REACH Robot: Motion capture-based robotic interfaces to enhance engagement and adherence in pediatric rehabilitation

Gilbert Yap
yap.g@husky.neu.edu

Chelsea Lau
lau.che@husky.neu.edu

Kalon Goonetilleke
goonetilleke.ka@husky.neu.edu

Danielle Levac, PhD
ReGame Virtual Reality Lab
Northeastern University
Boston, USA
d.levac@northeastern.edu

***Abstract*—Young children with hemiplegic cerebral palsy show evidence of learning new motor skills and having better independent performance through regular physical therapy. The challenging and motivational exercises needed to promote these improvements must be performed inside and outside of therapy hours, but are often not when outside of sessions. Technology-based systems that gamify the exercise process are shown to motivate children and stimulate physical and mental activity. These solutions are typically expensive or difficult to use by both caregiver and patient, and may not adapt to the child's need over time. The Robots Encouraging Action in Children (REACH) robot aims to promote upper extremity movement in children and provide the child's success metrics using a game-like system. This system is accomplished through low-cost consumer electronics and DIY kits that make them an accessible option for home-based physical therapy.**

Keywords—Robots, motion-capture interfaces, rehabilitation

I. INTRODUCTION

Children with hemiplegic cerebral palsy receive physical therapy (PT) interventions throughout childhood and adolescence to promote learning of new motor skills and enhance independent performance of daily living activities. There is strong evidence to suggest that PT interventions must be intense, challenging, motivating, and abundant in order to influence the neuroplastic processes that underlie learning of new motor skills [1]. However, children often fail to achieve the necessary practice intensity or dosage because they lack motivating interventions that are feasible outside of designated therapy hours. Indeed, children and families may have difficulty adhering to less repetitive exercise programs that can't be monitored in the home setting. As such, there is a critical need for home-based PT interventions that promote repetitive, challenging movement, monitor usage metrics, and offer motivating feedback by engaging the child in meaningful practice opportunities [2].

Motivation is defined as the psychological property that encourages or sustains actions toward a goal [14]. Animal and human studies provide substantial evidence for the importance of motivation as a mediator of the neuroplastic brain processes underlying motor learning [9,10]. In addition, a growing field of research explores the role of motivation and engagement in learning new motor skills. Motivation and engagement may be the key 'active ingredients' of PT interventions in that they can enhance processes of memory consolidation as well as encourage more sustained and repetitive practice [6]. Engagement may support motor learning from a neurophysiological perspective by activating brain areas involved in attention, planning and cognition [7]. A recent study demonstrated that practice of a new upper extremity timing skill in a more engaging gaming environment influenced learning as compared to practice in a more sterile environment in healthy young adults, when the task and feedback were the same [7].

Children with CP are more motivated by technologically-based interventions as compared to conventional practice [11,12]. In particular, motivating technology incorporates gaming principles of rewards, appropriate challenge, feedback, choice, interactivity, and clear goals [13]. iPads and tablets are popular therapy tools used to stimulate both small movements and cognitive processes through a huge variety of apps [8]. While the use of gaming technology within rehabilitation activities may enhance the engagement and motivation potential of therapeutic activities, many current technological options are inaccessible for children with more severe physical and cognitive impairment or do not elicit the functional movements that transfer to real life activities. Accessible technologies are often extremely expensive and may not be flexible to adapt to a child's changing needs over time. These options may not be easy to use by caregivers, limiting their widespread relevance. Instead, low cost, off-the-shelf products can be explored that have the potential to be integrated as motivating rehabilitation tools that do not require extensive training to use and can be adjusted to meet changing user needs. Low-cost consumer electronics and DIY kits are available to support creation of these tools. The objective of this project is to create a rehabilitation tool, the Robots Encouraging Action in Children (REACH) Robot, that

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE
978-1-5386-2534-7/17/$31.00 ©2017 IEEE

promotes functional, repetitive upper extremity movement in children with neuromotor impairments with options for additional dual-task and cognitive challenges. The tool will also track metrics relevant to children's adherence and success.

II. Methods

The REACH robot encourages children with hemiplegic CP to use their affected upper limb to control a robotic arm to pick up, move and put down objects in a game context. The program records accuracy and time for subsequent use by therapists and displays immediate visual and auditory numeric knowledge of results feedback to the user.

This paper describes the iterative development of the REACH robot's individual components. The system consists of five main components: a computer connected to the Leap Motion (www.leapmotion.com) controller that runs data collection and communication software, a four degree of freedom robotic arm attached to a four wheeled based that talks to the computer, a controller for the wheeled base, and a game board.

A. Software

Computer software tracks the user's hand and converts it into data for the robotic arm. The way that this is done is by calculating various angles that correspond with the available motions of the robotic arm. This includes the vertical angle between the wrist and middle finger metacarpophalangeal joint (MP) to control arm height, the horizontal angle to control arm rotation, the hand's position relative to the center of the Leap Motion controller to control the arm's forward position, and the distance between the thumb and index finger MP to control the gripper. These angles and distances are then normalized to fit into the user's limitations, which are recorded through a calibration script that is run before use. These final values are then sent to the microcontroller and applied to the corresponding motor to replicate hand motion. A 915 MHz ISM band radio network has been setup to communicate between various components of the REACH system so that the user can attain greater mobility. Currently, this includes the computer and controller for the robot arm, but will include base motion and game board information in the future. A key consideration for implementing each part of the network is ensuring that there is no crosstalk between components that are sending to the same receiver. The radio component being used (https://www.adafruit.com/product/3176 and https://www.adafruit.com/product/3070) has several open software libraries available, making development for the radio boards easier than cheaper, less documented transceivers.

B. Hardware

The robotic arm (www.robotshop.com/en/robotic-arm-mearm-nuka-no-controller-cola-blue.html) and base (www.amazon.com/Four-Wheel-Drive-Smart-Robot-Chassis/dp/B0100AEP8W/) are currently controlled by Adafruit's Feather M0 RFM69HCW microcontroller. This board combines a processor and has a 915 MHz radio chip to communicate with matching devices. In the current system, the computer and joystick also uses the same board to transmit data generated by the Leap Motion to the arm and directions to the base respectively. These boards are reported to work within 350 meters of each other, thus enabling the robot to travel well within the confines of most offices and homes. RF boards were chosen over Bluetooth and WiFi for their larger signal coverage, lower cost, and software simplicity.

A power supply circuit has been designed for the arm and base components of the REACH system that uses a 9.9V LiFe (Lithium Iron Phosphate) 2100 mAh battery as its power source. This high voltage is then converted to a usable 5V for the motors and microcontroller. Two separate power regulators are used to separate the DC motors from the servo motors so that the total current draw on each regulator is reduced, allowing them to operate in low-stress conditions. The LiFe battery was chosen over conventional batteries and LiPo (Lithium Polymer) batteries for its high maximum current output, battery life longevity, and safer charging method (compared to LiPo batteries).

The game board consists of a set of foam tiles with a few bend-sensing resistors that, when weight is applied, sends a signal to an Arduino Uno (store.arduino.cc/usa/arduino-uno-rev3) that determines if the right piece was placed into the right area. The current board design is compact and transportable due to its foldability, making it adaptable for various playing environments. Users can either play on smaller surfaces or expand the board for larger surfaces. The design also allows the course to be altered depending on the size of the playing area. On the smaller setting, the game objective involves picking up items from the game board and placing them in a designated goal. The objects used are of varying heights so that users of different levels can enhance motor skills by replicating effective exercises. On the larger setting, the previous objective will be complemented by the addition of a maze, requiring users to exercise greater dexterity with driving the chassis. Upon completion, an LCD screen that is affixed onto the board displays user success and provides feedback to the user. This is tracked and optimized for therapists to monitor a patient's progress.

III. Next Steps for Development and Evaluation

There are technological developments planned to further enhance the REACH interface. The software currently runs in Python in a command line interface, so creating a user-friendly interface that anyone can use is a top priority. Additionally, optimizing the processing speed of the script would help reduce any lag that is currently present in the wireless system. The game board is currently undergoing changes which include 3D printing game objects and changing the surface so that it can be adjusted to meet different sizing needs and fold for easy transportation. The inclusion of a wireless board would also allow the gameboard to send score information back to the computer. A custom printed circuit board will be created for the robot to reduce wire clutter and object footprint while making it easier to reproduce from a production standpoint.

Once prototype construction is complete, we plan to hold a feasibility and usability evaluation with a small sample of children from our targeted patient population. Feasibility testing will inform revisions to the tool and subsequent

978-1-5386-2534-7/17/$31.00 ©2017 IEEE

refinements. Ultimately, our goal is to evaluate the effect of a home exercise program that includes REACH game play on children's functional outcomes related to upper extremity use in activities of daily living. REACH robot activities can be integrated into evidence-based rehabilitation protocols such as constraint-induced movement therapy (CIMT) and compared to CIMT alone. In addition to neuromotor outcomes of interest, the research will investigate subjective and objective indices of motivation and engagement as well as adherence to established protocols..

IV. Conclusion

With subsequent development, user testing and effectiveness evaluation, our long term goal is the development of an effective, accessible, user-friendly and low-cost product that can be integrated into school, home, or community activity programs to enhance practice dosage of functionally relevant upper extremity movement skills and improve quality of life for children and youth with hemiplegic CP.

Acknowledgment

The Rehabilitation Games and Virtual Reality Lab would like to thank the Northeastern University Office of Undergraduate Research and Fellowships for providing the funding enabling Gilbert Yap to attend this conference. We would also like to thank Immanual Ampomah Mensah for his assistance with this project.

References

[1] Kleim J, Jones T. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res 2008;51(1):S225.

[2] Gordon AM, Magill RA. Motor Learning: Application of principles to pediatric rehabilitation. In: Campbell SK, editor. Physical Therapy for Children. 3rd ed. Philadelphia: Saunders; 2011.

[3] Biddiss E, Irwin J. Active video games to promote physical activity in children and youth: a systematic review. Archives of pediatrics adolescent medicine 2010;164(7):664-672.

[4] Biddiss, Elaine. Should we integrate video games into home-based rehabilitation therapies for cerebral palsy? Future Neurology 2012 September;7(5):515-518.

[5] Wulf G, Chiviacowsky S, Cardozo PL. Additive benefits of autonomy support and enhanced expectancies for motor learning. Human Movement Science 2014 Oct;37:12-20.

[6] Levac D., Rivard L., Missiuna C. Describing the active ingredients of interactive computer play interventions for children with neuromotor impairments: a scoping review. Developmental Medicine & Child Neurology 2012;33(1):214-223.

[7] Lohse KR, Boyd LA, Hodges NJ. Engaging environments enhance motor skill learning in a computer gaming task. J Mot Behav. 2016;48(2):172-82. doi: 10.1080/00222895.2015.1068158

[8] Fager SK, Burnfield JM. Patients' experiences with technology during inpatient rehabilitation: opportunities to support independence and therapeutic engagement. Disabil Rehabil Assist Technol. 2014;9(2):121-127.

[9] Bartlett DJ, Palisano RJ. Physical therapists' perceptions of factors influencing the acquisition of motor abilities of children with cerebral palsy: implications for clinical reasoning. Phys Ther. 2002;82(3):237-248.

[10] Danzl MM, Etter NM, Andreatta RD, Kitzman PH. Facilitating neurorehabilitation through principles of engagement. J Allied Health. 2012;41(1):35-41.

[11] Tatla SK, Sauve K, Jarus T, Virji-Babul N, Holsti L. The effects of motivating interventions on rehabilitation outcomes in children and youth with acquired brain injuries: a systematic review. Brain Inj. 2014;28(8):1022-1035.

[12] Tatla SK, Sauve K, Virji-Babul N, Holsti L, Butler C, Van Der Loos HF. Evidence for outcomes of motivational rehabilitation interventions for children and adolescents with cerebral palsy: an American Academy for Cerebral Palsy and Developmental Medicine systematic review. Dev Med Child Neurol. 2013;55(7):593-601.

[13] Lohse K, Shirzad N, Verster A, Hodges N, Van der Loos HF. Video games and rehabilitation: using design principles to enhance engagement in physical therapy. J Neurol Phys Ther. 2013;37(4):166-175.

[14] Tatla SK, Jarus T, Virji-Babul N, Holsti L. The development of the Pediatric Motivation Scale for rehabilitation. Can J Occup Ther. 2015;82(2):93-105.

978-1-5386-2534-7/17/$31.00 ©2017 IEEE