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

Veena Misra, Director and Professor of ECE

CCC Workshop, August 31st, 2016

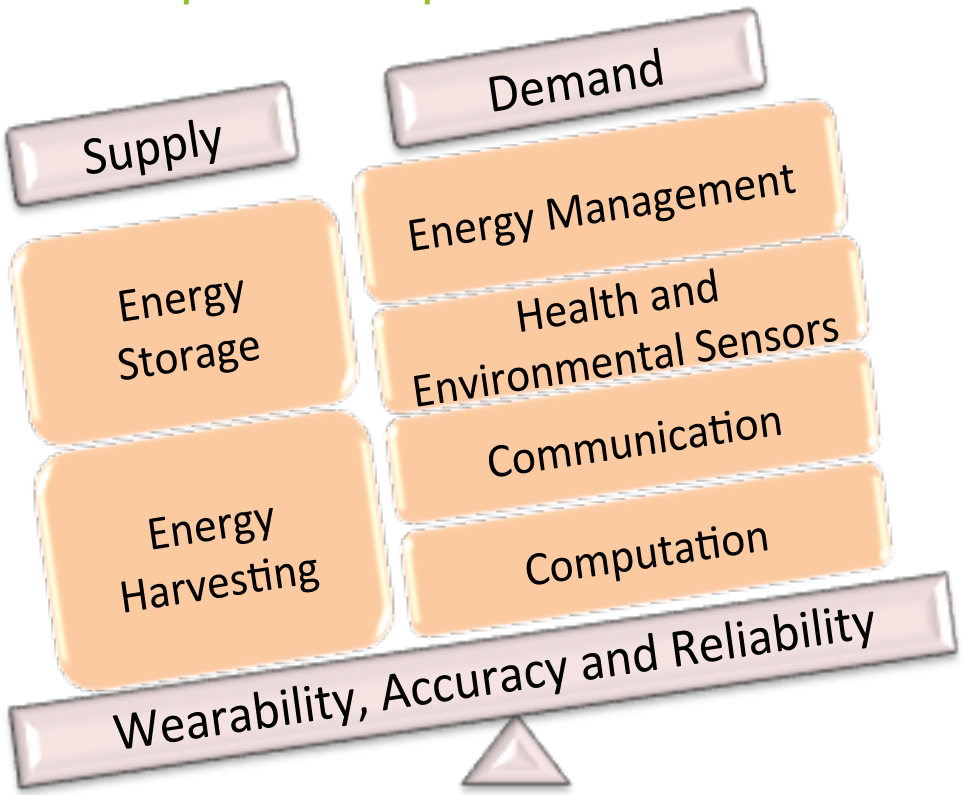
ASSIST's vision is to use nanotechnology to impact healthcare and manage wellness by building self-powered wearable, wireless, multiple sensor platforms that enable:

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

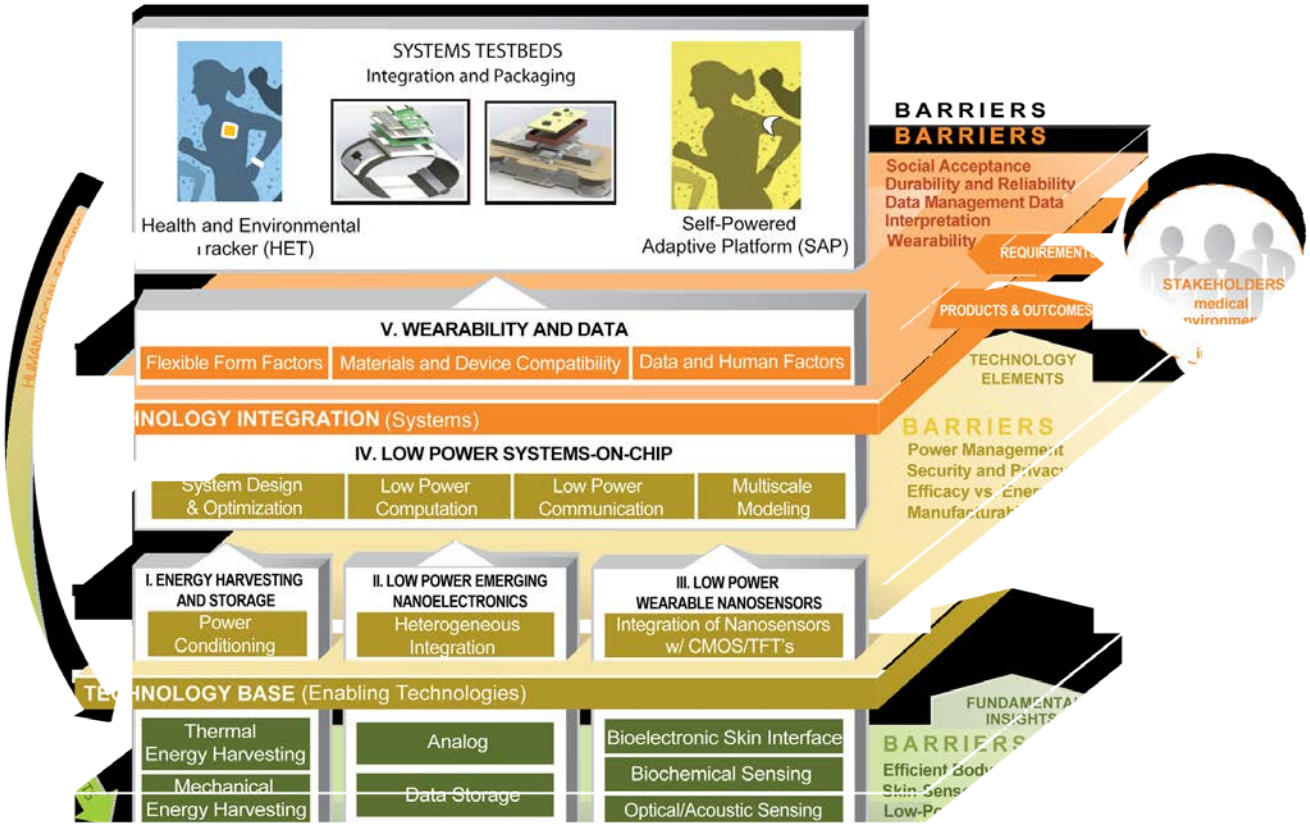
Sophisticated picture of health via correlation of multiple sensors

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

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

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

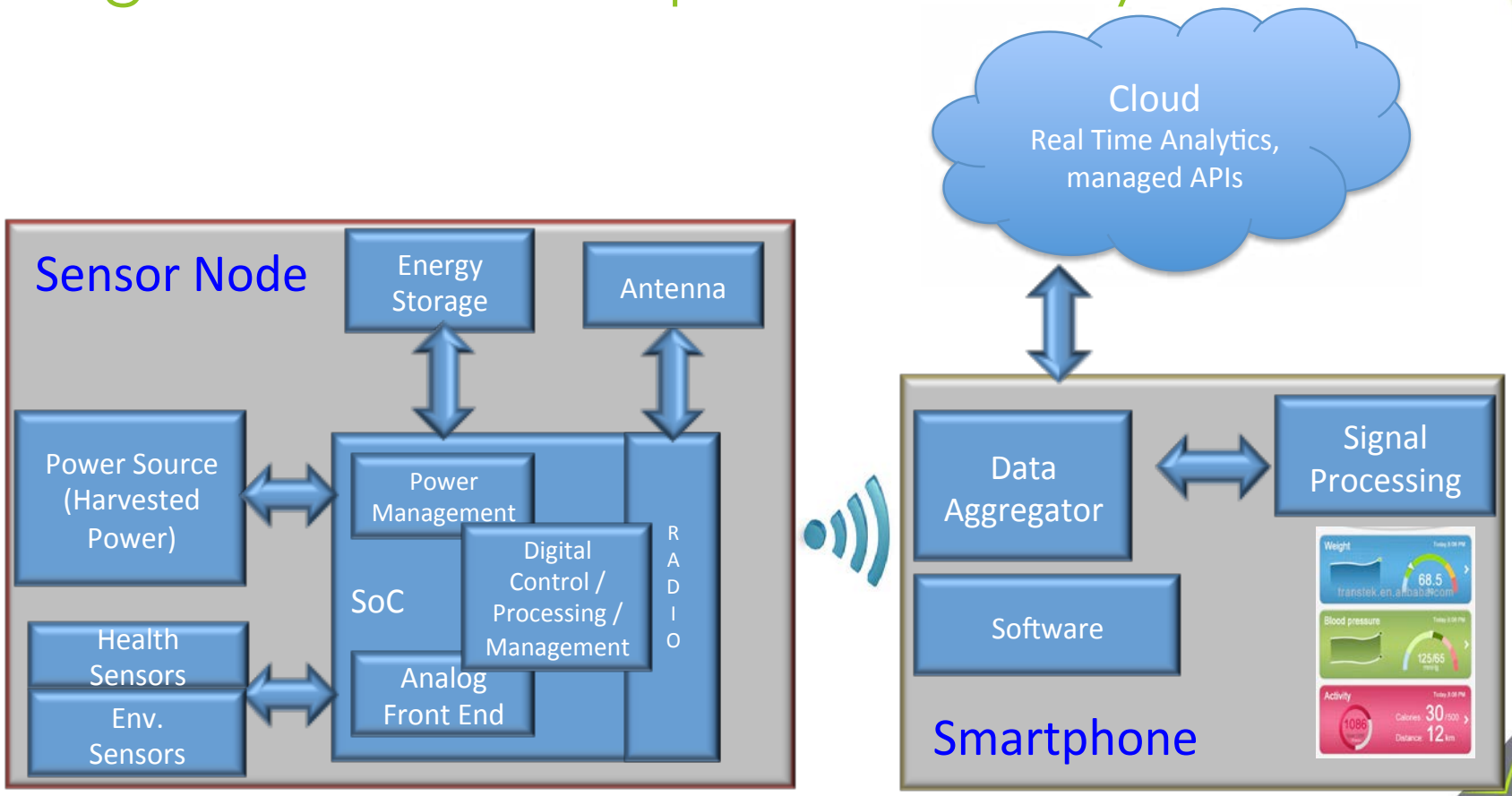
- Low power health and environmental sensors

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



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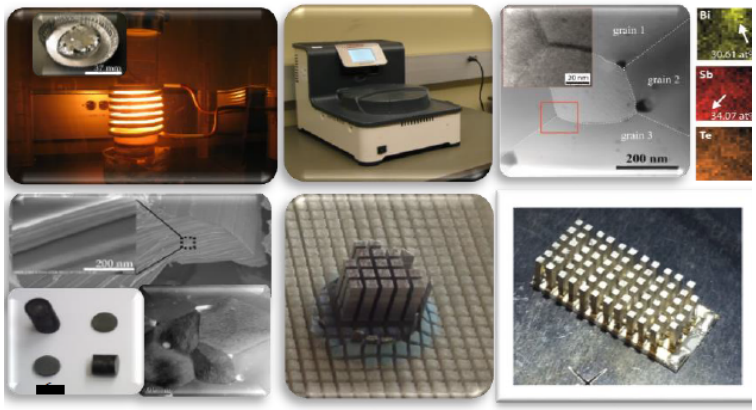
Mehmet Ozturk (NCSU)
Daryoosh Vashaee (NCSU)

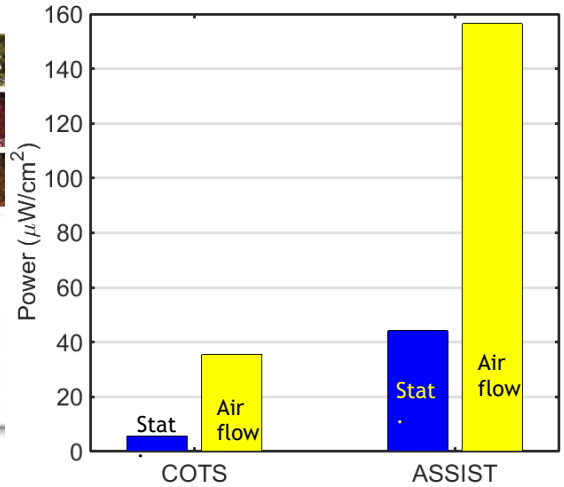
ASSIST Research Portfolio

▶ 1. Energy Harvesting and Storage

Thermoelectrics | Piezoelectrics | Reverse Electro-wetting | Storage

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





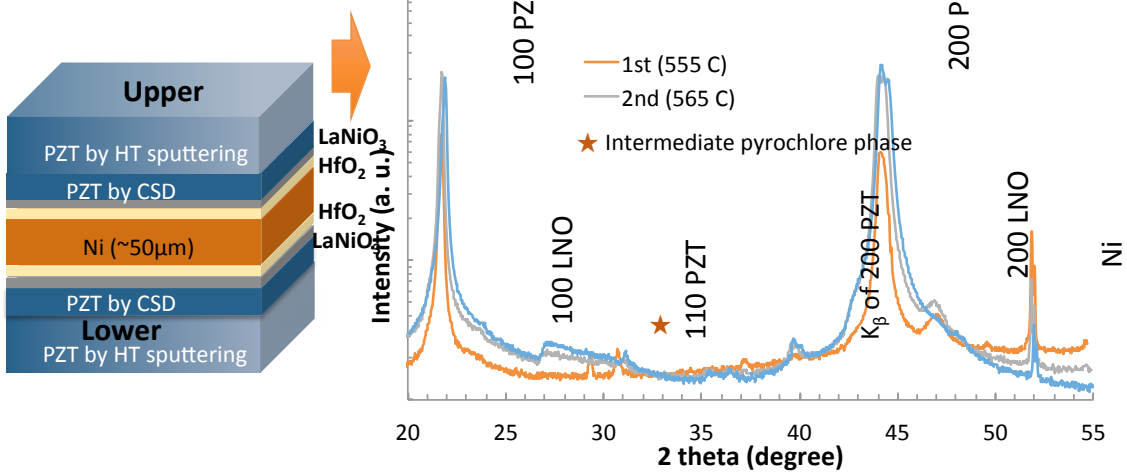
N and P type Bi_2Te_3 nanocomposites with state of the art performance
Flexible and open thermoelectrics packaging for flexible/stretchable TEGs

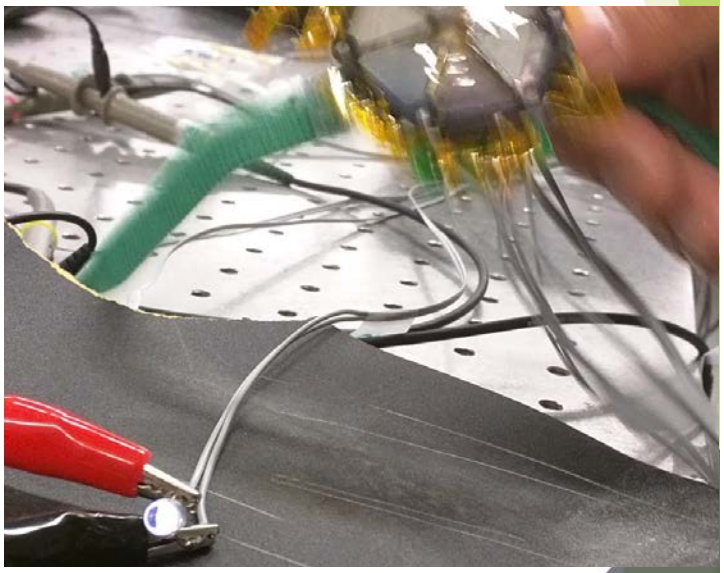
ASSIST Research Portfolio

Susan Trolier-McKinstry (PSU)
Chris Rahn (PSU)
Shad Roundy (Utah)

▶ Energy Harvesting and Storage

Thermoelectrics | **Piezoelectrics** | Reverse Electro-wetting | Storage





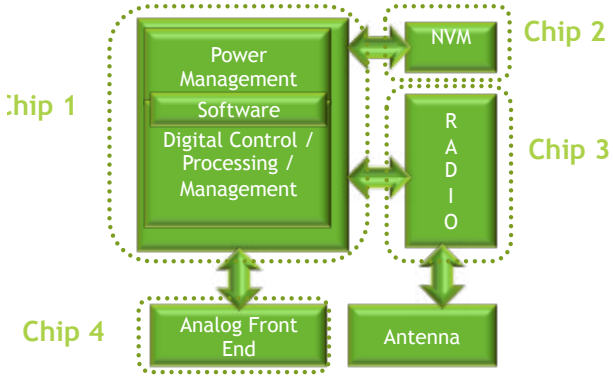
- Novel motion harvesting design with optimized damping has demonstrated **42µW of power** while pseudo-walking (best in class by 25%) w/ thick optimized PZT films

ASSIST Research Portfolio

Calhoun (UVA)
Wentzloff (Michigan)
Werner (PSU)

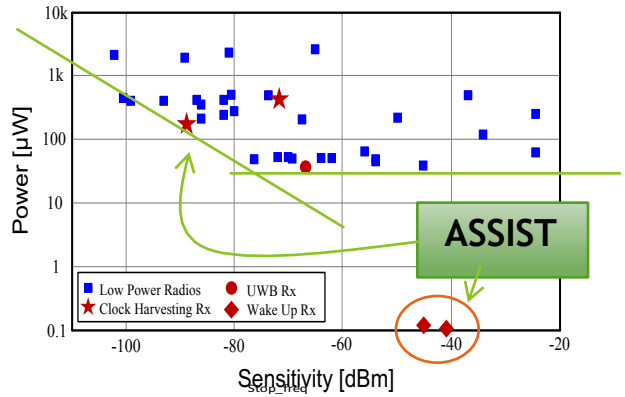
▶ Emerging Low Power Nanoelectronics

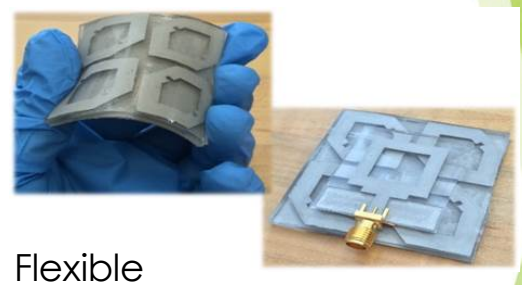
- Ultimate Energy Efficiency Devices
- Non-volatile architectures
- Ultra low power SoC
- Ultra Low power Radios
- Body Worn Antenna



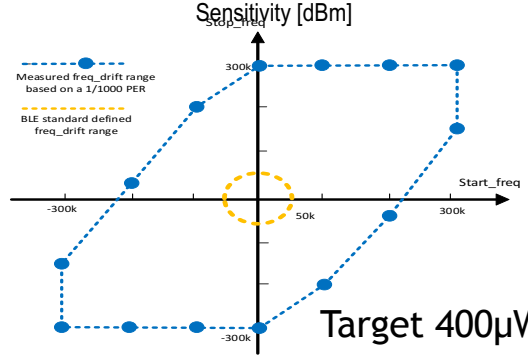
Multi-chip SoC solution

Multi-chip SoC with **central SoC < 1μW**, efficient sensor interfaces, external NVM and **new bluetooth compatible** radios





Flexible Antenna



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

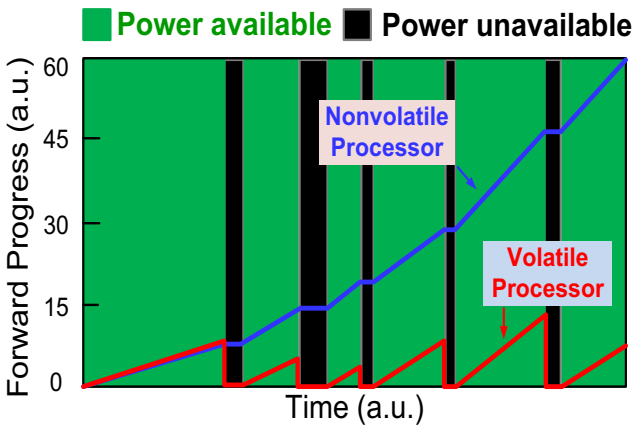
NVP Platform Demonstration

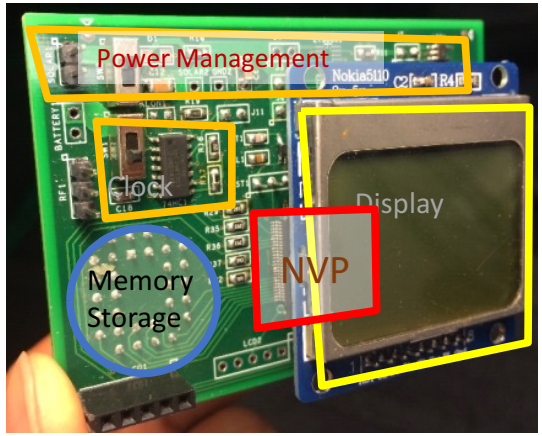
- Resistance to power failures
- Performance enhancement with dynamic frequency scaling

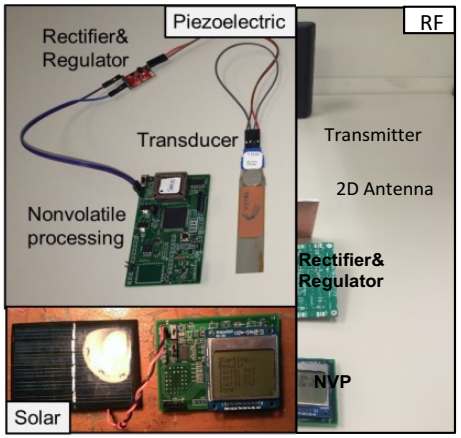
Emerging Device Demonstration

- Best-in class n-TFET demonstration
- Improved p-TFET demonstration

NVP Platform



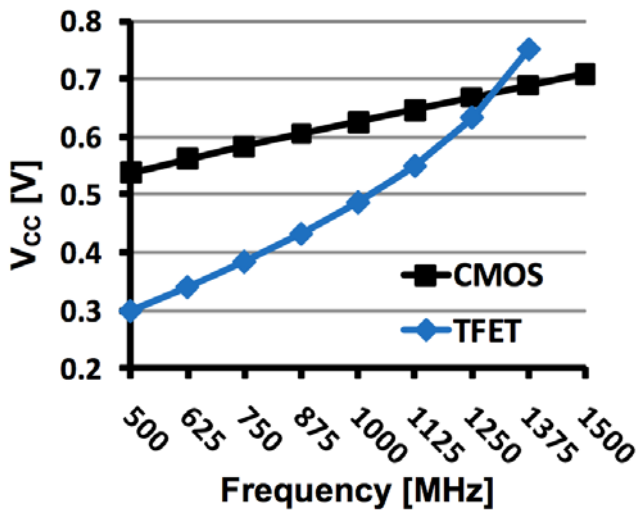


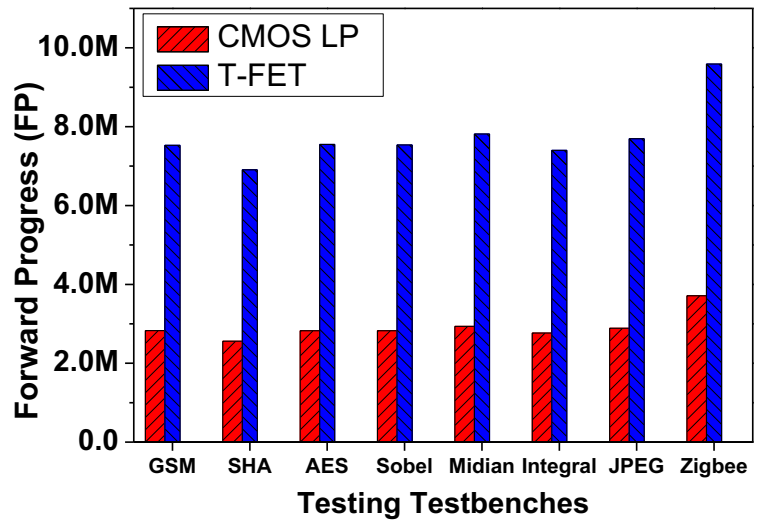


- 100% battery-less operation
- Zero stand-by power
- Maximum forward progress with instant backup and recovery options during power interrupt
- Micro architecture optimized by Penn St; NVP designed by Tsinghua University
- Interfaced to ASSIST energy harvesters (Werner, Trolier-McKistry groups)

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)

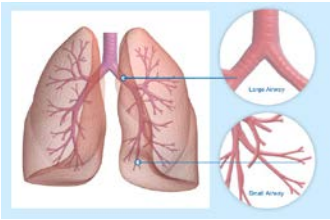
Krim (NCSU)

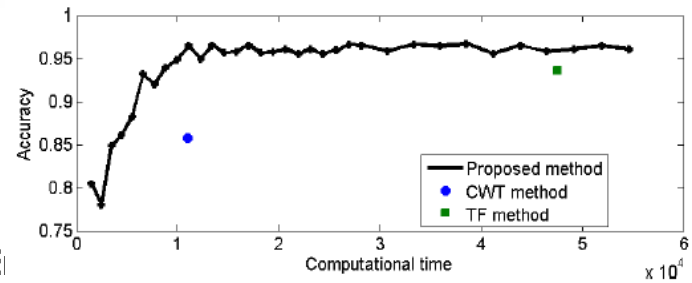
ASSIST Research Portfolio

▶ Wearability and Data

Data | Flexible Materials | Integration in Testbeds | Human Factors

Wheeze modeling and detection



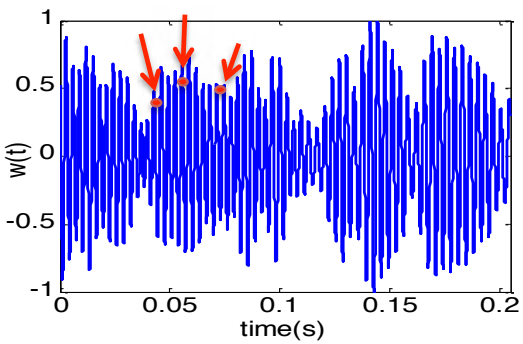


Choosing delays and embedding dimension

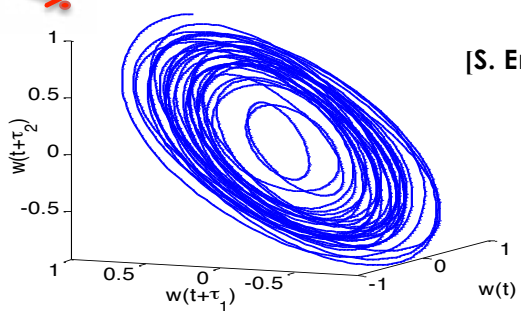
$$\begin{pmatrix} w(t) \\ w(t+\tau_1) \\ w(t+\tau_2) \end{pmatrix}$$

Time Delay E

Algebraic topology



Signal in time domain



3D delay embedding

[S. Emrani et al. . ICASSP'14]

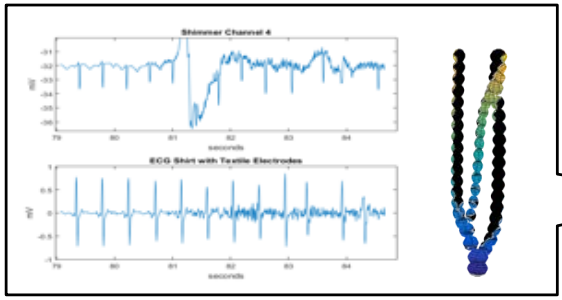
ASSIST Research Portfolio

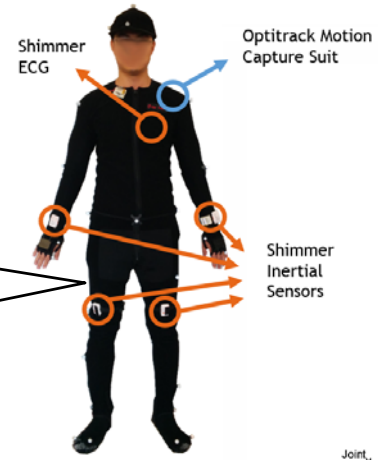
Lobaton (NCSU)

▶ Wearability and Data

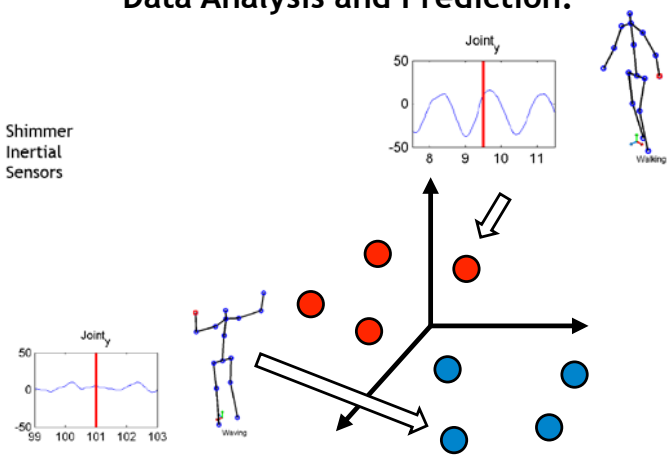
Data | Flexible Materials | Integration in Testbeds | Human Factors

Data Processing and Modeling:

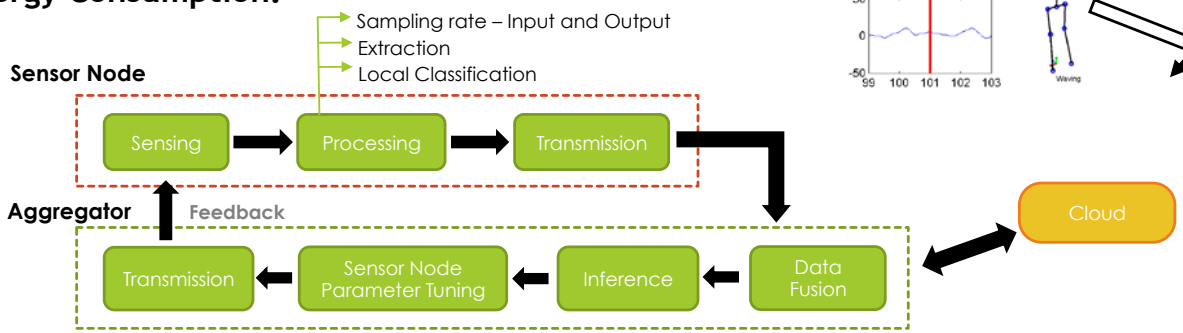




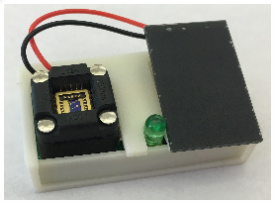
Data Analysis and Prediction:



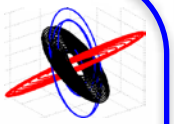
Energy Consumption:



ASSIST Testbeds

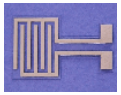


Total System Prototype



Wheeze Analysis

CMUT Sensors



AgNW

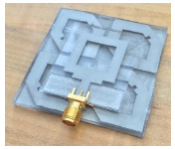
ALD Ozone Sensor

Gen 1 HET

Gen 1 SAP

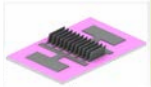
Total System Prototype

SoC board



Flexible Antenna

TEG Array

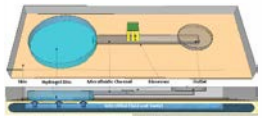


Supercaps

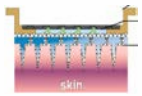
Nanocellulose

Cortisol/Glucose Sensor

Gen 2 HET



Hydrogel Interface



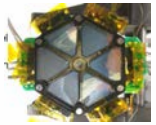
Microneedle Array

8/31/16

Gen 2 SAP

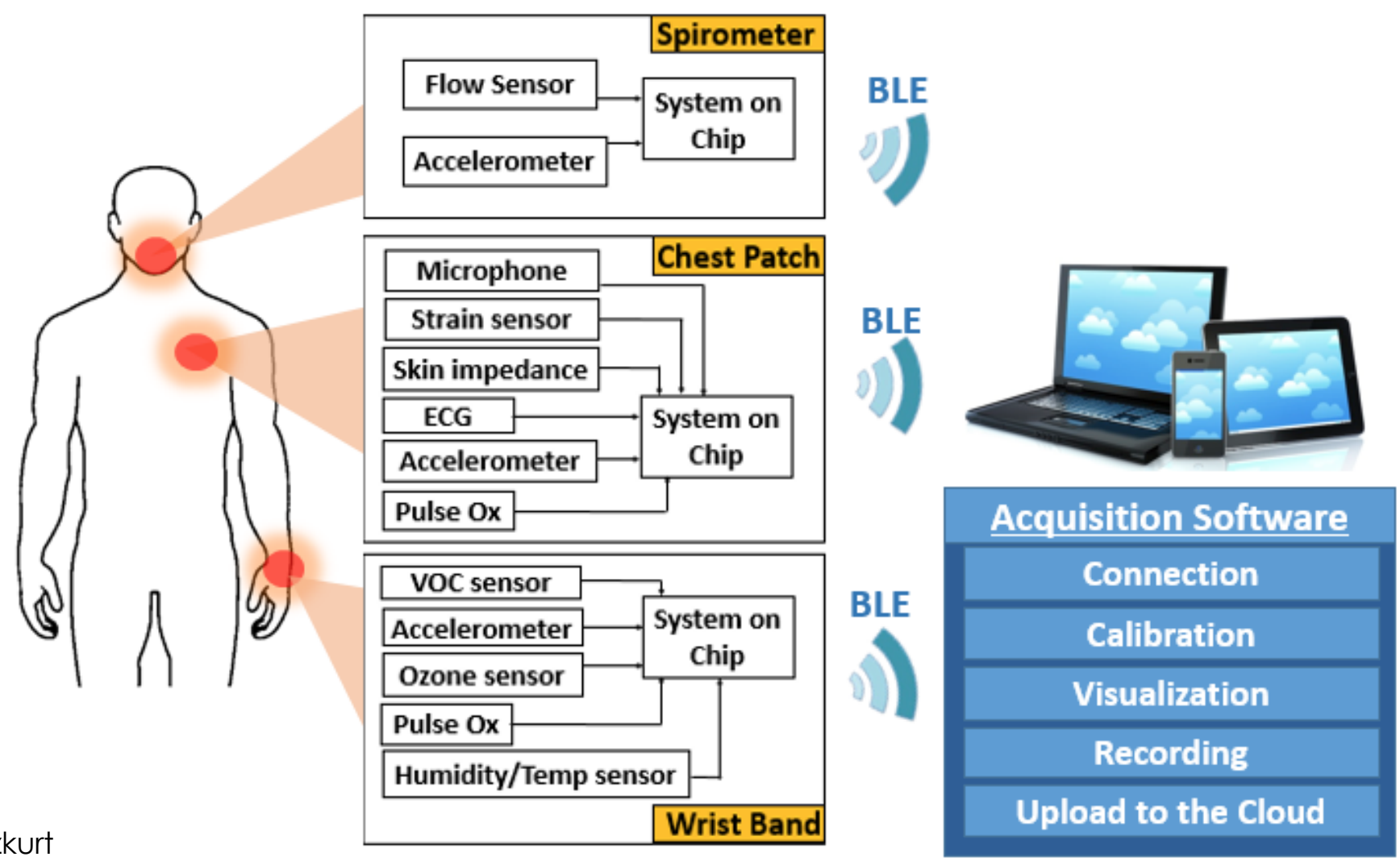
Textile Integration

Flexible TEGs

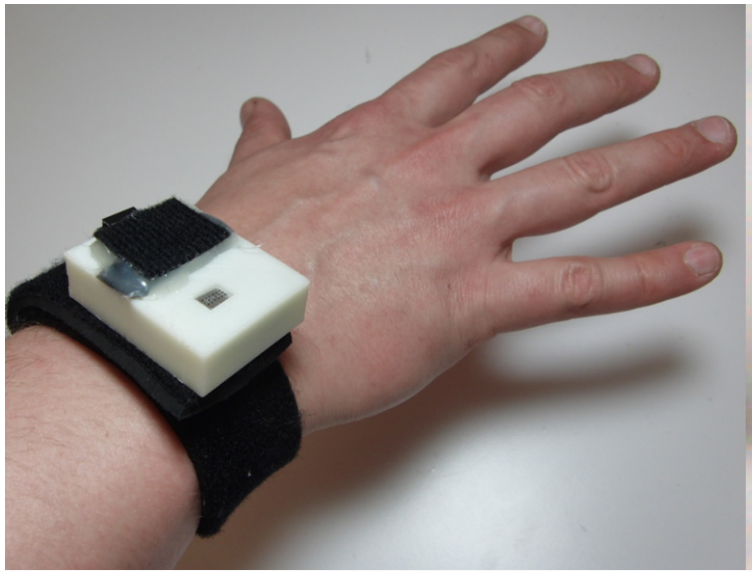


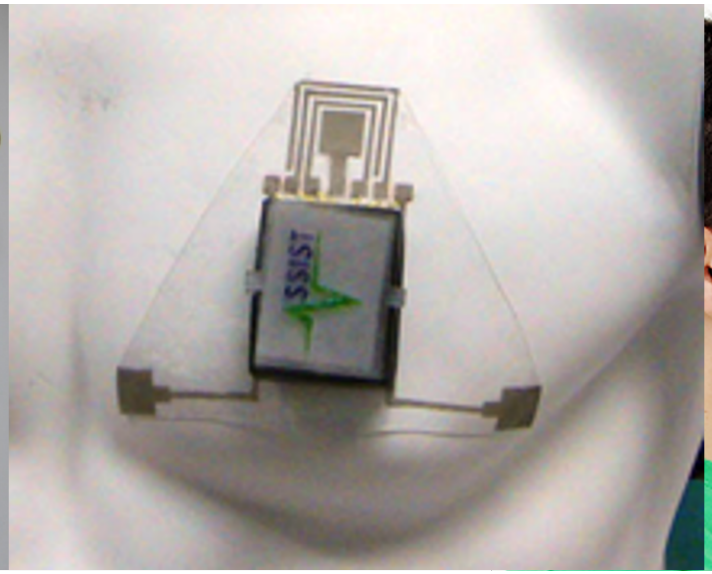
Piezoelectric Harvester

Nonvolatile Memory


Spirometer
Flow Sensor
Accelerometer
System on Chip
BLE
Chest Patch
Microphone
Strain sensor
Skin impedance
ECG
Accelerometer
Pulse Ox
System on Chip
BLE
VOC sensor
Accelerometer
Ozone sensor
Pulse Ox
Humidity/Temp sensor
System on Chip
Wrist Band
BLE
Acquisition Software
Connection
Calibration
Visualization
Recording
Upload to the Cloud

Bozkurt





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.

James Dieffenderfer, et al., "Low Power Wearable Systems for Continuous Monitoring of Environment and Health for Chronic Respiratory Disease", JBHI-00027-2016

Opportunity for Always-on Health Sensing

Battery	SoC/Radio	Avg. Power ECG/Accel	Avg. Power: PPG, Skin-G, Microphone	Avg. Power Ozone/VOC/ Temp/rH	Total Avg Power Consumed	Days of Operation
CR 2032	11mW* (COTS)	0.06mW*			11.1mW	2
CR 2032	0.03mW**	0.06mW*			0.09mW	266
CR 2032	0.03mW**	0.06mW*	1.13mW*	0.39mW*	1.3mW	17
Self-Powered (>1.3mW)	0.03mW**	0.06mW*	1.13mW*	0.39mW*	1.3mW	Indefinite!

* James Dieffenderfer, et al., "Low Power Wearable Systems for Continuous Monitoring of Environment and Health for Chronic Respiratory Disease", JBHI-00027-2016

** V. Misra, et al., "Flexible technologies for self-powered wearable health and environmental sensing," *Proc. IEEE*, vol. 103, no. 4, pp. 665–681, 2015.

- 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