Integrated Large – Area Sensor/Actuator Network (ILASAN) Technology for Structural Health Monitoring

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Diagnostics and Prognostics
Active and Passive Sensing

Passive Sensing

Active Sensing
SMART Layer

- Composite fiber prepreg
- Sensor/Actuator
- Carrier film

Embedded sensor network

- Existing composite or metal structure

Surface mounted sensor network
Sensors

- Piezoelectric
- Fiber-optic
- MEMS
- Strain gages
- Other...
Applications

- Concerns: (advanced materials)
- Accidental impact
  - Fuselage
  - Wings
  - etc.
- Disbond/cracks
  - skin-stiffeners
  - bonded or bolted joints
  - etc.
- Overloads
  - Impact
  - Operation
  - etc.
Challenges in Sensor Network

Key Components: Sensors, Network, Electronics and Software

- Large area coverage
- Multiple sensing capabilities (passive and active)
- Large number of sensing nodes
- Minimal weight
- Ease of installation
- Embeddable
- On-board and real-time monitoring capabilities
Problem Statement

How to cover large area?

polymer Layer

e.g. Kapton ultimate elongation: 72%

? stretching >2000%
Related Technologies

Thin film transistors (TFT) (switch in LCD displays)

- Source
- Gate oxide
- Drain

Glass/polymer substrate

PolySi (semiconductor)

Organic Thin film transistors (OTFT) (e.g. electronic papers, sensors, memory devices)

Flexible electronics

Assembling devices and electronic circuits on plastics (e.g. Kapton)

Semiconducting polymer
Our Approach

Integrate the SMART layer with advanced flexible electronics

Our focus

Stretchable Polymers

Make the SMART layer out of a “stretchable” polymer
### Overall Schedule

#### Milestones

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#### Overall Status:

- **October 2009**
- **Overall Status:** On Schedule starting year 3

- **Completed**
  - Sensor network development
- **85% completed**
  - Fabrication and integration
- **10% completed**
  - Interface toughening
- **50% completed**
  - Diagnostics development
- **50% completed**
  - Prototyping and validation

- **50% completed**
  - Overall status: On Schedule starting year 3
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NETWORK and SMART WIRE DESIGN

for Large Area Coverage
Our Approach

Develop a micro/nano-scale fabrication technique to create expandable infrastructure networks within polymer and silicon materials.

over 20,000% expansion!!

• Removing materials to improve network expansion capability
• Using CMOS fabrication to miniaturize the network systems
The Key Element

1) Allow “in-plane” “ultra-high extendibility” (>2000%)

2) Easy deployment

3) Allow extension sensing to:
   - Precisely position nodes at the macroscale
   - Minimize strain
   - Translation only of the micronodes

4) Allow electrical connectivity between nodes
Fabrication of Polymer-based Network

Result: top view

Optical microscope image
Results

L = 22231 μm, u = 20127 μm, Max. Principal Strain: 0.064%, no Plastic strain, Elongation Ratio: 10.566

M4 Large gap 3μm

M4 Small gap 1.5μm
Experimental and Numerical Study

NUMERICAL

*Experimental Data*

L/Lo = 385%

L/Lo = 815%

L/Lo = 1190%
Strain and elongation monitoring

- **VEDY GOOD AGREEMENT (THEORY AND EXPERIMENTS)**

- **ULTRA-LOW STRAIN (5.6%) FOR 1600% ELONGATION**
Fatigue Tests

Max load: 1.9144 Kips

500,000 cycles
5000 Nodes Network

Flexible and transparent

Microscope image of the network
5000 Nodes Network

5041 NODES
A 71 Nodes Silicon-based Network
Individual Silicon-based Node

Si NODE 200μm

Spiral Ridges 2μm
RTD Network
Temperature Gradient Display

Frame of Hotplate

Temperature Display

Square Region Heated by Hotplate from Bottom

Cooperated with Kyunglok Kim
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SENSORS DEVELOPMENT
PZT Integration Problem

Many Layers

Electrode & Dielectric in Load Path

Hard to Fabricate Step

Failure points

Image by Nathan Salowitz
Solution

Functional, but creates a vastly different electric field compared to traditional bulk transducers.

Planar, Radially Alternating Electrodes
PZT New Design

In Plane Polarization
PZT Preliminary Results

- Signals appropriate to SHM
- Interfaced with state of the art data acquisition system

![Graph showing signals change with simulated damage]
PZT + RTD Design and Result

RTD into the electrode pattern

Assembly and testing are underway

Spiral Pattern

Fingered Pattern
3
INTEGRATION IN COMPOSITES
Integration in composites

256 nodes network surface bonded to a composite and cured