Active Ankle Foot Orthoses (AAFO)

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The Problem: Drop foot is the inability of an individual to lift their foot because of reduced or no muscle activity around their ankle. The major causes of drop foot are severing of the nerve, stroke, cerebral palsy and multiple sclerosis. There are two common complications from drop foot. First, the individual cannot control the falling of their foot after heel strike, so that it slaps the ground on every step. This is referred to as slap foot. The second complication is the inability to clear their toe during swing. This causes the person to drag their toe on the ground throughout swing.

Motivation: There three major motivations for this work. The first is the development of a method of helping millions of individuals with lower leg disabilities. The current project will be able to provide assistance to those with permanent disabilities, such as cerebral palsy, as well as those in rehabilitation. The creation of a tool to study the mechanics of normal and pathological human gait is a second driving factor. By placing this device on normal individuals, it is possible to see how they respond to external disturbances and analyze the human motor control system. Finally, laying down the first step to develop a full bio-suit or full body orthosis that would allow anyone, including paraplegics to walk normally.

Previous Work: The assistive devices for this pathology are Ankle Foot Orthoses (AFO). The standard AFO is a rigid polypropylene structure that prevents any ankle motion. Several studies have analyzed other designs that could be of more benefit[8, 3]. More, however, have analyzed placing a dorsiflexion assist spring on a more flexible AFO to help lift the foot[9, 5]. This would provide a dorsiflexion moment to lift the ankle slightly above neutral position, while allowing the user to have more ankle motion. There are several commercial products currently on the market applying this concept. The ToeOFF(tm) is a compact, lightweight AFO that allows a wide range of ankle motion, while providing a dorsiflexion moment[7]. The more widely used device is a dorsiflexion-assist spring Ankle Foot Orthosis (AFO), produced by several manufacturers[4, 6]. This AFO is able help individuals during normal walking by lifting their toe during initial swing. However, it does not remedy slap foot because the ankle moments required for controlled plantar flexion are too large for the spring. Further, this AFO also cannot account for different walking speeds. As an individual speeds up, slap foot becomes more prominent and the foot needs to be raised faster for ground clearance. Neither of these tasks can be accommodated by the current orthoses. Lastly, the current AFO also cannot compensate for other factors such as inclines or fatigue of the muscles. The idea of an actively powered orthotic device has been explored since the early 1980's using hydraulic and pneumatic device[10]. More recently, compressed gas and dc motors have been researched to provide active assistance to the individuals with paraplegia[2, 1]. A computer controlled knee-ankle-foot orthosis (KAFO) was also designed to assist those with muscle weakness of the quadriceps[11].

Approach: A polypropylene Ankle Foot Orthosis (AFO) with a hinge joint at the ankle was used, as can be seen in Figure 1. A rotary potentiometer was placed at the ankle to measure the ankle angle and six capacitive force sensors between the AFO and the shoe to measure the total ground reaction force and the center of pressure. A Series Elastic Actuator (SEA), developed at the Leg Laboratory, is used to power the Active Ankle Foot Orthosis (AAFO). A finite state machine is used to divide the gait cycle into three states. The first state occurs from heel strike until the body passes over the foot. It will eliminate slap foot by acting as a virtual linear, rotary spring around the ankle. Current research being done at the Leg Laboratory shows that the ankle acts like a linear rotary spring during this phase of gait. Using the force and position sensors, the AAFO will be able to determine the abnormal stiffness of the user and add the correct amount of resistance to eliminate drop foot. The second state will continue until the person has pushed off with their foot and entered into swing. It will have the actuator apply zero force to the ankle to not disrupt normal ankle function. The third state occurs during swing. The actuator will lift the toe acting as a linear

rotary spring and damper combination. This will ensure that the toe clears the ground during swing.

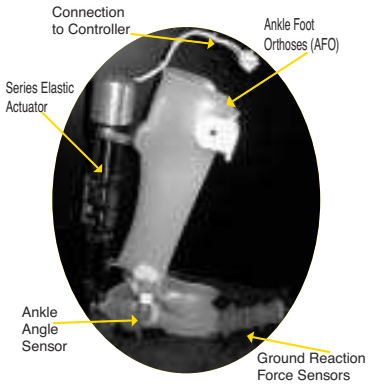

Figure 1: Description of the Active Ankle Foot Orthoses (AAFO)

Future Work: This project was a proof of concept that a person would allow a brace to both passively and actively assist motion of their ankle. There are three major areas where this research could expand. First, this could be developed as a research tool to study gait. The AAFO could be used as a method of analyzing the kinematics and kinetics of the ankle as well as the reaction of subjects to perturbed gait. The second area is the application of the AAFO to other pathologies of the ankle. The current work was done on individuals who could not use the muscles to lift their foot. A more challenging control scheme would be required to replace the calf muscles that lower the foot. The last area would be to extend this project into the knee creating a Knee Ankle Foot Orthosis (KAFO).

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