CPS: Synergy: Sensor Network-based Lower-Limb Prosthesis Optimization and Control

Ou Bai[PI,1], Douglas Murphy[2], Ashraf Gorgey[2], Ding-Yu Fei[3], and Zhixiu Han[4]

[1]Florida International University [2]Hunter Holmes McGuire VA Medical Center, [3]Virginia Commonwealth University, and [4]iWalk Inc.

BACKGROUND

More than one million people are living with lower-limb amputation in the United States, including a large number of warfighters who lost their limbs in the military missions.

Clinical Barriers:
Increased energy expenditure may result in amputees induced fatigue, secondary body damage, asymmetric joint loading, and increased risk of falls, etc.

Technical Challenges:
Though state-of-the-art lower-limb prostheses may provide net-positive power to reduce amputees' energy expenditure, however,

- Prostheses might not work at the best condition that may maximally reduce user's energy expenditure using current prosthetic tuning services;
- Prostheses are designed and tuned for optimizing the level walking; amputees would have difficulty in slope/stair walking, and/or walking on uneven plain.

OBJECTIVES AND SPECIFIC AIMS

The objective of this project is to develop Cyber-Physical Systems (CPS) technology for the prosthesis optimization to minimize the user's energy expenditure and for extending the capacity of the prosthesis to adapt to dynamic situations and environments.

Specific Aim #A: Design of a wearable body area sensor network system and computational algorithms for real-time measurement of the user's physical load and mental effort to support personalized prosthesis optimization for the goal of maximally reducing the user's energy expenditure;

Specific Aim #B: Development of volitional prosthesis control technology for comfortable and effortless user control of prosthesis to adapt to altered situations and environments.

IMPACT

The prosthesis optimization as well as the user control of prostheses will promote a natural gait and minimize amputee's energy expenditure in prosthetic use. An optimized prosthesis with user control capability will increase equal force distribution and decrease the risk of damage to the intact limb from the musculoskeletal imbalance or pathologies. Maintenance of health in these areas is essential for the amputee's quality of life and well-being.

ACKNOWLEDGMENT

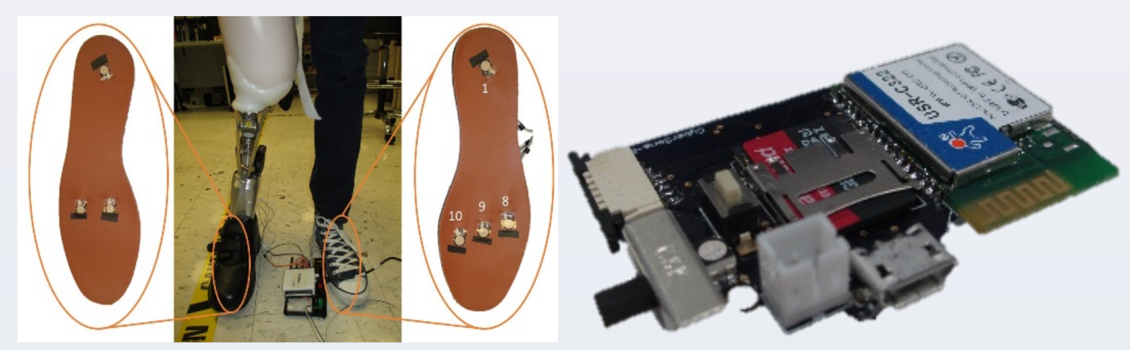
The investigators are very grateful for the support from NSF CPS program (Award Number: CNS-152163).

PROJECT PROGRESS

A. A Wi-Fi-based 'CyberSens' device to support wireless, high-speed, and real-time human gait analysis

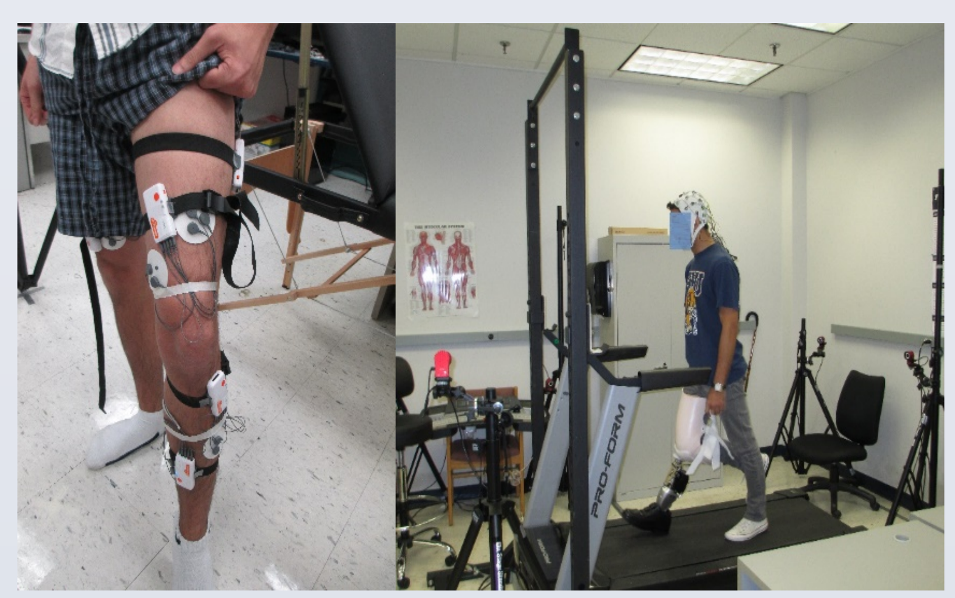
The underlying purpose of the *Cybersens* is spearheading innovation the field of user-communicating prosthesis. Here at HCPS we hope to better our field of interest by pushing for a custom piece of hardware. For this reason, we opted for the Wi-Fi technology that easily offers up to 150 Mbps with the recent 802.11n Wi-Fi technology or If used on a local network (802.11ac), a staggering range of 500 Mbps to 1300 Mbps. Beyond these speeds, Wi-Fi also offers a much bigger radius of service versus Bluetooth. With the more powerful technology, our device offers to be a more powerful data collection and analysis tool then those already on the market.

B. In-shoe sensor using piezoelectric for walking-balance evaluation



A large portion of the amputee population depends on the use of prosthetic limbs for mobility, current prosthesis fittings rely almost entirely on subjective feedback by the amputee and the expert opinion of a prosthetist. Using an in-sole setup consisting of inexpensive PTs will grant the capability to obtain balance information to be used in the prosthesis fitting, by adapting this method prosthetist could incorporate quantitative data, thus providing a more comfortable fit which helps in reducing biological limb wear, and overall energy expenditure.

C. Multi-channel EMG observation during normal gait and loaded gait from subjects with normal gait



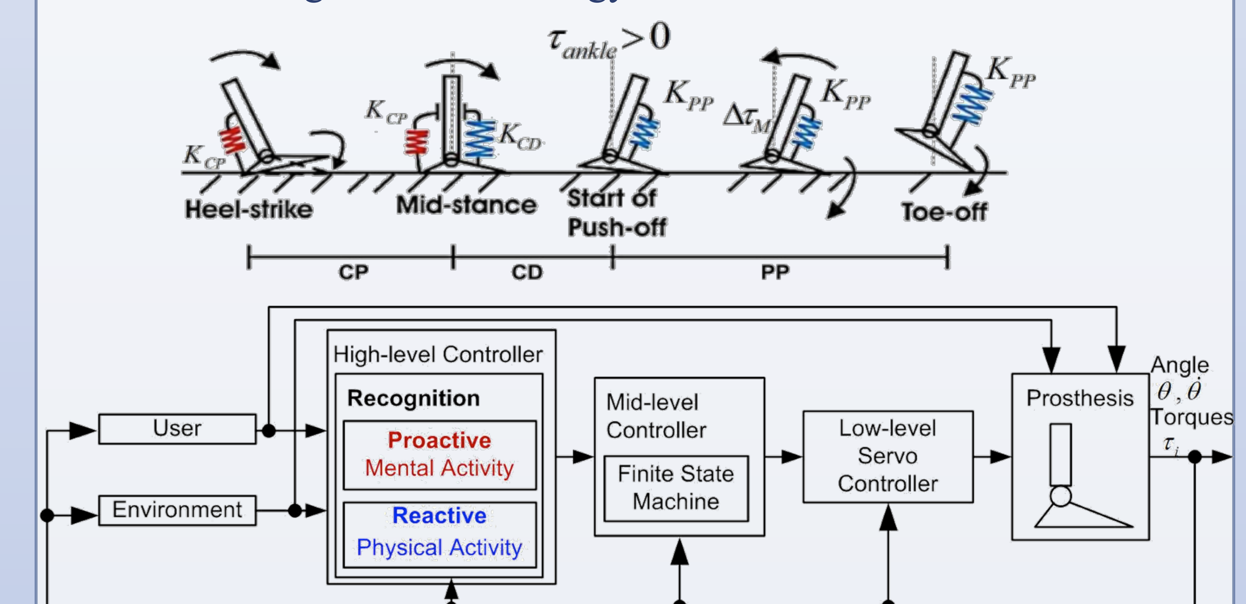
Gait cycle is a highly complex operation in which results as the collaboration of different parts of the body and many different muscle groups with various sizes and importance take part during each cycle. This project was done in order to identify the muscles that have great sensitivity in their neuro-muscular activity. It is assumed that with increase of the load on a leg of a non-amputee would change the electrical activity of the muscles on lower body in regards of amplitude and frequency. The results of this project will be useful in usage of muscle activity in control purposes.

D. Active prosthetic limb calibration using the muscle activity from residual limb and the sound leg of amputee subjects

Amputees require prosthetic limbs to replace their lost limb in order to maintain daily life. Most of the prosthetic limbs available now are passive ones which require the amputees to lean more on their sound leg and spend more energy during gait. Also, because of the asymmetry resulted from amputation they tend to insert more pressure on the residual part. The BiOM leg is only active leg that is available for amputees to be used in their daily life. This project focuses on the calibration and fitting of this leg for these patients which uses EMG sensors and IMU sensors to reach to this purpose. This will eliminate the cost and time consuming process of manual calibration.

FUTURE STUDY

User Control of Prosthesis using a Brain-Computer Interface-based Volition-Recognition Technology

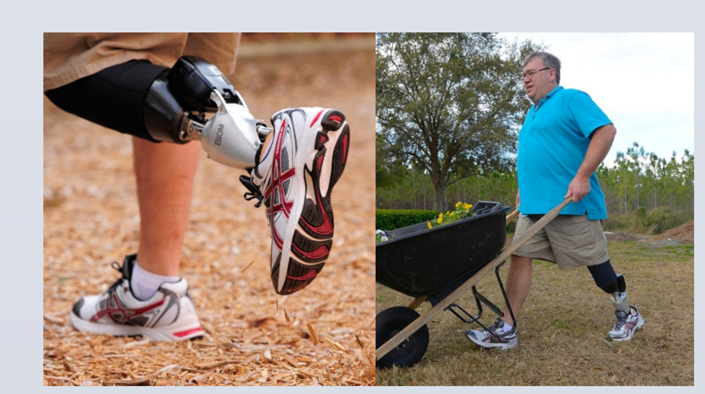


PUBLICATIONS

- Murphy D, Fox J, Burkhardt B, Lovegreen, **Bai O** (2016) Brain Computer Interface Control of a Prosthetic Knee in a Transfemoral Amputee. J. Prosthetics & Orthotics (In Review)
- Murphy D, **Bai O** (2016) Brain-Computer Interface – Applications to Amputees and Prostheses. 2016 Annual Hans Burger Clinical Neurophysiology Symposium, May 23-24, Richmond, VA
- **Bai O**, Graham K, Fei D-Y, Murphy D (2015) A Wireless, Smart EEG System for Volitional Control of Lower-Limb Prosthesis. Proceeding IEEE TENCON 2015, November 1-4, 2015, Macau, China
- Atri R, Marquez J., Murphy D, Ashraf G, Fox J, Burkhardt B, Lovegreen, **Bai O**, (2016) Investigation of Muscle Activity During Loaded Human Gait Using Signal Processing of Multi-Channel Surface EMG and IMU. The IEEE Signal Processing in Medicine and Biology Symposium (SPMB16), December 3, 2016, Philadelphia, Pennsylvania (Submitted)
- Wang Y, Wang Q, Liu X, Sun J, **Bai O** (2016) A Multifunctional Wireless Body Area Sensors Network with Real Time Embedded Data Analysis. IEEE 2016 Biomedical Circuits & Systems Conference, October 17-19, 2016, Shanghai, China.
- Marquez J., Atri R, **Bai O** (2016) Amputee Fitting and Load Analysis by Piezoelectric Transducers. Annual International IEEE EMBS Conference of the IEEE Engineering in Medicine and Biology Society, August 15-19, 2016, Orlando, Florida

REFERENCES

- K. Qian, P. Nikolov, D. Huang, D. Y. Fei, X. Chen, and O. Bai, "A motor imagery-based online interactive brain-controlled switch: paradigm development and preliminary test," *Clin Neurophysiol,* vol. 121, no. 8, pp. 1304-13, Aug, 2010.
- S. K. Au, J. Weber, and H. Herr, "Powered Ankle-Foot Prosthesis Improves Walking Metabolic Economy," *IEEE Transactions on Robotics,* vol. 25, no. 1, pp. 51-66, Feb, 2009.



Healthier & Better Walking