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

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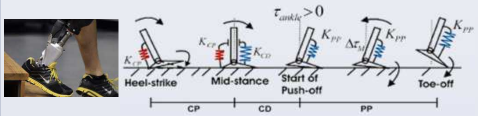
BACKGROUND

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 sensor system and computational algorithms for 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

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 is essential for the amputee's quality of life and well-being.

ACKNOWLEDGMENT

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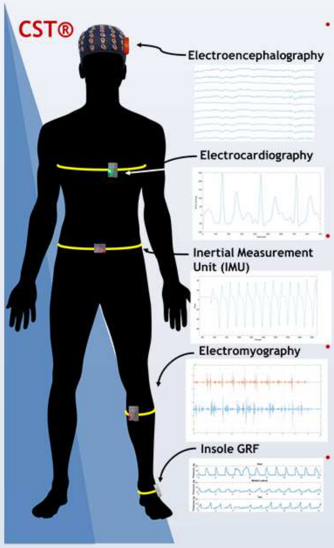
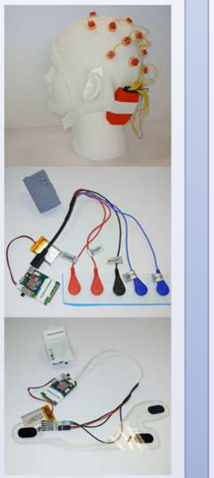
PRIMARY PROJECT OUTCOMES

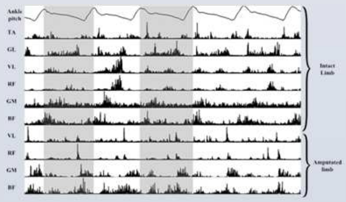
A. Real-time, non-interrupt long lasting, wearable, wireless, and synchronized solution for whole-body, behavioral and physiological monitoring and analysis



- **CST® EEG (Electroencephalography) Sensor**
  - Non-invasive brain wave reading
  - Synchronization with other CST sensors
  - 8 or 16 EEG channels with wet or dry electrodes
  - Additional 12 motion tracking channels (Acceleration, Gyroscope, Compass, Yaw/Pitch/Roll)
  - High-speed, low lost data transmission using WiFi network
  - High-fidelity data acquisition with maximal 1,000 Hz sampling
  - Low-power design for analog-front and data transmission
  - Capable 24 hour non-interrupt data acquisition and recording
  - Capable for direct cloud connection
  - Capable on-board computing for BCI application
- **CST® ECG (Electrocardiography) Sensor**
  - High-precision acquisition for electrical activity from the heart with additional 12 IMU channels
  - Synchronization with other CST sensors
  - Detection of cardiac trends and anomalies
  - Capable for stress testing, sports applications, and sleep studies
- **CST® EMG (Electromyography) Sensor**
  - High-precision, high-speed acquisition for muscular activity
  - Synchronization with other CST sensors
  - 2 or 8 bipolar channel options with additional 12 IMU channels
  - Onboard computing to support real-time prosthetic or exoskeleton biomedical control
- **CST® GRF (Ground Reaction Force) Sensor**
  - In-shoe pressure recording from heel, frontal and lateral locations
  - Synchronization with other CST sensors
  - Multi-channels acquisition with simultaneous 12 IMU channel signals
  - Capable for real-time detection of gait phases and analysis of gait symmetry

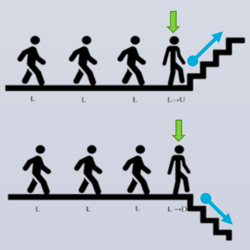


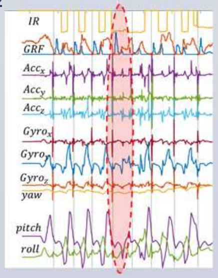
B. Electromyography sensor-based system and efficient optimization algorithm for fast and accurate prosthetic tuning for level walking

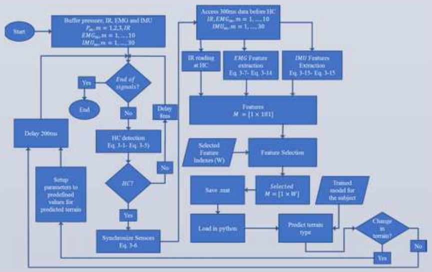


Subject	CPO Tuning	Target [1]	Genetic Algorithm		Nelder–Mead		Nelder–Mead with LHS	
			Iterations	Result	Iterations	Result	Iterations	Result
BK1	P = 25 S = 25	P = 22 S = 21	990 ± 180	P = 22.3 ± 2 S = 20.7 ± 1.4	35 ± 9	P = 25 ± 7 S = 17 ± 5	49 ± 9	P = 24 ± 3 S = 19 ± 2
BK2	P = 20 S = 40	P = 23 S = 11	900 ± 105	P = 25.8 ± 7.2 S = 11.1 ± 1	28 ± 13	P = 31 ± 10 S = 14 ± 8	45 ± 8	P = 25 ± 6 S = 12 ± 2
TT1	P = 40 S = 32	P = 45 S = 26	870 ± 165	P = 44 ± 3 S = 25 ± 3	21 ± 8	P = 28 ± 15 S = 23 ± 9	57 ± 15	P = 43 ± 3 S = 25 ± 1
BK3	P = 40 S = 65	P = 46 S = 41	945 ± 150	P = 40 ± 12 S = 40 ± 6	10 ± 4	P = 27 ± 15 S = 51 ± 18	24 ± 13	P = 26 ± 0.7 S = 62 ± 1
TT2	P = 40 S = 40	P = 41 S = 31	870 ± 60	P = 39 ± 8 S = 29 ± 7	11 ± 8	P = 26 ± 12 S = 25 ± 11	13 ± 8	P = 40 ± 1 S = 31 ± 1
TT3	P = 23 S = 36	P = 16 S = 41	930 ± 150	P = 28 ± 15 S = 31 ± 11	9 ± 4	P = 28 ± 16 S = 32 ± 15	12 ± 2	P = 18 ± 6 S = 43 ± 8

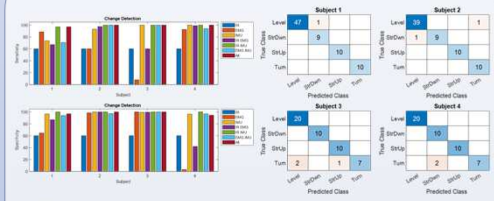
C. A reliable predictive prosthetic control to adapt terrain and locomotion changes in amputees before transition to new terrain occurs







C. Predictive prosthetic adaptation - continue



Timing before transition   Locomotion Prediction

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Healthier & Better Walking