy do not roll over, sit, crawl, or walk as early as other children their age. Conductive Education (CE) is a multi-disciplinary therapy that immerses children with cerebral palsy in feedback rich environments to promote coordinated functioning and ultimately an acceptable level of independence. The Child-Centric Interactive Exercise Device (CCIED) are part of an IOT system that immerses the child in an interaction rich environment to motivate enjoyable exercise sessions and interactions. As an example of a device the development and use case for an interactive exercise bar is described in this paper. The CCIED system architecture presented in this paper allows for child – instructor – computer game interaction, via an online browser based multiplayer game environment. The system leverages the MQTT protocol and HTML5 and WebGL technology to create a secure, easily accessible, scalable, real time responsive game environment.

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INTRODUCTION

There are more than 200,000 cases of Cerebral Palsy (CP) in the USA alone. The condition cannot be cured but effective therapy and exercise has demonstrated improvement. To improve their condition children with CP perform exercises to improve strength. There is strong evidence that suggest improvement in condition as a result of strength training. (Damiano, Vaughan, & Abel, 1995) There are a number of exercise regimes that have been reported in literature. (Verschuren et al., 2011; Verschuren, Ketelaar, Takken, Helders, & Gorter, 2008) Conductive Education developed by Dr.Andras Peto, is an intensive multidisciplinary exercise that seeks to immerse the subject in various coordinated functioning environments that aim to help the child independently perform daily activities. The objective is to improve physical and psychological functioning of the child along confidence and self-esteem. Over a sustained period of time the program shows improvements in the child's functional status (Anttila, Suoranta, Malmivaara, Mäkelä, & Autti-Rämö, 2008). As part of the therapy subjects are required to use an exercise stick to perform exercises to improve motor control. Typically in traditional Conductive Education (CE) the instructor observes, assists and provides the child with encouragement while doing the exercise.

The student is required to lift a wooden exercise above the head extending both arms fully while holding the stick level. The objective is to train the student to apply equal coordinated force on both arms. The instructor encourages the student to apply perform as many repetitions as possible with proper form. The instructor also observes the students condition and monitors subtle cue to detect changes in the student's condition. The condition makes sustained exercise difficult and typically the instructor provides the child with encouragement while doing the exercise to keep the child motivated.

The interactive exercise bar provides encouragement to the user via three principal modes which include audio, tactile and visual game based feedback. The feedback compliments the instructor's encouragement. The system captures performance data including, number of repetitions, number of alerts, patterns in user response to alerts. Presently the system architecture can support single player game but can be extended to support multi player games. The technology framework developed lends itself to scaling interactive features including the introduction on simulated computer agents that adapt to each students desired level of challenge. Additionally the system can be scaled to a multi-player environment to increase interactions amongst the students and the instructor in a virtual environment.

There are several design factors that need careful consideration while developing an input device for children with CP. The device needs to be inherently safe and easy to operate. The device should replace the wooden exercise stick with no additional training required to use the device. Additional design constraints include weight limitations, form factor, robustness it is likely that the device will be subject to uneven pressure and be dropped or even thrown at times. Several prototypes were developed and presented to the instructors at the Conductive Education Center of Orlando (CECO). Conceptual design for an interactive exercise bar and its implementation are described in this paper.

BACKGROUND

Internet of Things (IOT) based smart systems have been developed and successfully adopted for use in health care settings such as emergency alerts , fitness , chronic care , hospital environment and home-based health monitoring, health care training and in rehabilitative therapy. The emerging medical internet of things (mIOT) is a term that

applies to a networked medical and communication devices, wearable structures ,data storage and analysis systems that communicate with each other and other networks while ensure compliance with HIPPA. The space has attracted basic research along and significant deployment of venture capital. The data from various devices are integrated, contextual analysis based recommendations are made to improve health. Devices developed by Sensonics and Atricure, Sano, fitbit and ginger.io are examples of home based health monitoring. Similar devices are also available for use in clinical settings.

Gamification of the healthcare enterprise has transformed the healthcare application development landscape. Companies such as Akili Interactive Labs have developed neuroscience tools and gaming that has been validated with studies to help early detection of cognitive differences between elderly people at risk of developing Alzheimers. Serious Games have demonstrated that they can help to improve motivation and balance control in children with cerebral palsy (Bonnechère, Omelina, Jansen, & Van Sint Jan, 2015).

SYSTEM DESIGN and IMPLEMENTATION

System comprises of various motivational elements such as audio and tactile cues of various intensities that may be set by the instructor during the exercise session. The system captures performance data and exercise conditions such has intensity of feedback, feedback settings, and game settings such as level of difficultly. The data model of the system allows for causal models to be developed utilizing the instructor perception, exercise performance by the child and game score. This provides a data driven environment for decision making. A primary objective in Conductive Education is to observe, track and measure progress in order to develop individualized goal plans. The system captures feedback from the instructor at the conclusion of each exercise session. Capture of instructor feedback is helpful in tracking progress of the child. Figure 1 describes the basic work flow of the control application. The instructor uses this mobile application to select the game, student and the device. The instructor then starts the game. Once a session is started in the control application the game console loads the game for that particular student. The system checks to ensure that the device is switched on and the student has logged in the game console.
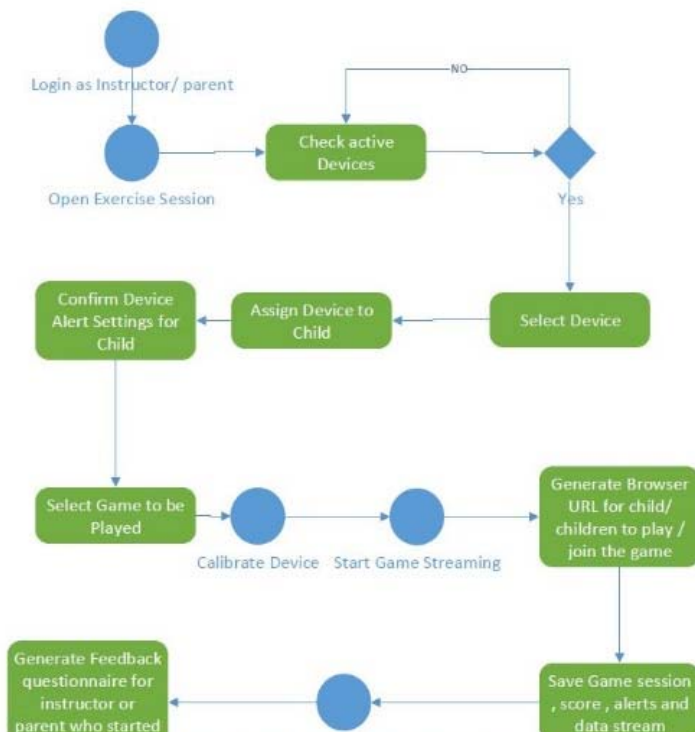

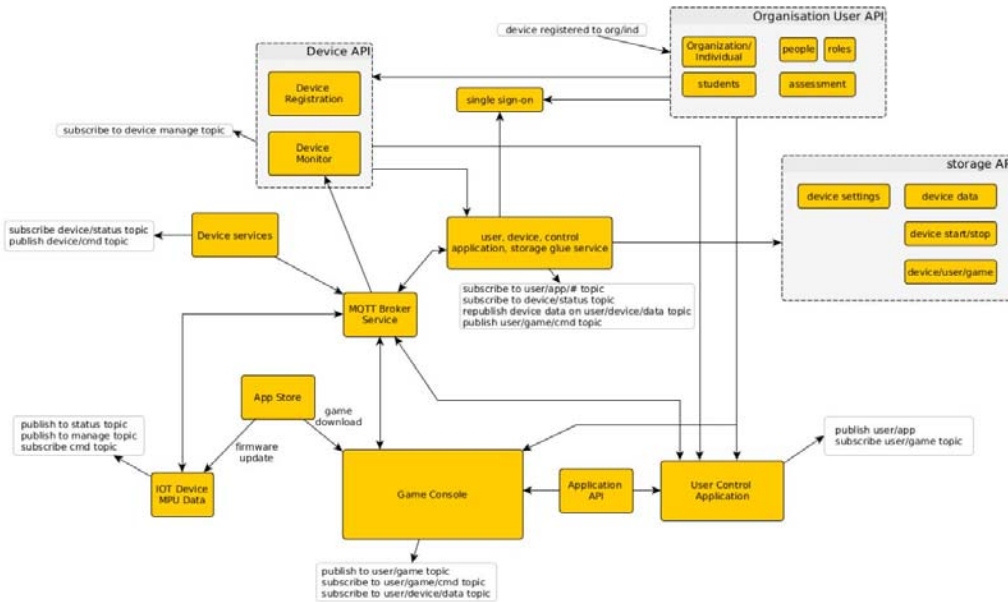*Figure 1: Exercise session set up process*

Figure 2: System Architecture

The data model supports the capture of child, game attributes, game score, exercise session attributes, instructor perception and actual exercise performance data. These parameters will feed the proposed causal model that will be developed in a future study. The system is designed to be highly scalable, accessible and secure. It takes advantage of the security features built into the modern browsers by using HTML5 / Webgl Games. The control application utilized by the instructor access the device data via the MQTT protocol. A socket connection is established between the control application and the game console. This socket connection streams the device data in real time to the HTML5/webgl game interface. The development can thus easily be ported to local, private or public cloud as required during deployment. There is separation of the data layer, middle ware and the user interface.

In this implementation the firmware is written on an ESP8266 wifi chip that controls the device. It can read MPU 6050 data, Publish/Subscribe MQTT message, and process device Start/Stop command. Further it can receive commands from the Cloud Application and based on logic programmed the processor can turn on or off various interactive elements such as buzzers. The cloud comprises of an Mqtt broker that facilitates, online registration, query and reading of payload from the devices. A detailed description of the system architecture is described in the figure2.

Interactive Exercise Device

The core module of the exercise bar consists of a microcontroller along, wireless transmitter along with a gyroscope and accelerometer detect roll, pitch, tilt and jerk of the device during the performance of the exercise. The data is streamed in real time back to the computer/database/cloud for further processing. These sensors collect the movement as and when the stick is moved. The accelerometer collects the movement in the x, y, and z axes. The gyroscope collects the roll, pitch and yaw of the stick.
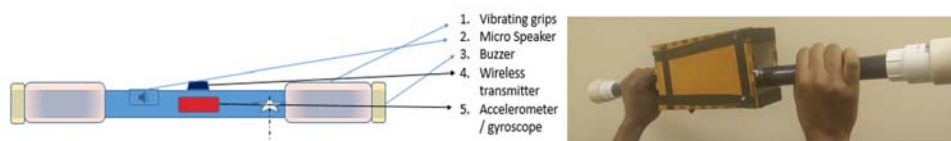

Figure 3 : Interactive Exercise Bar Schematic and early prototype.

The data from these sensors are collected by the microcontroller and sent wirelessly through Wi-Fi/Bluetooth/RF protocol. The microcontroller programmed to control the ringing of the buzzer, speaker and or vibration motors based on the sensor values in real time. The pitch or the yaw is used as an input control in the game. The early prototype used standard Arduino board and to build the device. The prototype demonstrated the concept and clarified that form factor of a simple pipe is critical for successful use. This required the development of a custom PCB to fit in a pipe enclosure. A custom PCB with the following dimensions was developed length 100 mm, width 24.8 mm and height 12.4 mm as show in the figure 4.
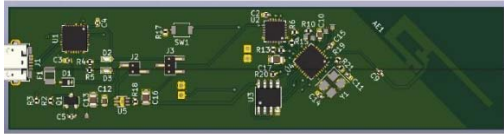

Figure 4: Custom PCB with ESP8266 and MPU6050

The esp8266 chip is programmed via a UART interface. Several chips were considered including the PL2303, CP2102 and the FT232. The system requires a chip that can perform with high degree of reliability and so the FT232 was selected. Similar selection criteria was applied to the other component. To write applications on the ESP8266 an external AT25SF041 4 Mbit flash was selected.

The enclosure for the PCB, battery and buzzer was then designed as a simple pipe like enclosure. The design allows for a simple three step assembly process as show in the figure below.
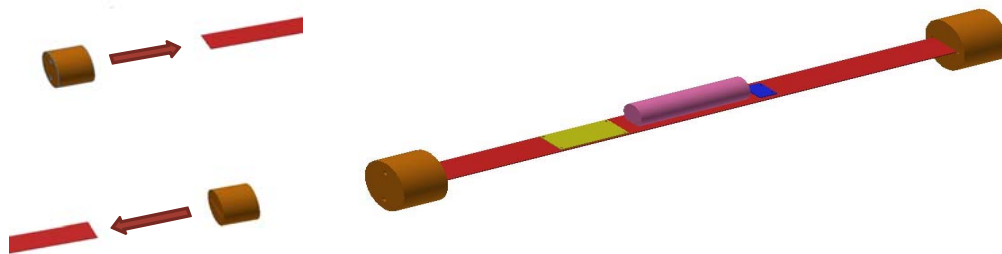Step 1: Placement of the major components on the frame.

Figure 5A: Inner frame to mount or secure the components with end caps

Step2: Insertion of the frame with components in the pipe enclosure

Figure 6: Insertion of frame with components into the pipe and securing the assembly with end cap

Step 3: Complete Assembly of the Pipe

This assembly method and design meets all of the human factors that are critical to appropriate evaluation of the interactive exercise device. These factors include length, width, weight and surface finish along with additional parameters such as safety and durability.

Game based Interactivity and Socialization

A simple game is designed to prove the concept of motivation for the children. The game is designed based on the following game design principles. (Nixon & Howard, 2013) . The initial game chosen has the following features easy to use interface, interactive feedback with a score, it encourages exploration and gives the user a sense of accomplishment. The initial game chosen for the prototype involves catching the eggs. Game design for this simple game is consistent with the principles listed above. Additionally, once the instructor starts the game on the application there is no need for any click by the child. The game can be enjoyed by controlling the interactive exercise bar. Tilting the bar to the right or left will cause the bucket to move and catch the falling eggs.

Figure 7: Game Scene View

Short-term goal – catch the egg

Cognitive challenge –know when to stop motion

Physical challenge -move the basket correctly under the egg

Immediate feedback – sound/haptic

Failure acceptance – not penalized if egg is missed

Difficulty – more eggs/minute

Easy to use interface

Attractive environment

The basket is main object of the game. It moves under the eggs and catches them. The basket movement is controlled by the data stream from the interactive exercise bar. The accelerometer measures the tilt based on the child's movement and accordingly moves the basket. The main objective of the game is to collect the eggs the visual and audio feedback provides the user a sense of accomplishment.

SYSTEM EVALUATION

The primary success criteria for the CCIED system is its ability to affect a sustained increase in motivation for children with CP. A multilevel model study is proposed to evaluate sustained motivation at the individual and group level.

Proposed Test Modalities

The modular device design allows for efficient testing in multiple modalities. The system can be configured to modalities perform in the following modalities.

1. No Feedback - Traditional device (wooden Stick)
2. Tactile and Audio feedback on the device (Buzzer)
3. Non responsive device with only Game Interface based feedback.
4. Tactile and Audio feedback on the device along with a visual interactive game with audio and video cues.

Proposed Study Questions

The CCEID system is designed to capture exercise performance, game play and instructor perception data to answer the following questions.
1. Do Instructors perceive the system to be user friendly and a valid means of exercise for children with Cerebral Palsy?
2. Do Instructors perceive increase in the motivation of the students to perform the exercise?
   a. Is there an increase in motivation in at least one of the modalities when compared to the traditional method?
   b. Does motivation increases with the increase the level of feedback stimuli
3. Does the system increases the performance of the students during the exercise.
   a. Is the average number of repetitions in a session is greater when the interactive exercise bar is used when compared with the traditional stick?
   b. Are total number of exercise sessions increased when the interactive exercise bar is used?

CONCLUSION

Children with conditions such as CP have better outcomes and can lead lives with greater independence if there is timely, adequate intervention with appropriate combination of physical and cognitive stimulation. The average lifetime expenses a family may expect can go up to $921,000 for each child with CP. Children with associated disabilities will cost more; an average of a little over $1 million is needed for children with intellectual disabilities, $601,000 for vision impairment, and $383,000 for hearing loss. The CCIED system provides a safe, low cost, affordable system that can be used in home and clinical setting to help engage, entertain and exercise the child. Initial review of the system at the Conductive Education Center of Orlando and with representative from the Scott Institute, along with interviews of parents has indicated the CCIED system is a useful tool in CP therapy. The system capabilities support the five major objectives of conductive education therapy management which are to assist and encourage the child, observe performance and emotional state of the child, analyze and evaluate the data, track progression and assist the therapist in development of an individualized goal plan for each child. Conductive education is expensive and demand for care far exceeds the ability to meet need. The CCIED system can assist the therapist and help provide care for more children.

FUTURE WORK

This work will be followed up with further investigation to measure the ability of CCIED system to increase and sustain motivation to exercise. The dissertation will test approximately 250 students from different sites. Multi-level

model will be used to discern individual and group motivation as a result of the using the CCIED system. The results of this development effort and study have significant implications in the treatment of Cerebral Palsy. The system capabilities will be expanded to include multiplayer and multi device games. A game arcade is under development which will bring a greater variety of games for the children.

Local Network, Private Cloud and public cloud versions of the CCIED systems are under development. This will support various IT requirements from hospitals to individual use at the home setting.

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