

# Soft Ankle Exoskeleton for Gait Assistance of Children with Cerebral Palsy in Home Settings

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**ABSTRACT**

*This paper represents the design and manufacturing of a lightweight ankle exoskeleton to assist walking of children with cerebral palsy. Cable-driven soft assistive robots typically require two motors to control the bidirectional motion of a single joint. Thus it is heavy and not cost effective. The novelty of this work is a mechanism that enables a single motor to control the bidirectional motion of a cable-driven robotic joint. Thus the ankle exoskeleton is lightweight, efficient and affordable. The purpose of this project is to rehabilitate the gait and to assist walking in home and community settings. Ankle Exo is active in both plantar and dorsiflexion phases while still remaining comfortable for the children. Evaluating and analyzing the gait of each user, the motor can be controlled to perform what is needed to support different cases of people with cerebral palsy.*

## INTRODUCTION

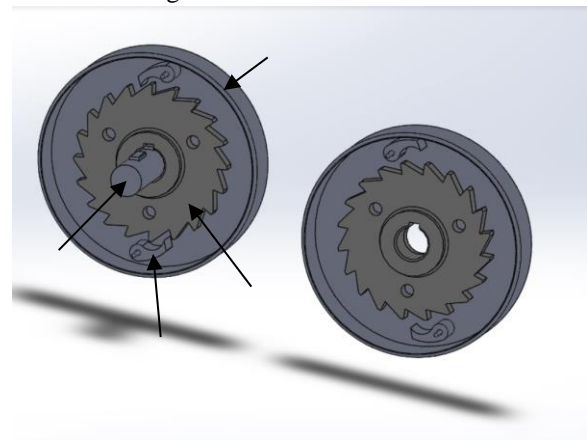
Cerebral Palsy is caused by abnormal brain damage that happens at birth or at early stages of life. The word *cerebral* refers to cerebrum which is the affected area of the brain and *palsy* refers to brain injury which impacts the disorder of movement. One of the main disorders is crouch gait. Crouch gait is a pathological walking pattern that is characterized by excessive ankle dorsiflexion during the stance phase. This ankle exoskeleton will be an untethered system to provide assistance to those children. The exoskeleton will provide assistance in both dorsiflexion and plantarflexion as both movements are needed during the complete walking cycle. The age range of children which will be able to use the ankle exoskeleton is 5 to 12 years old. The purpose of this study is to design an exoskeleton which would be able to save as much metabolic energy and also to make sure it weights under 2kg in order to be as comfortable for the children. The design will also be optimized to provide the correct amount of torque while maintaining an overall balance of the user to be as comfortable as possible.

At the moment tethered ankle exoskeletons exist but the majority of them are used in research facilities. No truly untethered system exists that can provide both dorsiflexion and plantarflexion. Researchers at Northern Arizona University have developed untethered ankle exoskeletons but are still in the early stages of a full product. Some of the designs of these universities are too heavy, only provide half the needed assistance, too expensive, or a combination of these limitations. Our design will be a great improvement from these existing and in development designs.

## METHODS

The ankle exoskeleton consists of mainly two sections; the control box that will be placed at the hip area, and the transmission cables which will deliver the necessary torque to the foot. The transmission cable will be paired with a back plate and a hook that will be connected to the shoes. The control box consists of the motor, gear assembly, our state of the art ratchet mechanism, battery, and the control system.

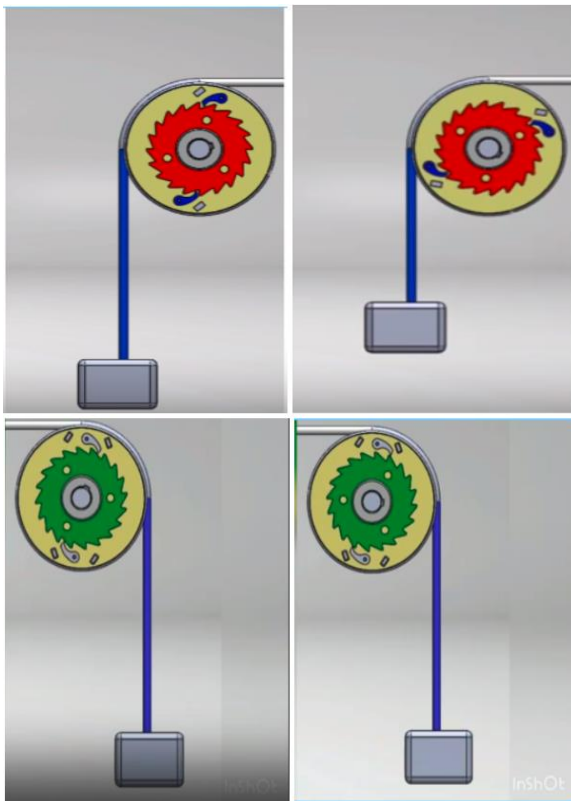
Figure 1 shows the design of the ratchet mechanism. For the purpose of visualization, the two ratchet housings are shown apart, however, in reality, the two housings are connected via the same shaft and are facing each other. The ratchet is connected to the shaft while the ratchet housing is connected to the shaft through a bearing. Thus, the rotation of the ratchet is dependent on the rotation of the shaft while the rotation of the ratchet housing is independent of the shaft. A stopper of special shape, which is connected to the ratchet housing via a pin, will be used to engage with the ratchet, which in turn will cause the ratchet housing to rotate when the shaft is rotating clockwise or counterclockwise. The design of the ratchet mechanism will ensure that only one ratchet housing is rotating when the shaft is rotating clockwise or counterclockwise. A transmission cable, which is connected to a shoe, will be connected to each ratchet housing. Thus, the clockwise or counterclockwise rotation of the shaft will ensure dorsiflexion or plantarflexion movement for the cerebral palsy patients due to the design on the ratchet mechanism.



**Figure 1:** Ratchet assembly inside the control box that is used to control transmission cables.

In order to ensure the design was reasonable and would work as intended, a motion analysis was performed using SolidWorks. Two different motion

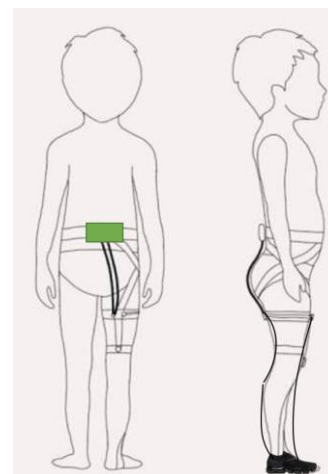
analysis was performed using two different gears in order to test both the dorsi and plantar flexion motions. In the motion analysis, a gear, ratchet housing, a stopper to lock the gear, transmission cables, and a box to represent the shoe were assembled. Torque was applied on the gear while keeping the overall gear assembly stationary in one position. In one direction, the stopper would lock into the gear and cause the ratchet housing to rotate resulting in movement of the transmission cable. This movement of the transmission cable would result in lifting the box upwards. When the direction of the torque applied on the gear was changed, the stopper would not lock into the gear and allow the gear to rotate freely. This would not cause any movement of the box as intended. These tests were performed again using the gear and the transmission cables in the other direction. As seen in Figure 2 below, the gear in the center would lock with the small stoppers on the side depending on what direction the torque was applied. This proved the designed worked as intended without any issues.



**Figure 2:** The motion analysis of the dorsi and plantar flexion assistance by the gear-ratchet assembly with the box to represent the shoe movement.

To further test the design and ensure everything would work as intended, a prototype was

created. Inside the control box, a housing was designed and 3D printed to hold the motor along with the gear assembly. The motor and the gear assembly were connected to each other with a belt on one end. On the opposite end, they were attached to the housing to keep stationary. A hole was created on top of the gear assembly to connect to the shaft. Both the shaft and the gear that was placed on the shaft were also 3D printed. The ratchet housings were also 3D printed with grooves on the side to attach the transmission cables. All components were attached using machine screws and bearing where necessary. As the motor turned, it rotated the gear assembly to increase the torque output. This torque output turned the shaft and the gear on it. Then, depending on the direction of the rotation, the ratchet housing turned. This either locked the front or the back stopper and moved the transmission cables accordingly. The attached shoe moved as intended resulting in proving the design was successful. Figure 3 gives the best description of the final assembly of the prototype and the way that it would be worn.



**Figure 3:** Sketch showing how the ankle exoskeleton would be worn. The green box shows the housing where the control system (motor, battery, ratchet gears) would be inserted. The strap shown in the left would connect the housing with the shoe in the front and in the back to provide both dorsi and plantar flexion.

### Conclusion

Unlike passive devices (e.g. orthosis, walker) and powered devices (e.g. robotic walker and rigid exoskeleton) in the market as of today, Ankle-exo is an untethered soft robot that assists mobility with an anthropomorphic form factor and the potential to worm undergarment in home and community settings. Since

this ankle exoskeleton can be put on and taken off in a few minutes thanks to the mechanism design that enables simple integration of the robot with shoes of a person, it makes this prototype comfortable without providing any rigid components that might cause bruises and support independent living of this user population.