Interface Monitoring System to Promote Residual Limb Health

NORTHWESTERN UNIVERSITY FEINBERG SCHOOL OF MEDICINE

S. Fatone, PhD, BPO(Hons), Y. Huang, PhD, T. Coleman, PhD, J. Rogers, PhD, A. Banks, L. Tran, R. Caldwell, CP, D. Brown, M. Pharr

s-fatone@northwestern.edu

ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UNIVERSITY OF CALIFORNIA SAN DIEGO

Background

This proposal builds on development of stretchable and flexible sensor technology capable of transforming healthcare from reactive and hospital-centered to preventive, proactive, evidence-based, and person-centered. This new sensor technology offers 'skin-like' properties to enable intimate, complete non-invasive integration with the patient. The resulting 'epidermal' electronic devices shown in the picture [1] may allow clinicians to monitor their patients, and the general public to assess, continuously, their health and well-being. These 'skin-like' sensors allow us to develop the proposed interface monitoring system, designed to promote residual limb health in persons who wear prostheses.

Aims

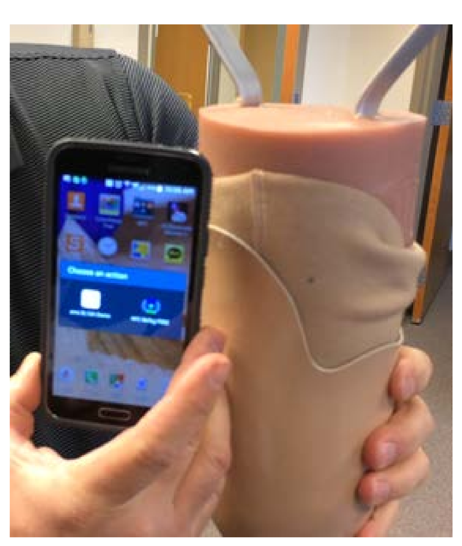
Work on this project involves collaboration across three institutions to:

1. Develop 'skin-like' pressure, shear and temperature sensors, with wireless operation, as well as hydration and blood flow sensors that operate inside a prosthetic socket.
2. Develop computational modeling and algorithms for statistical signal processing of the sensor data and pattern recognition to create a user-friendly interface for clinicians and patients.
3. Apply the proposed sensor technologies and data processing and pattern recognition techniques to prosthetic clinical practice. The continuous capture, storage and transmission of sensor data are critical to the design of lower limb prosthetics for improved health and healthcare.

Initial Sensor Development

We tested the ability to wirelessly read temperature sensors through socket materials using a smartphone app. We have established that up to 65 temperature sensors can be measured simultaneously using a long range reading system.

Sensor



Scanning the sensor

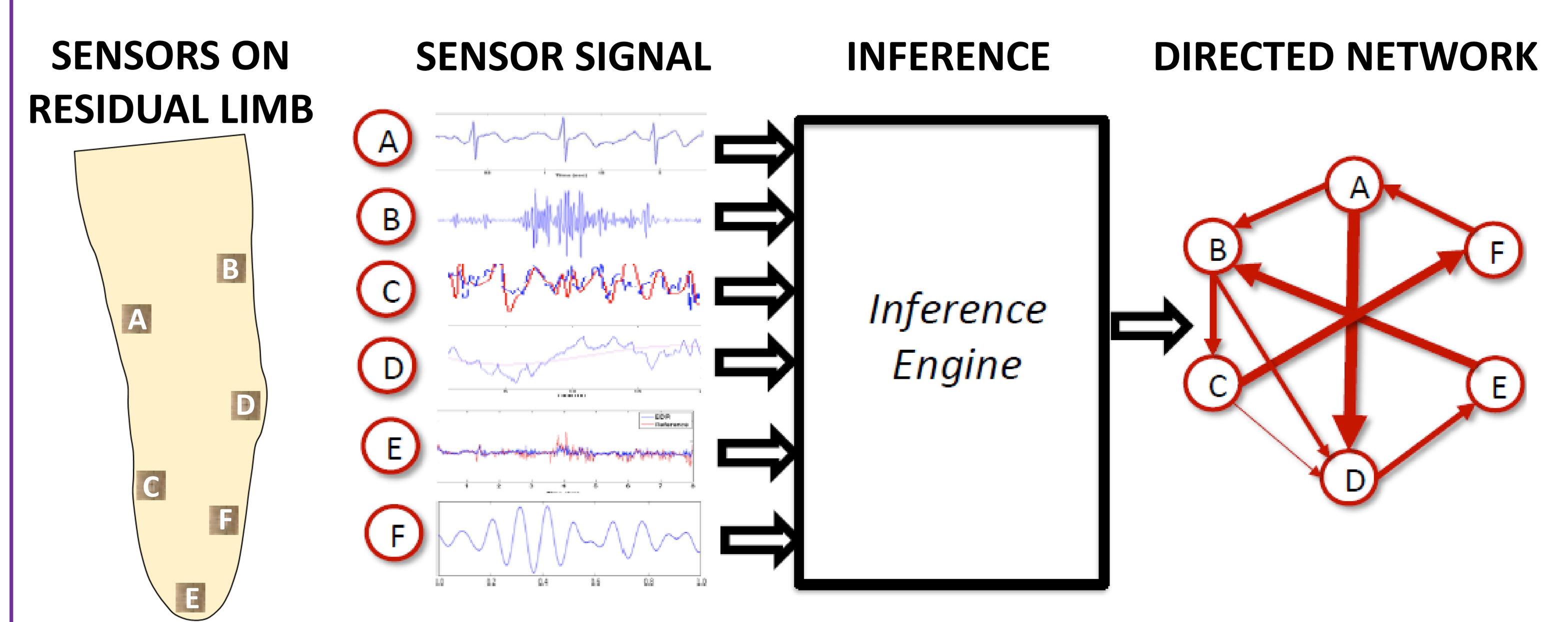
Temperature Reading

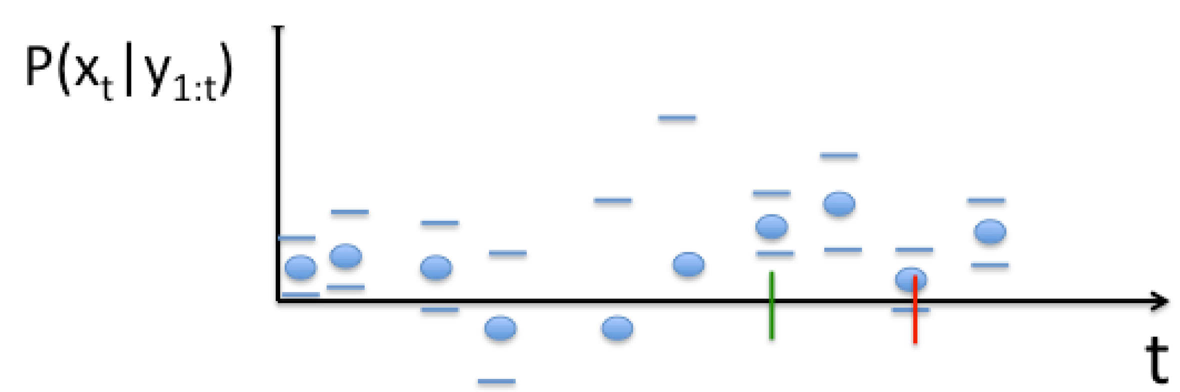
We tested the durability of sensors when worn on the heel of the foot where the sensor is subjected to mechanical stresses similar to a prosthetic socket.

We are also developing piezoelectric pressure sensors to examine pressure levels in vulnerable areas (e.g. bony prominences) during walking.

Signal Processing

We reviewed existing literature regarding temperature measurements inside prosthetic sockets and began developing measurement models of the fluctuations in skin temperature as it relates to residual limb health.





Model the residual limb health as a latent time series:

$$X_t = X_{t-1} + a_t N_t + u_t$$

Developing physiologic modeling assumptions that loading of the residual limb in vulnerable areas (e.g. tibia) causes reduced blood perfusion leading to a local fall in skin temperature, and a rise in temperature and color recovery ensues with removal of pressure and subsequent reactive hyperemia. This allows for a measurement model of the spatiotemporal dynamics of temperature on the residual limb - at locations and time scales commensurate with the sensors - as a function of underlying limb health [2].

Clinical Application

Focus Groups Used to Gather Stakeholder Input

We gathered information from stakeholders about how a residual limb monitoring device might be used and how it might best be configured. Focus groups consisting of similar individuals provided information during a moderated interactive discussion.

Certified Prosthetists (CP)

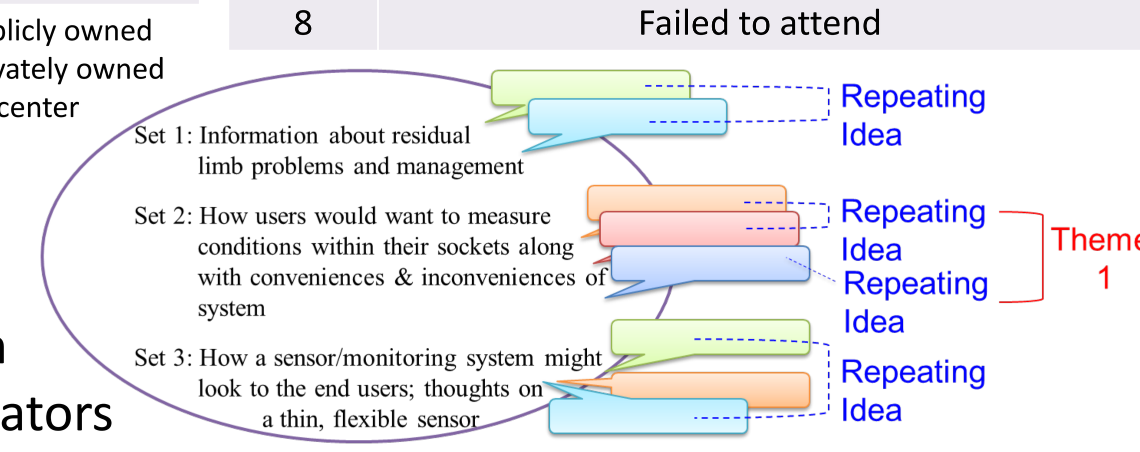
Subject	Gender	Years as CP	Practice Setting
1	F	4-5	A
2	F	4-5	C
3	M	4-5	C
4	M	5	B
5	F	9	C
6	M	13	C
7	M	33	B
8	Failed to attend		

A. Multi-facility practice, publicly owned
B. Multi-facility practice, privately owned
C. Hospital or rehabilitation center

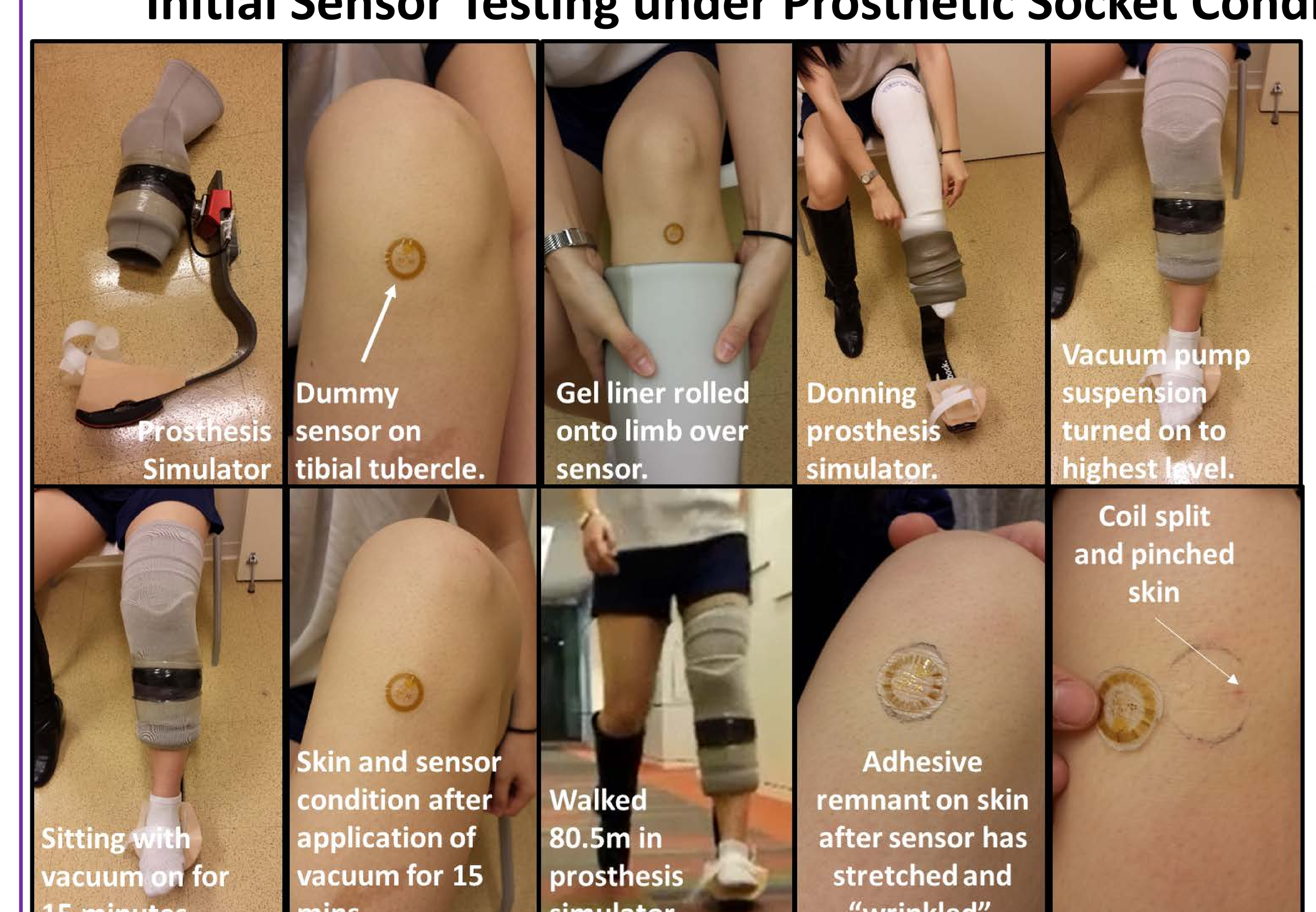
Lower Limb Prosthesis Users

Subject	Gender	Amputation Level	Years as Amputee	Etiology
1	F	TTA	< 1	trauma
2	M	TTA, PFA, TRA, PHA	10	infection
3	F	TTA	> 40	congenital
4	F	TTA	25	trauma
5	F	TTA	12	vascular
6	F	TFA	> 20	trauma
7	M	TFA	13	trauma
8	Failed to attend			

Data explored using Thematic Analysis wherein multiple investigators assess focus group transcripts for repeating ideas and themes [3].



Initial Sensor Testing under Prosthetic Socket Conditions



Subject did not report feeling any irritation or dis-comfort during the process depicted in the pictures.

References

[1] Kim et al. (2011). "Epidermal electronics." Science 333(6044):838-843. [2] Quinn et al. (2014). "Efficient Methods to Compute Optimal Tree Approximations of Directed Information Graphs." IEEE Transactions on Signal Processing. [3] Guest et al. (2012). "Applied Thematic Analysis." SAGE Publications, Inc.

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