The CosmoBot™ System: Evaluating its Usability in Therapy Sessions with Children Diagnosed with Cerebral Palsy*

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Abstract - The CosmoBot™ system has been designed and developed for therapy, education, and play. Children interact with CosmoBot™, controlling the robot's movements and audio output, using a variety of gestural sensors and speech recognition, while actively targeting their therapy goals. We evaluated the usability of CosmoBot™ to contribute to physical therapy intervention for upper extremity movements in children with cerebral palsy who are patients of the Outpatient Rehabilitation Program at Mount Washington Pediatric Hospital in Cheverly, MD. The results of this study showed that the CosmoBot system provided great motivation for the children during the therapy sessions, was easy for the therapist to set up and use, and alleviated the therapist's job of trying to engage the children in therapy.

Index Terms – usability, therapy, gestural interface, interactive robot, cerebral palsy, user-centered design

I. Introduction

Over 10% of all school children have one or more disabilities. "More people have cerebral palsy than any other developmental disability, including Downs syndrome, epilepsy, and autism. About two children out of every thousand born in this country have some type of cerebral palsy. Studies have shown that at least 5000 infants and toddlers and 1,200 - 1,500 preschoolers are diagnosed with cerebral palsy each year. In all, approximately 500,000 people in this country have some form of cerebral palsy." [1]

Currently, physical and occupational therapy address issues such as lack of coordination, fine/gross motor development, spasticity, and activities of daily living. However, these issues associated with cerebral palsy also may impact children's educational development, such as access to computer learning and traditional tools (e.g., books, writing tools, etc.), as well as their social development, such as communication and interpersonal skills. Therefore, combining physical and occupational therapy with cognitive and social development is crucial. Physical and occupational therapists' access to assistive devices that can aid in therapy is limited. Available devices have one or more of the following limitations:

- Specific to one developmental goal (e.g., wrist extension or flexion)
- Low tech (e.g. simple games or puppets)

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- Focus solely on physical or occupational therapy instead of an integration of physical and occupational therapy with cognitive and/or social development
- Primarily toys with no inherent purpose for physical or occupational therapy
- Do not include the element of fun, making therapy more of a chore than an enjoyable exercise
- Cannot be modified, therefore the child's interest in the therapeutic exercise decreases with the novelty of the tool

Several studies have shown that when children with cerebral palsy participate in exercise, their fitness level improves. For example, [2] demonstrated that children with CP could increase the strength of their quadriceps to the point at which they did not differ statistically from the norm, and [3] indicated that a child with CP obtained a noticeable increase in strength and independent leg and torso function as a result of using a custom walker.

Play has been successfully introduced into physical therapy and rehabilitation of children with disabilities. Reference [4] found that embedding exercise within a play occupation enhanced the prone extension of two children with hypotonic cerebral palsy. Reference [5] found that purposeful activity (playing a game) by two 6-year old boys with second-to-third-degree burns *yielded better results in range of motion goals than those achieved using rote exercise.* Reference [6] has indicated that when children play they are relaxed in the present setting, intrinsically motivated, and actively engaged, all behaviors that are conducive to learning.

CosmoBot™ is a high-tech, integrative system designed to overcome the limitations listed above (Fig. 1). Product development is dedicated to creating a system that is fun and motivating for the child over a considerable period of time. The interactive robot is controlled by the child's gestures, movement, and voice, via wearable sensors, sensors on a console, speech recognition technology, and interactive games.

CosmoBot™'s software includes data tracking capabilities to automatically record data from therapy sessions. The first version of CosmoBot™ to be developed for the marketplace is intended for professional use, in clinical and educational settings.

Fig. 1 The CosmoBot™ robot (left), Mission Control™ (interface board device, center right), the Therapist Module software (interface shown on module, back right), and plug-in gestural interfaces: a joystick, and wearable head and arm sensors (front center).

With therapy taking place in a variety of settings, the potential for use of our robot system is widespread. Potential customers include therapists (over 340,000), which include but are not limited to, physical, occupational, speech and language, and recreation; other health care professionals; teachers (1.7 million elementary); special education teachers (430,000); teachers' aides (250,000); and parents of children with disabilities (5.2 million school age children) [7].

This paper reports the results of a technical feasibility study using gestural interface technology and interactive robotics to facilitate motor development and functional mobility of children with a wide range of physical disabilities. The prototype Gestural system called "CosmoBot™" is an interactive robotic rehabilitation tool, disguised as a toy, which can be controlled via body movements, through voice activation, or via a control station – "Mission Control™."

II. Methods

A. CosmoBot System Description

1) CosmoBot™: CosmoBot™, a child-friendly space robot, is designed to be a motivating toy/friend to interact with a child in the context of entertaining games and activities while addressing developmental and educational goals. The current robot prototype is illustrated in Fig. 2. The child can control CosmoBot™'s head, arm, and mouth movements, and can activate a set of wheels hidden under his feet to drive him forward, backward, left, and right.

2) Mission Control™: Mission Control™ (Fig. 3), an interactive control station, is the child's interface for interacting with CosmoBot™. Mission Control™ consists of four aFFx™ activators--proportional pressure sensors--and a built-in microphone. Mission Control™ is expandable through external ports - four RJ12 plug-in jacks for external analog sensors, four mono-plug jacks for external binary switches, and two USB ports for external USB devices. These external ports allow for the child to interact with CosmoBot™ with additional gestural interfaces.

Fig. 2 CosmoBot

Fig. 3 Mission Control™

3) Plug-in Gestural Sensors: Gestural interface sensors that plug into Mission Control™ are shown in Fig. 4 (from left to right): an OEM joystick that has been adapted to be child-friendly and easy to use, a wearable leg sensor, wearable arm sensor, wearable head sensor, wrist extension glove, and pronation/ supination sensor with arm restraint brace. Other commercially-existing sensors that can interface with Mission Control™ include all types of available binary switches, any proportional sensor that can be adapted to plug into Mission Control™'s ports, and any sensor with a USB interface. The sensors can be classified in three categories. (1) The first category is general-use, platform based sensors such as joysticks and COTS binary switches (e.g., AbleNet's Jelly Bean® switch www.ablenetinc.com), (2) The second category is general-use, wearable sensors that detect position, velocity, and/or acceleration in one or more dimension. The leg, arm, and head sensors developed by AnthroTronix are examples, using embedded accelerometers to monitor vertical tilt. (3) The third category is comprised of sensors that are custom-made to monitor prescribed therapy exercises, such as the illustrated wrist extension and pronation/supination sensors. These sensors were developed after consulting with therapists, who identified wrist extension, and forearm pronation and supination as high-priority movements to be quantitatively, objectively measured with custom sensors. The wrist extension sensor consists of two modified gloves, one right handed and one left handed. An accelerometer is sewn onto the dorsal side of the glove in the middle of the hand. The user's arm is placed in the adjustable arm brace assembly to isolate the intended movement. The child's arm is secured in the brace with two Velcro straps. The pronation/supination sensor consists of a ring coupled to a potentiometer. The potentiometer's electrical resistance changes in proportion to the angle of the ring. The ring assembly is attached to the arm brace by adjustable metal rods.

4) Therapist Module; System Software: The CosmoBot™ system is controlled by the therapist toolkit: desktop computer software developed in Java This integrated system connects the robot, Mission

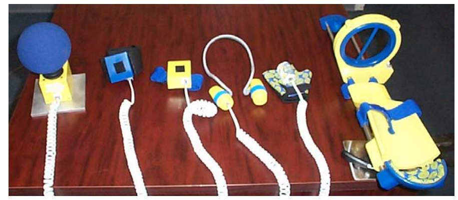

Fig. 4 Gestural sensors (from left to right): joystick, leg sensor, arm sensor, head sensor, wrist extension glove, and pronation/supination sensor and restraining arm.

Control™, wearable sensors, and the desktop computer. Fig. 5 shows the main graphical interface of the therapist module. The status window (upper left) shows the system status and allows the therapist to start, pause, or stop the activity or exit the software. The player settings (lower left) allow the therapist to choose an already-existing child player (including guest). The activity settings window (middle left) allows the therapist to set up the type of activity in which the child will interact with the CosmoBot™ robot. Currently, there are three types of activities: Live Play, Record, and Playback. For each activity, audio capabilities can be set to sound feed (audio fed out to the robot's speakers), sound recognition (control CosmoBot™'s movements with speech commands), or inactive; and movement capabilities (controlling CosmoBot™'s movements with gestural sensor) can be turned on or off. In Live Play mode, the child controls CosmoBot™'s movements and audio output in "real" time; in Record mode, the child can record movements and/or audio, and in Playback mode, recorded movement and/or audio sequences can be played back. The Mission Control™ settings window (upper right) allows the therapist to set, in software, which sensors are plugged into Mission Control™ and, for all plug-in and built-in sensors, to map each sensor input to a robot function output. After each sensor is mapped to a robot output, the sensor values, thresholds, and resulting command state are displayed. The robot settings window (lower right) monitors the state of the robot's head, mouth, arm, and drive train wheels as well as the robot's battery power status and the wireless

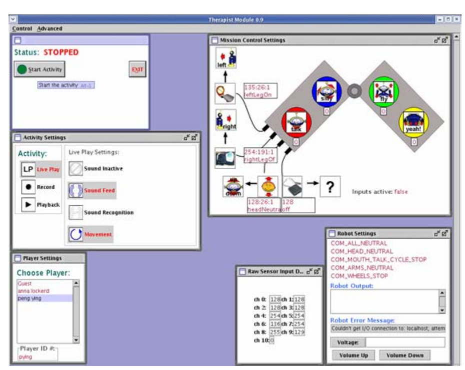

Fig. 5 Therapist Module Interface

communication status between desktop and robot. Finally, CosmoBot™'s audio volume can be adjusted in this window. The raw sensor window (lower center) displays the raw sensor values coming from Mission Control™.

B Setting Testing occurred at Mt. Washington Pediatric Hospital (MWPH) in Cheverly, MD. Staff from AnthroTronix and MWPH worked together to: review research protocol and aims, develop research mechanisms, recruit children, test the technology, and collect data.

C. Participants MWPH staff recruited a total of 6 children for testing. These subjects were all receiving outpatient therapy at MWPH prior to the study. The subjects range in age from 4 – 10 years old, each subject has a diagnosis of cerebral palsy and receives physical and/or occupational therapy for treatment of upper extremity motor deficits.

D. Procedure Dr. Katharine Alter, a pediatric physiatrist from MWPH, recruited 6 children who were already receiving outpatient physical and occupational therapy services with Michelle Kerber, a physical therapist at MWPH. Parents were invited to learn more about their child's participation in the study. Per approved IRB procedures, AnthroTronix staff provided an overview of the technology to parents and received signed written informed consent forms for each child participant. In addition, each parent signed an optional photo consent form. A condition of the study was that each child would participate in the study at least once per week over a 16 week period.

The therapist, Ms. Kerber, participated in two training sessions to learn about the technology, one off-site, and one on-site. Engineers and the Clinical Director at AnthroTronix worked with the therapist to ensure comprehensive understanding of the technology and potential avenues for meeting clinical therapy goals.

Knowledge gained by the therapist during the baseline evaluation period and technology training allowed the therapist to define appropriate sensor selection and placement for use during the study. Sensors used during testing are listed in the "Participants Results" section below.

The Clinical Director from AnthroTronix was on site during the first two weeks of CosmoBot™ technology deployment. Technical assistance for the technology, as well as implementation strategies for use, was available to the therapist during each session in the first two weeks of the project. Throughout the project, assistance was available to the therapist via phone or email.

E. Data Collection Data were collected using three different qualitative methods: observation of videotapes to assess the child's level of participation, questionnaires to capture the therapist's clinical evaluation, and interviews of parents.

We evaluated the following criteria to assess the feasibility of CosmoBot™ during therapy:

- Therapist ease of use.
- Child Motivation.
- Efficacy in therapy.

III. Results

A. Therapist Feedback The therapist involved in the study gave us the following feedback on CosmoBot™'s impact on her as a therapist:

1) CosmoBot™ is extremely easy to use -- In the past, technology has been complex and she has had to come in early to prepare or prepare two therapy regiments in case the technology failed. This is not the case with the current-generation CosmoBot™ system.

2) CosmoBot™ is motivating -- It is always a challenge for a therapist to continually be creative and motivating in every session and over a period of time with each child. It has been difficult, in conventional therapy sessions, to find something novel each time for clients. The therapist reports that CosmoBot™ does it all for her!

3) CosmoBot™ stimulates creative play -- With CosmoBot™, the therapist noted that the children imagine their own pretend play much more with CosmoBot™ than other forms of therapeutic intervention.

4) Interest in CosmoBot™ is sustaining-- The therapist no longer has to look through catalogues or buy new things to constantly change tools to motivate the children in therapy.

B. *Subject Results* Two representative subjects' results are below

1) ***Mark (Pseudonym; see Fig. 6):***

Targeted Goals:

- Improve right upper extremity range of motion and strength, particularly shoulder flexion and abduction
- Increase ability to use his right hand and arm together with his left for bilateral upper extremity coordination
- Increase his ability to independently dress and maintain hygiene.
- Increase attention to task.

Baseline Assessment:

- Had good fine motor control on his right side however, he had difficulty extending his elbow as well as supinating the right arm muscle.
- Had extreme difficulty attending to task.

- Fig. 6 Mark is playing with CosmoBot™ while therapist Michelle Kerber monitors the interaction with the aid of the Therapist Module software.

- Unable to use both his right and left side to accomplish tasks such as bringing his hands together to tie his shoes or fasten his belt.

Sensors used: MC buttons, wrist extension, and supination/pronation brace.

Clinical Observations:

- Attention to task increased significantly.
- Engaged in pretend play with CosmoBot™ and was fascinated with the response to simple movements.
- While receiving speech language and occupational therapy, both the speech language and occupational therapists used CosmoBot™ as a reward system. He was allowed to visit CosmoBot™ after these therapy sessions if his behavior was acceptable during the session.

Post-Data:

- Able to do two tasks at the same time as opposed to one during baseline.
- At times, he performed three activities at once.
- Improved focus and attention to task while using CosmoBot™.
- More motivated during therapy with CosmoBot™ then with other therapeutic interventions used at MWPH.

2) Franklin (Pseudonym; see fig. 7): :

Targeted Goals:

- Increase attention to task.
- Improve left upper extremity range of motion and strength.
- Improve functional use of his left upper extremity.
- Raise or sustain his left arm without falling forward.

Baseline Assessment:

- Was able to do some things in the standing position however, had difficulty lifting and sustaining her arm high over her head in this position.

Fig. 7 Franklin controls CosmoBot™ with pushbutton sensors while therapist Michelle facilitates interaction by driving CosmoBot™ with the use of the joystick sensor.

- When in a seated position, she slumped over and was unable to life her arm very high.
- Was able to isolate each muscle group when cued heavily.
- Used "chatting" and telling stories to avoid therapy exercises and to distract the therapist.

Sensors used: Mission Control™ buttons, joystick, and arm sensors.

Clinical Observations:

- Was able to isolate her movements with greater control when cued by the therapist and using the arm sensor.
- Attended to task very well with CosmoBot™ and didn't display the earlier behaviors of avoiding therapy exercises.
- Interest and motivation level with CosmoBot™ was so successful that the therapist used time with CosmoBot™ as a reward for doing other therapy exercises.

Post Data:

- Was able to maintain the standing and seated posture while lifting and sustaining her arm over her head.
- Was able to walk approximately 200 yards using her walker.

B. Overall Results A summary of all subjects' results is below:

1) Metric 1: Technology's Ease of Use for Therapist

- Technology needed repair once over a four month period
- Therapist reported that the technology was robust and easy to use
- Therapist reported that CosmoBot™ gives her the ability to keep therapy sessions new and fun each time over a period of months
- Therapist reported that motivation level is high when using CosmoBot™ for each child, which

leaves more time for therapy and less time coaxing the child.

2) Metric 2: Children's Motivation in Using Technology

- Each child engaged in pretend play with the technology in every session over a four month period
- Each child asked for the technology during each session (e.g., "When do I get to use CosmoBot™?)
- Not one child stated that he/she was bored or did not want to use CosmoBot™ in therapy
- Other therapists in the clinic used CosmoBot™ as a reward for some of the children during SLP and OT

3) Metric 3: Efficacy of Technology

- Increased / improved upper extremity strength in 4 children
- Improved coordination in upper extremities in 3 children
- Increased attention to task in 4 children
- Improvement in daily activities of living in 3 children

IV. Discussion

The results discussed in this paper show that CosmoBot™'s usability is high in therapy sessions with children diagnosed with Cerebral Paly working on therapy goals to improve upper extremity strength, coordination, range of motion, and dexterity. The technology was easy to set up and use and motivates the child to engage throughout many therapy sessions. These preliminary results also indicate that, due to CosmoBot's motivational influence, the children may meet their therapeutic goals more effectively while working with CosmoBot, compared to other therapeutic interventions currently available to the therapist.

Future studies, examining functional outcomes of children over a longer period of time, are needed to evaluate CosmoBot's efficacy in targeting therapy goals. Further development for the CosmoBot system will take place to bring the robot system closer to production quality and to develop content for structured, robot-based games designed to provide long-lasting play value to motivated children in therapy over an indefinite period of time. It is anticipated that these future studies and development efforts will take place in the next two years and that the CosmoBot system will be commercially available in 2007.

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