Smart Health at the Cyber-Physical-Human Interface

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Healthcare Costs → 17% U.S. GDP

1 in 3 Americans: Multiple Chronic Diseases

1 in 4 Americans: Poor air quality
Opportunities in Healthcare

- Personalized Health
- Population Health
- Digital Biomarkers
  - Explain/ Influence/ Predict health outcomes
  - Gain fundamental insight into disease origins
Personalized Health

Current Medicine
One Treatment Fits All

Examples: blood pressure, diet management

Future Medicine
More Personalized Diagnostics

https://blog.crownbio.com/pdx-personalized-medicine#_
How do we get there?

CONSIDERATIONS

*n of 1 (individual):*
- Facilitate individual-level collection of longitudinal data
- Health and treatment planning based on personalized baselines

*Population subgroups:*
- Results in higher resolution data to identify and stratify subgroups within a population
- Measures changes over time, establishing sequencing of events
- Control for previous/existing disease states
- More likely to find evidence of causality

Need continuous/regular monitoring for individuals that provides actionable and empowering data
Long-term monitoring and management of chronic disease health targets can lead to a paradigm change in health outcomes.
Long term monitoring requires disruptive powering

Ultra low power electronics/sensors

Directed energy

Self-powered operation for vigilance
Self-powered operation for vigilance

Power Generation
- Harvested and Stored Power

Power Consumption
- Low Power Electronics and Sensors

Wearability and Data
ASSIST’s Always-on Wearable Platforms

Long Term Monitoring of health and environment
Correlation of multiple sensors signals
Clinical studies in various health domains

• **Self-powered**
• **Physiological, biochemical and environmental sensors**
• **Wearable, wireless and comfortable**
• **Informative and continuous data**
ASSIST's Engineered System
ASSIST is working on transformative research to enable a self-powered multimodal platform to support CPS applications

- Energy Harvesting
- Low power SOC and Sensor Interfaces
- Non-invasive biochemical panel for targeted diseases
- Flexible, stretchable materials
- Data Analysis
1. **Asthma** (1 in 12 Americans)
2. **Atrial Fibrillation** (>600,000 deaths per year)
3. **Diet management** in pre-diabetics (36% adults w/BMI > 30kg/m2)
4. **Wound Healing** in Post-surgery/diabetic patients (~$15B)
5. **Medication Detection** (> $300B avoidable costs)
Technology Integration Specific to Use Cases

Management of: asthma, cardiovascular health, pre-diabetes and wound care
Use Case #1: Vigilant A-Fib Monitoring

“Irregular and often rapid heart rate that can increase your risk of stroke, heart failure and other heart-related complications” and “Episodes...can come and go” [Mayo Clinic]

- Detection requires heartbeat detection and accurate interval timing (R-R intervals)
- Even after detection patients need continuous monitoring to detect frequency of events

**Sensors needed: continuous ECG, activity**
Vigilant ECG System

- Self-powered operation in ECG Shirt demonstrated!
- Multiple ASSIST technologies (SoC, Radio, TEGs, supercap, smart textile garment with dry electrodes)
- Power consumption of SAP end-to-end system reduced from ~ 400µW to 65µW

Lach and Calhoun groups at the Link Lab, UVA

Michael Lim, NCSU
TEG device integrated for vigilant ECG
Vigilant ECG

- End-to-end functional
- Wearable
- Self-powered

Lach and Calhoun (UVA)
Jur and Ozturk (NCSU)
Enabling Research

TEG Area = 40 cm²

Disruptively low power consumption of SOC and radio (42uW) enabling successful SAP Gen 1 demo today

Lach and Calhoun (UVA)
Jur and Ozturk (NCSU)
Use Case #2: Asthma

In 2015, 108 million Americans -- one third of the population -- lived in counties with ozone levels that exceeded standards set by the EPA.

Sensors needed: Ozone, VOC, HR/respiration, activity
Asthma Platform

- ECG /PPG chest patches, ozone/VOC/PPG wristbands
- 5 Gen 1 systems in 3 IRB-approved studies
- 30 additional Gen 1 systems produced for human studies

Total power consumption of less than 1 milliWatt for wrist and chest platforms with multiple health and environmental sensors

ECG, microphone, pulse, accelerometry, skin impedance

Bozkurt, Misra, Oralkan (NCSU)

Ozone, VOC, pulse, accelerometry, Temp/rH

10uW

150uW

CMUT

MOx

Human Subjects Testing and Clinical Validation

<table>
<thead>
<tr>
<th>IRB Number</th>
<th>Project Title</th>
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<tbody>
<tr>
<td>14-1849</td>
<td>Exercise training and monitoring for environmental research</td>
</tr>
<tr>
<td>15-1938</td>
<td>Effect of gamma tocopherol enriched supplementation on response to inhaled O3 exposure</td>
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<tr>
<td>15-2418</td>
<td>Comparison of the VitalFlo spirometry system with commercially available spirometers</td>
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<tr>
<td>15-2677</td>
<td>Human biological responses to low level ozone</td>
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<tr>
<td>16-2131</td>
<td>Identification of allergic asthmatics reactive to house dust mite inhalation</td>
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<tr>
<td>18-7799</td>
<td>Physiological and Environmental Tracking</td>
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<tr>
<td>18-0969</td>
<td>Extraction of Dermal Interstitial Fluid with Soft Microneedles for Analysis</td>
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<tr>
<td>18-0984</td>
<td>Noninvasive Perspiration Monitoring with a Wearable Device</td>
</tr>
<tr>
<td>17-2483</td>
<td>Evaluation of the Pharmacokinetics of Lisinopril and Tracer Compounds in Sweat, Saliva, and Plasma to Inform the Design of a Non-Invasive Wearable Sensor to Detect Medication Adherence</td>
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Preliminary Results from ASSIST Asthma Platform showed reduced heart rate associated with drops in lung function.

- Wrist sensor levels highly correlated with the EPA’s O₃ exposure chamber.
- Rapid decline was observed in the HR in the first four hours with O₃ v. filtered air.
- Changes in lung function noted with slowed heart rate after low level O₃ exposure.
  - Clinically significant physiologic changes in lung function could be detectable by physiologic monitoring of Heart Rate.
- First report of its kind Indicating personalized monitoring of O₃ exposures is a needed adjunct for preventing asthma exacerbations.
ASSIST’s disruptive research for cyber-physical-systems

- Energy Harvesting
- Low power SOC and Sensor Interfaces
- Non-invasive biochemical panel for targeted diseases
- Flexible, stretchable materials
- Data Analysis
Energy Harvesting/Storage

Innovation in motion harvesting

Maximize thermally generated power

Susan Trolier-McKinstry
NAE Elected Member

~10x smaller internal resistance and leakage than COTS coin-type capacitors and ultra thin pouch cells for flexibility
Ultra low power electronics and sensor interfaces

Central SoC: <1μW

External NVM: better system operation

Chip 1
- Power Management
- Software
- Digital Control / Processing / Management

Chip 2
- NVM
- RADIO

Chip 3 (UM)
- Analog Front End
- Antenna

Chip 4
- External sensor interfaces for faster upgrades
- External RFIC and antenna

Multi-chip approach
- Chip-chip interfaces
- Energy harvesting / power management
- Core system platform

Liquid metal antenna with excellent flexibility with a bandwidth: 2.38-2.5 GHz and isolation: 25 dB

Ben Calhoun, UVA

Mixed-mode (ECG/PPG/O3) sensor interface consuming 100 nW/400nW/100nW (10X lower than COTS)

Werner, PSU
ASSIST Co-authorship Network 2012-2017
CNS @ Indiana University
2017

#Papers
38
18
1

#Co-authored Papers
13
7
1

ASSIST Faculty
Other ASSIST authors

This network was generated from 271 ASSIST publications. It comprises 551 authors and 2,511 edges and covers the years 2012 through March 2017. The 48 faculty associated with ASSIST are colored in green. All other authors are colored in light green.
ASSIST’s Innovation Success
Current ASSIST Industry Membership

Full
- MERCK
- SAS
- RENFRO CORPORATION

Associate
- HANES Brands Inc
- muRata
- NOVEn PHARMACEUTICALS, INC.
- MANN + HUMMEL
- REX HEALTH VENTURES
- FUJI FILM
- ANALOG DEVICES
- AstraZeneca

Affiliate
- DeviceSolutions
- VALENCELL
- WAVE SCIENCES
- VitalFlo
- FUNXION
- DS
- GLOBAL COMM WEAR, INC.
- psikick
- NOCTURNAL PRODUCT DEVELOPMENT
- proFusa
- KWJ ENGINEERING
- Wireless Research Center of North Carolina
- NeuroSynchrony
- Voler SYSTEMS
Innovation in Education

Dr. Elena Veety
Education Director

Wearable Device Challenge
K-12 Engineering Competition

- 15 middle/high school teams at NCSU, 14 expected at PSU
- > 1,750 students
- > 80 Teachers

Nanoscience Minor and Capstone Projects

- 5 Capstone Teams in Yr 7, 30 total
- Multidisciplinary minor enrollment
- 33% win awards!

Translational Engineering Skills Program

- Systems Thinking
- Entrepreneurship/Innovation
- Industry/Manufacturing
- Mentoring/Leadership
- Communication
- Ethics/Diversity Awareness
ASSIST’s self-powered systems play a critical role in the cyber-physical-human loop and enable disruptive solutions for smart health