TrAVELER – Triple hinge Ankle foot Exoskeleton for Lower Extremity Rehabilitation

Design Team
Mary Chenard, Kevin Davids, Kim Masi Axel Paganakis, Amy Sauger

Design Advisor
Prof. Constantinos Mavroidis

Abstract
One of the most common traumatic episodes that severely affects human motion (or gait) is stroke. According to the national stroke association, stroke is the leading cause of adult disability in the United States. Research indicates that there is a particular market and clinical need for a device that specifically addresses the measurement of relative ankle motions, in addition to gait data. This capstone project involves the development of a device that fills the market need of a modular, passive ankle foot orthosis (AFO) and provides real-time gait rehabilitation feedback data to physical therapists. This feedback increases the efficiency of a therapy session and allows for a better understanding of a patient’s impaired gait. It will also allow physical therapists to better tailor therapy sessions and to track progress of the patient’s rehabilitation. The project also works in conjunction with a rehabilitation exoskeleton, called ANdROS. Analyses were conducted to determine the optimum choice of materials, structure geometry and sensors for the design. Preliminary tests provided pilot data for verification of the current design. Ultimately, as a continuation of this project, modifications to the design will be made, with careful considerations from industry experts and Physical Therapists at Spaulding Rehabilitation Hospital, patient testimonies and analytical results.
The Need for Project

Stroke is a leading cause of gait impairment. There is a lack of devices that provide feedback to physical therapists. According to the national stroke association, stroke is the leading cause of adult disability in the United States with at least 700,000 new cases each year (Ref. 2). It was demonstrated that robotic-assisted devices improve the way gait disorders are diagnosed and treated. After researching current rehabilitation devices including: exoskeletons, active foot orthoses, and treadmill based devices, a need was determined for a device that can provide a physical therapist with quantitative feedback about a patient’s gait cycle. The project will also interface with a current exoskeleton, ANdROS, (Active Knee rehabilitation Orthotic System) for post-stroke gait rehabilitation.

The Design Project Objectives and Requirements

The main objectives of the design are to support the patient while passively measuring gait parameters such as acceleration and joint flexibility.

Design Objectives

The design meets two sets of objectives. First, the device can act as a stand-alone foot-ankle rehabilitation device. It is passive and is able to support the patient. The device was designed to be comfortable, lightweight and not impede the patient during normal gait. The device also senses and measures ankle acceleration, pressure distribution and angular displacement of the ankle joint.

Second, the design interfaces seamlessly with ANdROS, an exoskeleton in development in Northeastern University’s Biomedical Mechatronics Lab. The device must provide ANdROS with sensor data and ground contact for weight support.

Design Requirements

The main design requirements are listed below (Rep. 3):

- The device is safe and does not harm the patient while in use
- The device weighs less than 3 pounds
- The design allows for ankle motion in two degrees of freedom
  - +10° to -20° in dorsiflexion and plantar flexion
  - +4° to -11° in inversion and eversion
- The base of device supports the patient’s weight as well as the weight of the ANdROS exoskeleton

Design Concepts Considered

Five main design concepts were developed; the three top designs are detailed below. The final design concept discussed
are discussed here. below, the Triple-Hinge, was developed after reviewing the other four original concept designs during a design review with advisors and physical therapists (Rep. 5.1).

**Ball and Socket Design**

This design revolves around the use of a ball and socket joint, which allows for a full range of motion in three degrees of freedom. There is a telescoping shaft that aligns with the outside of a patient’s leg that can adjust for different patient heights. The base of the device will support the total weight of the patient, the device, and an exoskeleton. This device is unique in that all the motion of the ankle is represented by one joint.

**Curved Runner Design**

The curved runner slides through the base of the device under the user’s heel. This runner acts as a guide for motion in the inversion and eversion plane. The hinge on the side of the device allows for dorsiflexion and plantar flexion. Angle displacement can easily be measured in this design using strain gauges on the curved runner.

**Triple-Hinge Design**

The triple hinge design uses a system of three sets of bearings to achieve ankle motion in two degrees of freedom. Eversion/inversion motion is achieved at the rear of the ankle, while dorsiflexion and plantar flexion are achieved through the bearings located on both sides of the ankle. Ground support for the patient is provided by the base plate. Unwanted moments on the device are prevented through a double support structure. Sensors can be easily placed into this design to measure angular displacement and acceleration.

**Recommended Design Concept**

The triple hinge design was the best design that satisfied our requirements and was practical to make. Design Description

There are three main subassemblies in the chosen design. The base assembly consists of a rubber base attached to a rigid aluminum structure. The structure is very similar on the inside and outside of the foot. At the top of the side supports are two bearing sets that allow for dorsiflexion and plantar flexion. There is an encoder on one bearing set to measure the ankle’s angular displacement. There are also force sensors on the bottom of the device to help determine when the patient contacts the ground during therapy. The base also
incorporates a binding that wraps over the top of the patient’s foot to secure the foot to the device.

The rear cuff extends from the side supports to the back bearing joint. This assembly is also made of aluminum and its purpose is to connect the joints to allow for a smooth motion. The rear bearing set allows for eversion and inversion motion. An encoder, mounted on the rear cuff, measures angular displacement in the inversion/eversion plane.

The final main subassembly is the shank support. This encompasses the part of the device that lies above the rear joint. The double bars on the sides support the patient and ANdROS and prevent bending moments. The top of the device will also connect with ANdROS mechanically and electrically. There is another on the lower leg of a patient that is used to secure the patient’s lower leg to the device.

An important component of the overall assembly is the resistance bars that are mounted outside each hinge. The resistance bars stabilize the hinge and are made of different materials that can be easily changed out to allow for variable joint resistance. Since they are interchangeable, a physical therapist will be able to customize the range of motion and tailor the therapy session depending on a patient’s progress.

The encoders, force sensors, and accelerometer are all controlled using a LabView User Interface. The sensors also integrate with ANdROS to provide complete data acquisition.

**Analytical Investigations**

Finite Element Analysis, was performed on the base, rear cuff, and shank support assemblies, which calculated deflection, compared the von Mises stress to the material yield strength and checked for fatigue failure. The forces used were calculated using a biomechanical analysis utilizing link segment modeling. The completed analysis revealed that the device will not fail due to material stresses or fatigue (Rep. 5.2).

An initial estimate of the device’s final weight was calculated by performing a weight analysis in SolidWorks. A confirmed final weight was determined during the manufacturing and assembly.

**Key Advantages**
A key advantage of this device is that it allows for easy measurement of angles of each joint using sensors that integrate seamlessly into the mechanical design. This ability will assist in the measurement of the absolute angles of the patient’s ankle in each degree of freedom without interfering with the patient’s natural motion.

Another advantage is that the device is designed to be simple enough for a physical therapist to easily place onto a patient; adjustable bindings allow for a custom fit to each individual.

What sets this device apart is the adjustability of resistance for different ranges of motion. This allows for better therapy sessions more tailored to a specific patient’s needs.

**Financial Issues**

The total cost spent to date is $1,241.28 on all commercially available parts and raw materials.

The amount spent on the project is $1,241.28. This includes the cost of commercial off the shelf parts in addition to materials required for machining custom parts. Market research shows competitor products and other stroke-rehabilitation devices have costs listed at or above $40,000 (Ref. 44). One goal of this project was to fall well under competitors prices and to design a device that even a small therapy office can afford.

**Recommended Improvements**

Potential improvements include material selection and the damping component of the hinges.

In a future version of the device, the use of alternative materials would further lower the weight below the current 3lbs limitation; this would be beneficial to the overall operation of the device as well as patient comfort. Alternate materials could be carbon fiber or high strength plastics.

Design alterations could also be made to the hinges. Although the resistance bars are a simple solution, an alternate way to limit the motions of the patient would be to use torsion springs at the joints.

Ideally a portable user interface would be implemented to further enhance the physical therapist’s interaction with the device. The current device must be connected with a wire, which is standard in industry, but a portable device with an iPhone or iPad app that can better interact with the physical therapist would further enhance the patient’s experience.