International Journal of Advanced Culture Technology Vol.7 No.1 231-236 (2019)
DOI 10.17703/IJACT.2019.7.1.231

IJACT 19-3-31

Dual Mode Feedback-Controlled Cycling System for Upper Limb Rehabilitation of Children with Cerebral Palsy

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Abstract

Background/Objectives: *This paper proposes a dual mode feedback-controlled cycling system for children with spastic cerebral palsy to rehabilitate upper extremities. Repetitive upper limb exercise in this therapy aims to both reduce and analyze the abnormal torque patterns of arm movements in three- dimensional space.*
Methods/Statistical analysis: *We designed an exercycle robot which consists of a BLDC motor, a torque sensor, a bevel gear and bearings. Mechanical structures are customized for children of age between 7~13 years old and induces reaching and pulling task in a symmetric circulation. The shafts and external frames were designed and printed using 3D printer. While the child performs active/passive exercise, angular position, angular velocity, and relative torque of the pedal shaft are measured and displayed in real time.*
Findings: *Experiment was designed to observe the features of a cerebral palsy child's exercise. Two children with bilateral spastic cerebral palsy participated in the experiment and conducted an active exercise at normal speed for 3 sets, 15 seconds for each. As the pedal reached 90 degrees and 270 degrees, the subject showed minimum torque, in which the child showed difficulty in the pulling task of the cycle. The passive exercise assisted the child to maintain a relatively constant torque while visually observing the movement patterns. Using two types of exercise enabled the child to overcome the abnormal torque measured in the active data by performing the passive exercise. Thus, this system has advantage not only in allowing the child to perform the difficult task, which may contribute in improving the muscle strength and endurance and reducing the spasticity but also provide customizable system according to the child's motion characteristic.*
Improvements/Applications: *Further study is needed to observe how passive exercise influences the movement characteristics of an active motion and how customized experiment settings can optimize the effect of pediatric rehabilitation for spastic cerebral palsy.*

Keywords: *Cerebral Palsy, Upper Limb Rehabilitation, Primitive Reflex, Cycling Exercise, Dual Mode*

1. INTRODUCTION

Incidence rate of cerebral palsy is known to be 3.2 children per 1000 live births [1], and it may occur either before or after birth. Although it is known as the most common disability in childhood, approximately 42 percent of the cerebral palsy children are not receiving appropriate cares or therapies for rehabilitation [11]. Children with cerebral palsy mostly have limited movements in three-dimensional space, and it is generally accompanied by problems such as the lack of ability to communicate and recognize, such as the sense of sight, hearing, and speaking. Especially, due to the spasticity of the muscles, the muscles cannot function sufficiently, and weakness or unbalance of the muscles lead to a certain form of movements specific to cerebral palsy [3].

All rehabilitation methods share the common goal that main purpose of the rehabilitation itself is to

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Manuscript received: December 6, 2018 / revised: January 2, 2019 / Accepted: March 10, 2019
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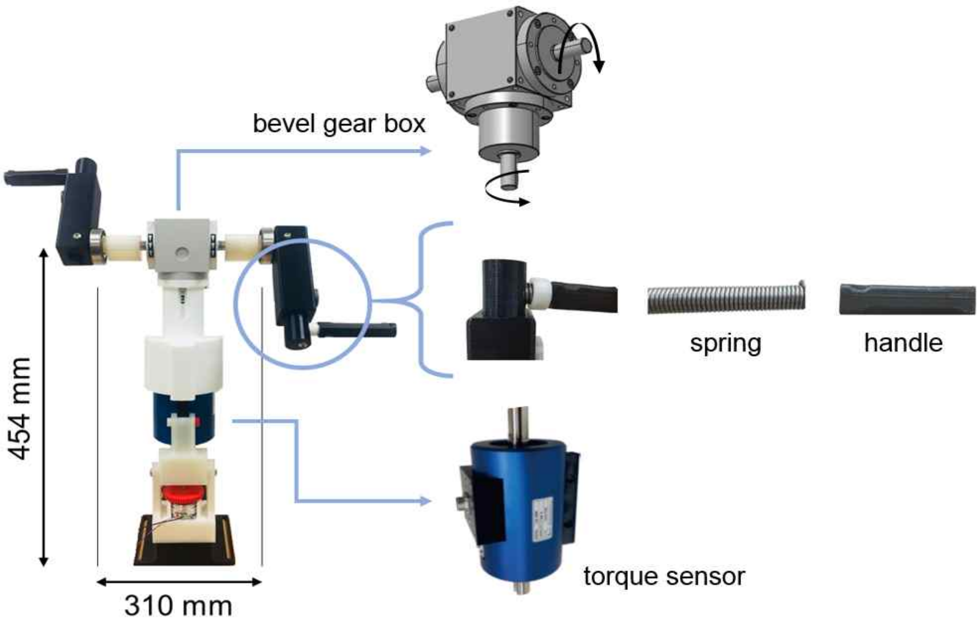

Figure 1. 3D Model of the Cycling System Device and Its Mechanical Components

To measure the torque value, use the bevel gear box to change the direction of the torque from horizontal to vertical.

Use flexible handle to prevent body twisting of children with cerebral palsy.

maintain the posture, reduce spasticity, and develop, or recover, functional abilities. However, many of the current therapies fail to induce voluntary movements from the patient and does not include quantitative assessments. [4] Cerebral palsy children have many limitations in functional operation due to their difficulty in separating other body movements due to primitive reflections and their delayed physical development. Therefore, existing rehabilitation treatment mainly focuses on reducing muscle strain or abnormal motion (spasticity or convulsions) caused by primitive reflections without any specific assessments.

Pediatric rehabilitation must be considered as an important issue because unlike rehabilitation of adults, rehabilitation of child treats the disorder that occurred during the growth from birth to adulthood without reaching any functional achievement, while the goal of adult's rehabilitation is to recover the motor functions lost by the disability. For this reason, diagnosis and treatment approach of pediatric rehabilitation are much more complicated and difficult than that of adults. Therefore, we suggest a motor-controlled robotic device to induce and assist voluntary movements that provide supervised assignments with pedal cycling system, and we expect that repeated exercise of voluntary motions will eventually improve the ability to independently carry out daily living activities and Quality of Life (QoL).

2. MATERIALS AND METHODS

2.1. *Mechanical Components*

Conventional pedal exerciser is mostly intended for adults and does not consider the different growth gap in child patients. In this study, we designed a pedal exerciser hardware with length and height adjustable shafts for younger patients. Additionally, it is composed of a potentiometer, BLDC motor MW-VBL24D030S-M-G, a bevel gear box SLG-65, and a torque sensor SA-5kgfm, as demonstrated in Figure 1. In general, there are two types of gears used to lower the rotational speed or transmit power between two orthogonal axes: worm gear and bevel gear. The gear box used here connected to the motor decelerates to 100:1, where deceleration is not required. Hence, a bevel gear is used to minimize power loss due to friction. As the motor power input is applied to the bottom shaft of the gear box, the bevel gear switches the direction of the input rotation and outputs a rotation in a perpendicular direction. Under DC 24V power supply, BLDC motor included in the figure can rotate at high speed and is semi-permanent and wear-free. Unlike other general DC motors, this particular one has no brushes, so a separate drive circuit is required. Therefore, the motor drive and DAQ board are connected and the motor is controlled via PC. The range of motor rotation is minimum of 100 to maximum of 3000 rpm, the rated torque is 0.12 Nm, and the gear ratio is 100:1. The power generated by the BLDC motor

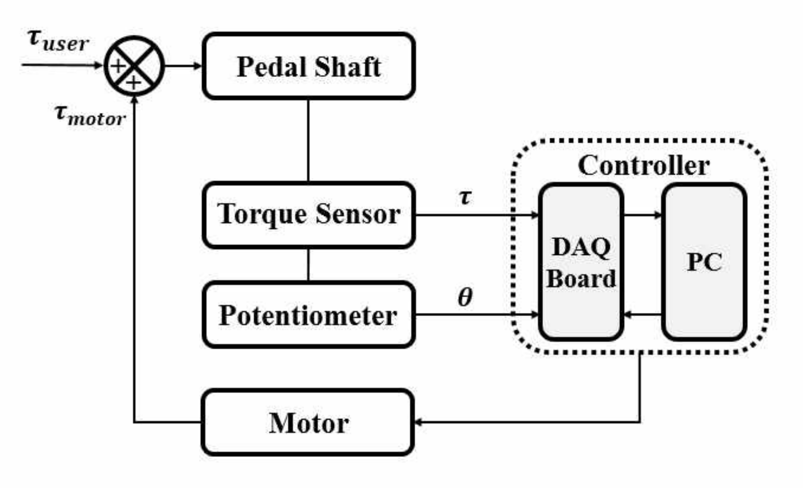

Figure 2. System Control Block Diagram

NI USB-6216 was used controller to control the motor and collect the sensor data with a sample rate of 200 hz

is transmitted without loss by the rotating torque sensor connected to the motor and transmitted to the shaft through the bevel gear box.

Based on the Modified Ashworth Scale (MAS), children with level 2 or higher tends to load more weight on the shaft and handle due to upper limb spasticity. To prevent handles from breaking apart from the shaft, we wrapped a spring with the external frame of handle, as shown in the Figure 1. In this prototype, all couplings are 3D printed, and the input value was set to 100% for printing because they shall be fixed and not swayed when the device operates. A bottom frame is made to fix the device to the experiment table, and the lower part of this frame is made thinner and laterally wide so that it can be fixed to the table using clamp.

2.2. *System Components*

To implement the mechanical structure, torque sensor modelling was done using linear fitting method. Torsional force input is given to the torque sensor, and we observed the torque value through the indicator. After linear fitting Torque vs. Voltage, we used a curve fitting tool, a built-in function of MATLAB, to solve for the coefficient of sensor model. Rated torque of this model is 50 Nm, and rated output is 1.3±0.3 mV/V. Since torque data did not show too prominently large noise signals, moving average filter is applied to eliminate the short-term fluctuations in time series.

Dual mode system is divided into 1) active and 2) passive exercise mode. Active mode system is designed to induce the patient's voluntary movements by receiving the patient's own force and intentions as input. Repetitive rotation element in such exercise improves the coordination between muscles and contributes in enforcing the triceps and serratus anterior muscles of the cerebral palsy children whose movements are usually hindered by primitive reflex. The role of a passive mode system, on the other hand, is to help the patient to overcome abnormal torque reaction when performing the reaching and pulling task. It allows the patient to perform the difficult task even without intentions to input force.

Potentiometer comes in after all and plays a role in measuring the angular position and angular velocity of the pedal shaft that patient grabs. Angular position and magnitude of corresponding torque reaction are displayed and shown to the patient as a real time visual feedback. Angular velocity is calculated afterwards by differentiating the data of angular position. Since spasticity is a speed-dependent pathology, angular velocity is an important parameter for control and analysis.

3. EXPERIMENTS

3.1. *Dual Mode Trials*

The device is placed and set up in a height that center of the bevel gear box meets the subject's chest level when the subject is sat upright on the chair. Patients were asked to simply grab the handles of the cycling device and follow the rotational movement. The purpose of this experiment was to observe the reactive force

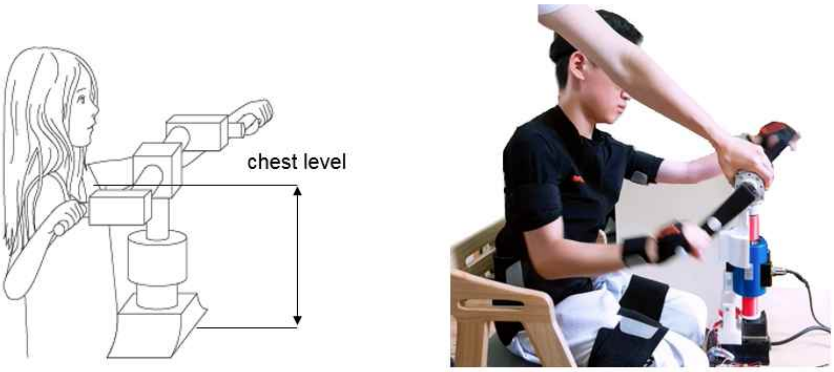

Figure 3. Prototype

The prototype was 3D printed and tested by a normal subject beforehand. While in passive mode, the pedal rotates at 80 deg / s, operates for 30 seconds and then stops.

of the affected (spastic) limb when it was put to motion by outside force. According to the severity of each subject, reactive force may differ, and thus, appropriate velocity must be set for each patient. In order to provide appropriate angular velocity of the motor under consideration of subject's spasticity level, active trial was conducted beforehand. After 2 sets of 30 second trials, the average velocity was calculated. This result was then set as the input velocity of the passive mode trials, and the reactive torque values were measured. Each trial was repeated for 2 sets and 30 seconds each set. Two children with spastic cerebral palsy, either hemiplegic or diplegic, participated in the experiment. Sitting height of the child was measured to set the hardware at its appropriate level of height, and the lengths of each arm were measured to adjust the length of the shaft.

Active mode trials were followed by, and patients were asked to provide physical efforts to give rotational motion to the pedal exerciser. The device was set as free load, and angular torque and angular velocity were measured again. The subjects were instructed to exercise with an angular velocity they prefer, which induced their intention and voluntary motions. For each quadrant of angular position, the change in angular velocity and corresponding torque values were measured and displayed on the monitor as a visual feedback to the subjects. Afterwards, again, passive mode trial was repeated for 2 sets with 30 seconds each set to compare the effect of active exercise.

3.2. *Results and Discussion*

Two child subjects demonstrate different torque patterns throughout the cycling exercise. Subject 1 seems

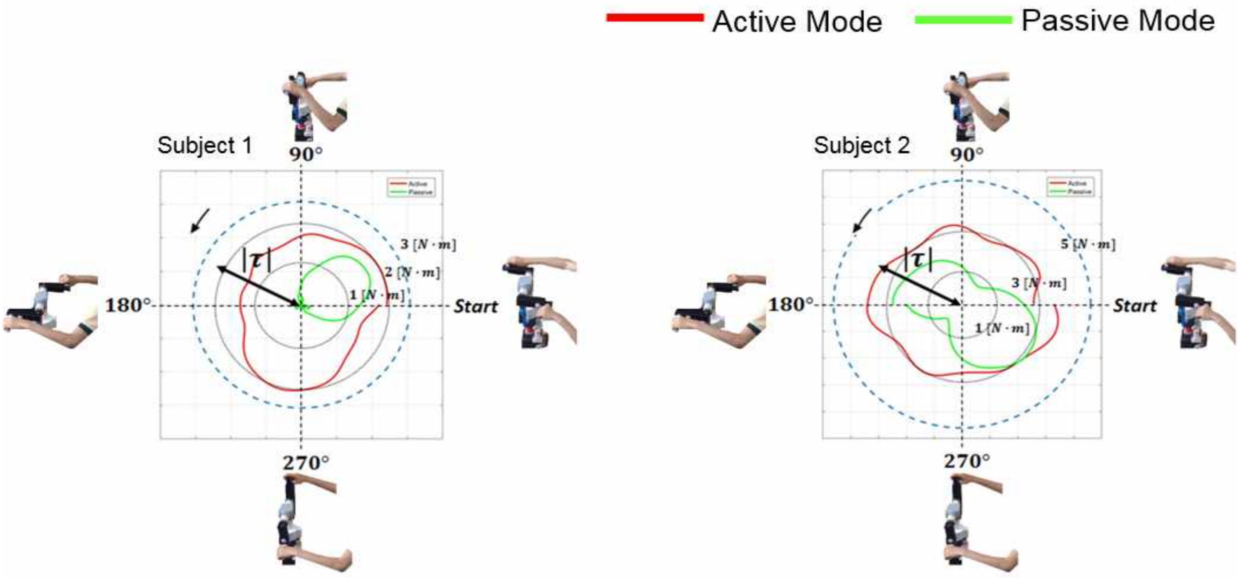

Figure 4. Dual Mode Experimental Results

Comparison of two subjects' Polar coordinate data. The experiment starting position is the same.

to have an irregular torque in the first quadrant, between 0 to 90 degrees, during the passive mode, while subject 2 tends to show an irregular pattern in the second and fourth quadrant, between 90 to 180 degrees and 270 to 360 degrees. The active data curves, shown in red, display that two subjects have significantly different characteristics in cycling motion. Mostly, the subjects showed difficulty in pulling task of the cycle, while reaching task needed less force. The passive mode exercise assisted the child to maintain a relatively constant torque while visually observing the movement patterns. The polar coordinate plots are drawn from the left side view of the hardware, and the direction of motion is denoted with the arrow within the figure. Additionally, hand positions within the device are displayed every 90 degrees in the figure. The corresponding angular positions are labeled appropriately, and the absolute value of the distance from the origin to the curve represents the magnitude of the patient's torque at that angular position.

3.3. *Future Plans and Improvements*

In this cycling rehabilitation system, visual feedback is provided to let the patients be aware of their condition in real time; however, the patients are simply just aware of their condition, and they are not assigned to specific tasks. Therefore, we are looking forward to design and include a target-tracking system where each user is assigned a target to follow. Control of kinematic parameters in the target is expected to help improve the patient's movability and intention for voluntary motions. Especially with the children, entertaining target tasks will attract their sight and improve motivation.

Control of angular velocity in the target will contribute in reducing the patient's spasticity in forearms and elbows. A sinusoidal signal is given as a default path, and as the patient performs the cycling exercise, one target will represent the subject's pedal velocity, while another target on the same path represents the control target. The velocity of a control target changes depending on the change in velocity of the pedal. Our control algorithm will calculate the error between the patient's target and control target and display on the monitor in real time.

We expect that our system would also provide the error between the patient's motion torque and recommended torque in each quadrant of angular position. The data collected during this exercise is expected to give appropriate feedback to patients of how normal or abnormal exercise they are performing. Magnitude of abnormal torque will play an important role in analyzing the movement patterns and level of spasticity in each child patients.

4. CONCLUSION

In this study, we suggested a dual mode feedback-controlled cycling system for upper limb rehabilitation. Different from previous studies on upper limb rehabilitation methods for children with cerebral palsy, the proposed system aims to induce and assist children's voluntary movements with a single motor. Angular position, angular velocity, and reactive torque are measured and collected by BLDC motor and torque sensor. Experiment was conducted on two cerebral palsy children. The experiment result revealed that this system has advantage in being able to provide customized system for each child with different characteristic of movements and enable both active and passive rehabilitation with quantitative assessments.

ACKNOWLEDGMENT

This paper is supported by CESEE (Convergence Education for Sustainable Energy and Environment) program funded in part by the Ministry of Education (ME, Korea), and National Research Foundation of Korea(NRF) grant funded by Korea government(MOE) (No. 2017R1D1A3B03035973).

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