Variable Stiffness as Control Scheme for Enhancing Active Ankle Foot Orthosis

Kevin Abishek, Robotics and Autonomous Systems (Mechanical)
Mentor: Dr. Hyunglae Lee, Associate Professor
School for Engineering of Matter, Transport and Energy

Research question

Can a control scheme developed using the natural ankle kinematics (stiffness change during stance phase) be helpful in correcting ankle trajectory during walking?

Motivation

- Ankle is an important lower extremity joint providing up to 80% torque required for balance and locomotion.
- Ankle trajectory can be altered due to near-fatal injury or neurological disorder like stroke or CP.
- Ankle Foot Orthosis is an exo device that is worn by a subject and is capable of providing part of torque required to correct such alterations.
- This research focuses on development of a control scheme called Variable Stiffness Control (VSC) that uses change in natural ankle stiffness during gait to provide torque required to correct simulated alterations (added mass around ankle) on healthy subjects.

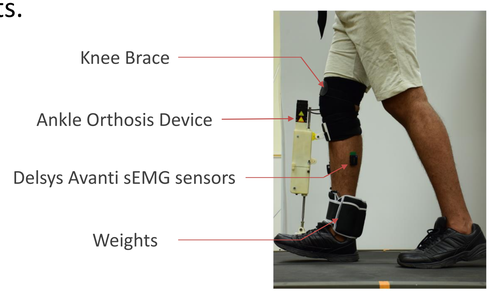

Fig. 1

Methodology

- 5 young, healthy participants were chosen to walk on a treadmill to track ankle angle trajectory under nominal (baseline) and passive (with 2 kg ankle weight) conditions
- VSC is used to correct the difference between passive (actual) and nominal (desired) ankle trajectory
- Torque to the AFO is applied according to the equation:

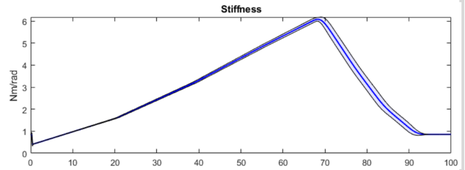

Fig. 2

$$\tau = k\ (\theta\ -\ \theta_{eq})$$

- Stiffness constant k varied according to the control schemes (Fig. 2)
- Constant stiffness method is used for comparison of VSC's performance where k is average of VSC stiffness through the stance phase (3.05 Nm/rad/kg)

Conclusions and future work

- As expected, VSC has proven to be a better control scheme to restore baseline ankle trajectory
- Plan to compare performance of VSC to other control schemes such as Auto Impedance Tuning (AIT) and Fixed State Machine (FSM)
- Study effects on muscle activity

Results

Trajectory correction

- Preliminary results show that the VSC controller exhibits better trajectory tracking than that of constant stiffness controller (Fig. 3)

Peak position Error

- VSC deviation: 13.52%
- Constant stiffness deviation: 17.66%

ROM deviation

- VSC deviation: 6.19%
- Constant stiffness deviation: 8.44%

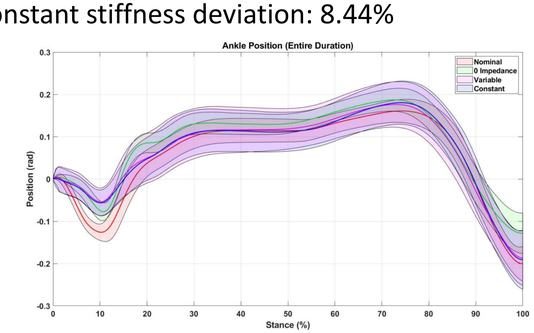

Fig 3

References:
1. Shorter, A. L. and E. J. Rouse, "Mechanical impedance of the ankle during the terminal stance phase of walking", IEEE Transactions on Neural Systems and Rehabilitation Engineering 26, 1, 135–143 (2018).
2. Lee, H. and N. Hogan, "Time-Varying Ankle Mechanical Impedance During Human Locomotion", IEEE Trans Neural Syst Rehabil Eng 23, 5, 755–764 (2015).

Acknowledgements

I would like to thank Dr. Hyunglae Lee for his guidance and for giving me an opportunity to conduct this research at his laboratory. I am equally grateful to Omik Save for his assistance and for conducting foundational research towards these findings. Additional thanks to the MORE committee for funding this research.

MORE
Masters Opportunity for Research in Engineering

Ira A. Fulton Schools of Engineering
Arizona State University