Development of an Interactive Gestural Upper Extremity Robotic Feedback System: From Bench to Reality

Krista A. Coleman Wood, Corinna E. Lathan and Kenton R. Kaufman

***Abstract*—Development of an interactive system to treat patients with movement impairments of the upper extremity is described. Gestures and movements of patients as instructed by therapists are detected by accelerometers and feedback is provided directly to the patient via a robot.**

I. Introduction

THERAPY to help patients with upper extremity movement impairments requires focused practice and uses repetition to change motor control patterns and extremity use. Physical and occupational therapy can address issues such as lack of coordination, gross/fine motor development and control and activities of daily living. Creative use of ordinary objects such as blocks, puppets and balls, help therapists engage their patients on a task which is therapeutically beneficial. These toys, unfortunately, have no inherent therapeutic value and patients, particularly children, become bored with both using the same object and repetition of the same task making it difficult for therapists to keep the children engaged in their therapy. This is a problem of significant magnitude as it is estimated that over 10% of all school children have one or more disabilities (5.2 million children [1]) with about 10,000-12,000 new cases of cerebral palsy annually [2], [3]. Clearly, there is a need for an upper extremity treatment system which can assist therapists to engage their patients in therapeutic movements.

II. Historical Perspective

Robotic systems designed to support productivity of clinicians by providing movement therapy (such as the MIT-MANUS) in an effort to train patients by forced repetition and supporting movement error reduction have proven useful [4] and represent an improvement over assistive technologies which merely support or enable movement. A feedback system based on sensors which respond to specific gestures or movements produced by patients as directed by their physical or occupational therapist was proposed as a potential solution. The CosmoBot™ Learning System by AnthroTronix of Silver Springs, MD, is a high-tech, integrative system originally designed and developed for therapy, education and play (Fig. 1). The system was developed over a five year period through an iterative process which focused on the needs of children with disabilities, their parents, teachers and clinical professionals. Consideration was given to the needs of all stake holders with the overall goal to create a motivational tool for use in education and physical, occupational and speech therapies. The core component of the resulting CosmoBot™ System was a robot designed as an interactive tool to interface with the patient. CosmoBot™ is controlled via Mission Control™, a command unit with 4 jumbo-sized buttons which provides an interface both with software and the robot. Teachers and therapists can use a microphone to create a "voice" for the robot and engage the child in interactive play using the control unit.

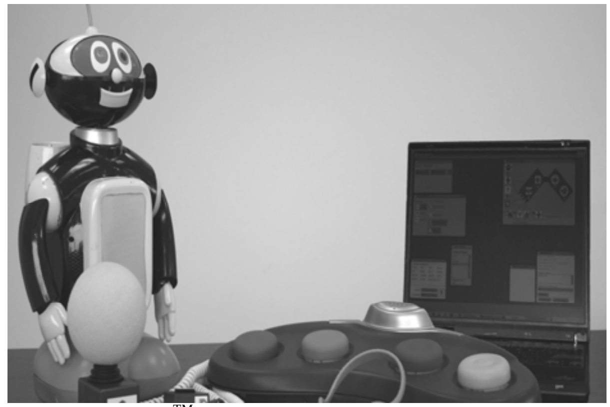

Fig. 1. CosmoBot™ Learning System with graphical user interface and robot for therapy, education and play.

Good results were reported from initial use of the CosmoBot™ Learning system as an interaction tool for patients with Autism Spectrum Disorders, in speech therapy and in classrooms assisting children with basic concepts such as order (first, second, etc.) and physical location (before, after, behind, etc.). Overall, the therapists, children and parents agreed that the technology was highly motivating and the provision of immediate feedback without the need for language was beneficial. However, use of the Mission Control™ unit was a key shortcoming of the original CosmoBot™ system limiting use for upper extremity therapy. Although the universal accessibility

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design was easy for patients to use, the motion of pressing the buttons engaged wrist flexion with forearm pronation which is opposite from the direction which is therapeutically needed to support functional use of the wrist, hand and forearm, specifically, wrist extension and forearm supination. A different sensor was required to more fully realize the goal of using a CosmoBot™ system for treating upper extremity movement impairments.

A second problem was the computer interface for the therapist. Many games and computer based components did not allow the therapist to adapt the system for individual patient capabilities or limitations. A different interface was needed to allow therapists to change the thresholds and adapt the system for use with a variety of patients.

Finally, several limitations related to the fragile nature of the robot experienced during pilot testing. The shell of the robot was prone to cracking with the enthusiastic interactions with children. The drive unit became overburdened with the weight of the overall structure. And the arms had limited range of motion due to weight of the servos driving limb movements.

III. Current Configuration

A. Robot

For the upper extremity therapy system, the original CosmoBot™ robot provided the framework around which a gestural interface for movement feedback was created. Rather than making the robot mimic movements, the decision was made to mount an inanimate version of CosmoBot™ onto a mobile base (Fig. 2). A commercially available mobile base, "Roamer-Too" (Valiant Technologies USA, Forest Park, IL 60130) was selected to provide movement of CosmoBot™. The mobile base is remotely controlled by computer via Bluetooth.

Fig. 2. CosmoBot™ robot mounted on mobile base.

B. Sensor

A three degree-of freedom accelerometer was integrated into the CosmoBot™ system to allow control of the robot as a feedback type of device. The accelerometer responds to specific gestures or movements produced by patients as directed by their physical or occupational therapist. We focused initially on the movements which therapists indicated are most needed by patients with upper extremity movement impairments secondary to cerebral palsy, brain injury or stroke, specifically, wrist extension and forearm supination. The choice of avoiding any exoskeleton type design was to allow flexibility in use of the system beyond the currently envisioned application.

The accelerometer was embedded in a sealed case for protection of the sensor from any liquid or body fluid contamination and to allow the sensor to be cleaned between patients (Fig. 3). Hook type Velcro was affixed to one side of the sensor box to allow the sensor to be attached to any body location via a cuff made from athletic wrist/forehead sweat bands. The sensor communicates via a USB connection with a laptop computer.

Fig. 3. Three degree-of-freedom accelerometer enclosed in sealed case and attached on dorsum of hand.

C. GUI

A graphical user interface (GUI) was developed to provide therapists with control of sensor parameters and the CosmoBot™ robot. One component of the GUI is the sensor definition and set up (Fig. 4). After the therapist determines the therapeutic movement required of the patient for the treatment session, a reference position for the sensor and identification of sensor orientation is determined. Threshold limits are set individually for each of 4 directions of movement away from the reference position and are mapped to a 3x3 display grid. The process of mapping can accommodate both right and left sides of the body.

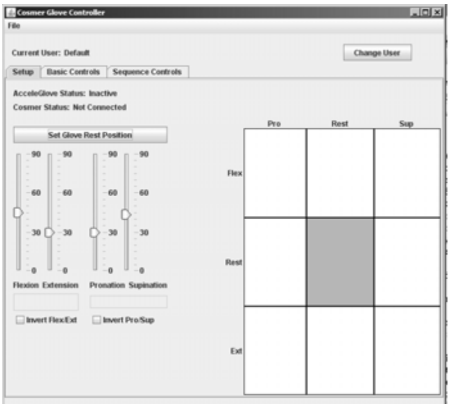

Fig. 4. Image of GUI used to establish reference position and define thresholds for movement to trigger a response from the CosmoBot™. For this patient, a motion in extension greater than 30° from the rest position would trigger CosmoBot™.

A second component of the GUI addresses control of the CosmoBot™. Signals are transmitted via Bluetooth to the mobile base triggering movement of CosmoBot™. Two modes of movement are available to therapists via the GUI. During "Free Play", each movement of the sensor which results in crossing a predefined threshold, results in a single movement of CosmoBot™. Default movement of CosmoBot™ is forward one length of the mobile base. Left clicking a wireless mouse prior to triggering the sensor will result in the CosmoBot™ turning to the left, while right clicking causes a right turn. During "Patterned Play" the therapist can define a path on a grid which the CosmoBot™ will follow (Fig. 5). Before starting the sequence, the therapist defines a motion that the patient will be required to move and the time the movement must be sustained before CosmoBot™ will move (Fig. 6). From the start position to the final position, the direction of movement and turns are programmed on a grid.

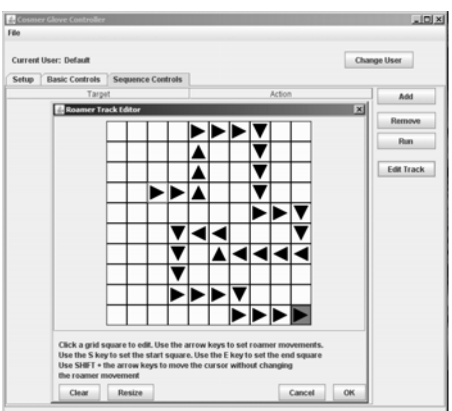

Fig. 5. Image of GUI used to establish track for CosmoBot™ to follow during the "patterned play".

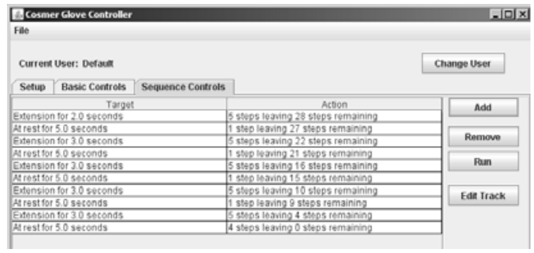

Fig. 6. Image of GUI used to define movement required and time movement is sustained to trigger feedback of CosmoBot™ as it follows the path established for the "patterned play". For this patient, an extension motion sustained for 2 seconds would result in the CosmoBot™ moving through the first five steps in the track shown in Fig. 5.

IV. Conclusion

This use of a robotic feedback system for habilitation/rehabilitation represents use of robotics in facilitation of patient's movements rather than supplanting patient movement with robotically assisted movement. The current configuration of the CosmoBot is being used in a rigorous clinical trial for patients with brain injury, cerebral palsy or stroke needing upper extremity intervention. Future reports will provide quantitative measures of movement and strength and objective measures of functional ability acquired in a repeated measures crossover study.

Acknowledgment

C.E. Lathan thanks Valiant Technologies.

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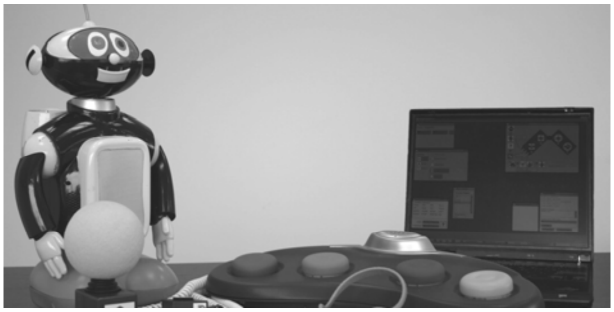

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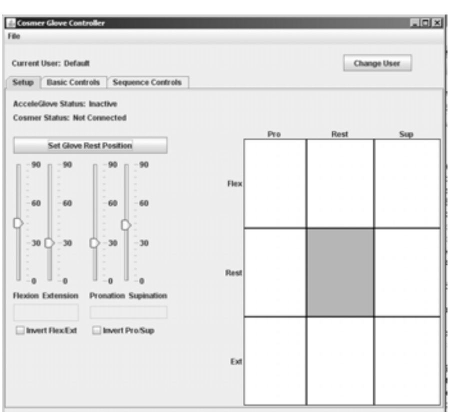

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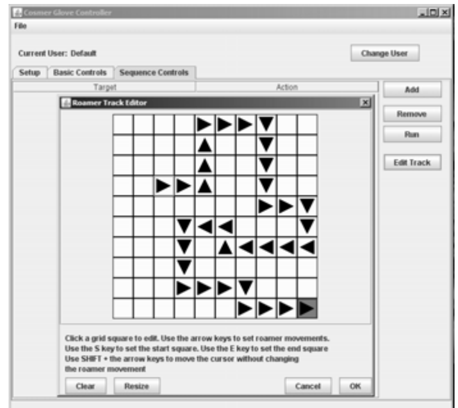

Fig. 5. Image of GUI used to establish track for CosmoBot^{TM} to follow during the "patterned play".

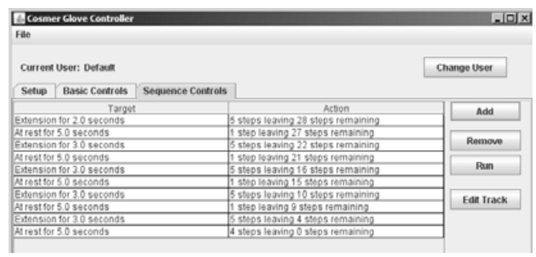

Fig. 6. Image of GUI used to define movement required and time movement is sustained to trigger feedback of CosmoBot^{TM} as it follows the path established for the "patterned play". For this patient, an extension motion sustained for 2 seconds would result in the CosmoBot^{TM} moving through the first five steps in the track shown in Fig. 5.