Self-organizing Cyber-Substrates: Exploring a Modular Computing and Communications Architecture for Structural Health Monitoring

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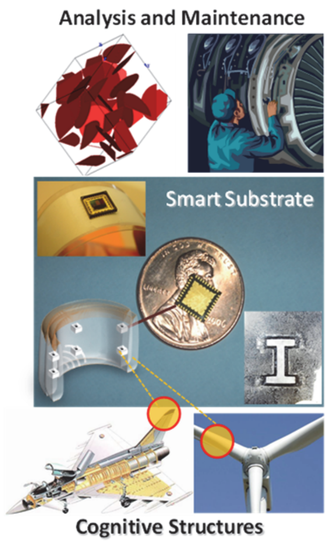
1. Motivation and Broader Impacts

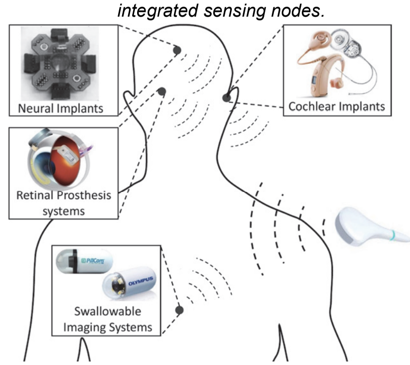
Vision *Self-aware substrates with embedded sensors that can self-power, sense, compute and self-organize their communications.*



Impact *Continuous monitoring of structural health with minimal maintenance and configuration costs.*

Rationale *Substrate – as continuous source of energy and communication medium.*

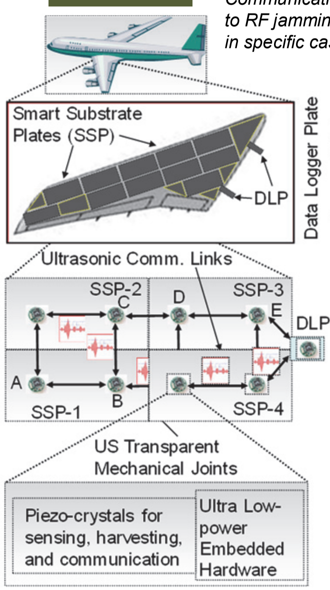
Outcome *Concept of Smart Substrate Plate (SSP) – a modular platform with integrated sensing nodes.*



2. Intellectual Merits

Uniqueness *Modular architecture where SSP can be assembled without need for additional instrumentation or wiring..*

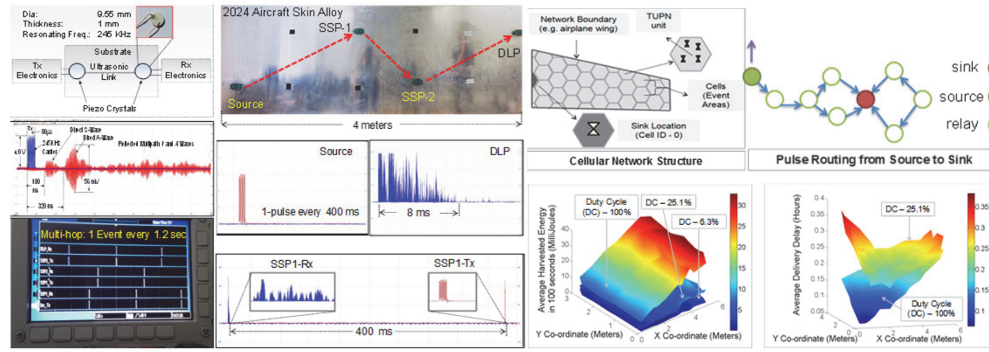
Robustness *Communication through substrate makes the architecture robust to RF jamming or denial or service attacks. More energy efficient in specific cases.*



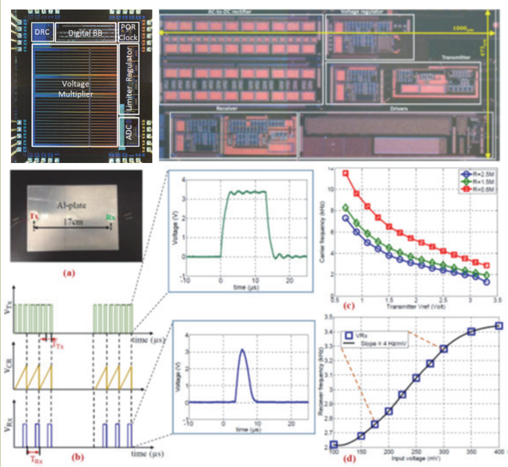
Through-substrate Ultrasonic Pulse Networking	Remove Cost of Radio Network Retrofitting
Energy Harvesting from Ambience (e.g. vibration)	Scalable, Zero-Maintenance, and Battery-less
Modular Structure Assembly	Reduced Construction Cost
In-substrate Sensor Embedding	Integrated SHM as opposed to Retrofitting

3. Results and Milestones

Results 1: ***Pulse based Ultrasound Networking – Using Pulse-interval encoding (PIE) for transmitting and routing information through the substrate [1].***

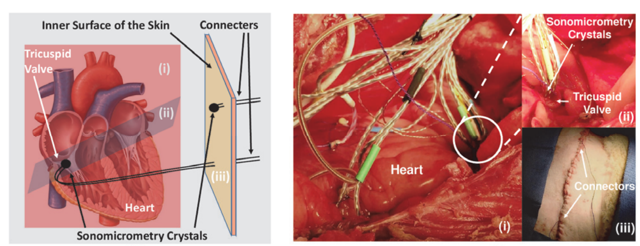


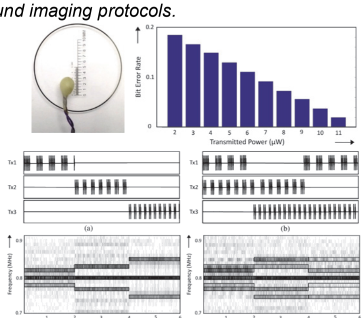
Results 2: ***Custom substrate computing and communications processor [3].***



- *Each sensor node harvests its operational energy from ambient vibrations in the substrate.*
- *When sufficient energy is harvested, the measurement module wakes up determine the failure state in its local environment.*
- *If a salient event is detected, the transmitter module is activated, which continuously transmits the local ID.*
- *When a node receives a PIE packet from its neighboring node, it retransmits the packet. The process is repeated till the sink receives the event.*
- *The sink then examines the source of the event, filters out false-alarms and localizes the substrate area to be examined.*
- *The proposed approach is scalable and can be applied to different types of substrates including biological substrates.*
- *Demonstrated different multi-access PIE ultrasound telemetry that is compatible with standard B-scan and M-scan ultrasound imaging protocols.*

Results 3: ***In-vivo substrate communications [2].***





1. S Das, H Salehi, Y Shi, S Chakrabartty, R Burgueno, S Biswas, ``Towards packet-less ultrasonic sensor networks for energy-harvesting structures", Computer Communications 101, 94-105, 2016.
2. S. Kondapalli, Y. Alazzawi, M. Malinowski, T. Timek, S. Chakrabartty, ``Multi-access In-vivo Biotelemetry using Sonomicrometry and M-scan Ultrasound Imaging", IEEE Transactions on Biomedical Engineering, 2017.
3. Y. Alazzawi, S. Chakrabartty, ``Design of CMOS Telemetry Circuits for In-vivo Wireless Sonomicrometry", IEEE Symposium of Circuits and Systems (ISCAS 2016), Montreal, Canada, 2016

Acknowledgement: National Science Foundation, CSR 1405273