Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)

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ASSIST’s vision is to use nanotechnology to impact healthcare and manage wellness by building self-powered wearable, wireless, multiple sensor platforms that enable:

Long-term monitoring of personal health & environment enabled by always-on platforms

Sophisticated picture of health via correlation of multiple sensors

Personalized Medicine
Self-Powered Sensor Platforms based on Nanotechnologies: ASSIST is uniquely innovating both sides of the power problem.
ERC: 3-Plane Strategic Research
Application: Health and Wellness Use Cases

- **Goal:** Long Term Personal Health and Personal Environmental Monitoring

<table>
<thead>
<tr>
<th>Chronic Condition</th>
<th>Use Cases</th>
<th>Barriers</th>
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<tbody>
<tr>
<td><strong>Respiratory Health</strong></td>
<td>• A child with asthma rides the school bus for 1 week&lt;br&gt;• Nurse exposed to hospital chemicals containing VOCs</td>
<td>• Low power ozone&lt;br&gt;• Low power VOCs&lt;br&gt;• Real-time wheeze detection&lt;br&gt;• Data correlation</td>
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<td><strong>Cardiovascular Health</strong></td>
<td>• Heart patient with arrhythmia needs continuous/vigilant ECG monitoring</td>
<td>• High harvested power&lt;br&gt;• Low power chip/radios&lt;br&gt;• Flexible TEG/MEG&lt;br&gt;• Real-time arrhythmia detection with low latency</td>
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<td><strong>Glycemic Index Management</strong></td>
<td>• A pre-diabetic wants to correlate glycemic index trends to diet&lt;br&gt;• Physicians wants to correlate neurocognitive function in adolescent to stress exposure</td>
<td>• Sweat collection under low and high sweat&lt;br&gt;• Biocompatibility&lt;br&gt;• Biomarker validation in sweat</td>
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</table>
ASSIST Research

- Energy Harvesting and Storage
  - Thermoelectrics
  - Piezoelectrics
  - Reverse Electro-wetting
  - Storage

- Emerging Low Power Nanoelectronics
  - Ultimate Energy Efficiency Devices
  - Non-volatile architectures
  - Ultra low power SoC
  - Ultra Low power Radios
  - Body Worn Antenna

- Low power health and environmental sensors
  - Ozone and VOC Sensing
  - Next Gen (Pulse-ox and BP)
  - Sweat Biochemical Glucose and Cortisol
  - ISF Extraction

- Wearability and Data
  - Data
  - Flexible Materials
  - Integration in Testbeds
  - Human Factors
Integration of all components into systems

Sensor Node

- Power Source (Harvested Power)
- Health Sensors
- Env. Sensors
- SoC
  - Power Management
  - Analog Front End
- Energy Storage
- Antenna

Data Aggregator

- Digital Control / Processing / Management

Signal Processing

- Software

Smartphone

Cloud
- Real Time Analytics, managed APIs

Integration of all components into systems
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ASSIST Research Portfolio

1. Energy Harvesting and Storage

- Thermoelectrics
- Piezoelectrics
- Reverse Electro-wetting
- Storage

Three Efforts: Optimized materials, flexible thermoelectric packaging and system modeling

N and P type Bi$_2$Te$_3$ nanocomposites with state of the art performance
Flexible and open thermoelectrics packaging for flexible/stretchable TEGs
Novel motion harvesting design with optimized damping has demonstrated **42μW of power** while pseudo-walking (best in class by 25%) w/ thick optimized PZT films.
ASSIST Research Portfolio

Emerging Low Power Nanoelectronics

- Ultimate Energy Efficiency Devices
- Non-volatile architectures
- Ultra low power SoC
- Ultra Low power Radios
- Body Worn Antenna

Multi-chip SoC solution

**Multi-chip SoC with central SoC**

< 1µW, efficient sensor interfaces, external NVM and new bluetooth compatible radios

Flexible, wearable antenna matched to ASSIST RFICs with PDMS/AgNWs shows world record efficiency of 80%

Target 400µW (COTS = 10mW)
Beyond CMOS Devices and Architectures

**Project Strategy:** Leverage emerging nanodevices to enhance battery less at node computing capability

**Architecture Innovations**
- NVP Microarchitecture exploration
- Dynamic voltage and frequency scaling
- Input power prediction by machine learning

**Circuit/Device**
- TFET for low power logic, memory, analog design
- Tunnel junction Characterization with Atomic Resolution
- Gate stack interface enhancement
- Group IV Ge-Sn based pTFETs

**NVP Platform Demonstration**
- Resistance to power failures
- Performance enhancement with dynamic frequency scaling

**Emerging Device Demonstration**
- Best-in class n-TFET demonstration
- Improved p-TFET demonstration
100% battery-less operation
Zero stand-by power
Maximum forward progress with instant backup and recovery options during power interrupt
Micro architecture optimized by Penn St; NVP designed by Tsinghua University
Interfaced to ASSIST energy harvesters (Werner, Troller-McKistry groups)

Narayanan Group
NVP + Tunnel FETs

- TFET is superior to CMOS at low voltage supply voltages
- NVP computational progress is improved by 2.7x using Tunnel FETs instead of LP CMOS (evaluation done with ambient RF power source)

Narayanan & Datta Group
ASSIST Research Portfolio

Wearability and Data

- Data
- Flexible Materials
- Integration in Testbeds
- Human Factors

Wheeze modeling and detection

Choosing delays and embedding dimension

\[
\begin{pmatrix}
  w(t) \\
  w(t + \tau_1) \\
  w(t + \tau_2)
\end{pmatrix}
\]

Time Delay E

Algebraic topology

[S. Emrani et al. ICASSP’14]

Signal in time domain

3D delay embedding

Krim (NCSU)
ASSIST Research Portfolio

Wearability and Data

Data Processing and Modeling:

Data Analysis and Prediction:

Energy Consumption:

Sensor Node
- Sensing
- Processing
- Transmission

Aggregator
- Feedback
- Transmission
- Sensor Node Parameter Tuning
- Inference
- Data Fusion

Cloud

Lobaton (NCSU)

Lobaton (NCSU)
Asthma Management Platform:

- Neoprene wrist strap with ABS plastic shell containing the circuitry with sensors for: ozone, PPG, motion, temperature, and humidity.
- Elastomer patch with ABS plastic shell containing circuitry with sensors for: ECG, skin impedance, PPG, wheezing, and motion.
- Handheld spirometer for measuring lung functionality.

Opportunity for Always-on Health Sensing

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<tbody>
<tr>
<td>CR 2032</td>
<td>11mW* (COTS)</td>
<td>0.06mW*</td>
<td></td>
<td></td>
<td>11.1mW</td>
<td>2</td>
</tr>
<tr>
<td>CR 2032</td>
<td>0.03mW**</td>
<td>0.06mW*</td>
<td></td>
<td></td>
<td>0.09mW</td>
<td>266</td>
</tr>
<tr>
<td>CR 2032</td>
<td>0.03mW**</td>
<td>0.06mW*</td>
<td>1.13mW*</td>
<td>0.39mW*</td>
<td>1.3mW</td>
<td>17</td>
</tr>
<tr>
<td>Self-Powered (&gt;1.3mW)</td>
<td>0.03mW**</td>
<td>0.06mW*</td>
<td>1.13mW*</td>
<td>0.39mW*</td>
<td>1.3mW</td>
<td>Indefinite!</td>
</tr>
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Compute locally or in the cloud?
- Low power radios can change this dilemma
- Latency and liability

Privacy and Security
- Medical data vs. fitness data

Perception
- Nano and toxicity
- Human Centric

Partnerships
- We are seeking to work synergistically towards realizing self-powered, small form factors, multi-functional sensor platforms