Flexible Hybrid Electronics in The Digital Industrial World

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GE ‘s Digital Industrial Portfolio

Power  Renewable Energy  Aviation  Healthcare

- More than 500 Manufacturing Sites globally
- Customers in over 150 countries
- ~200k Employees
Flexible Hybrid Electronics (FHE): set of technologies focused on integration of sensing, communication, and computational elements to create flexible or conformable electronic assemblies that can adapt to a multitude of geometric and environmental constraints.
GAME CHANGING combines previously impossible attributes for systems in:
- form factors
- cost points
- lot sizes
- delivery schedules

NOVEL FORM FACTORS
Flexible, Stretchable, 3-D
Lightweight

LOW TEMPERATURE MANUFACTURE
Bio Materials, TPU, PET, Compatible

Designed for environment
-rugged, harsh industry, body interaction

DIGITAL PROCESS FLOW
Feedback Control Manufacturing, Virtual Assets, No Tooling Overhead

MASS CUSTOMIZATION
Economic High Mix, Low Volume and Customized Production

SPEED TO MARKET
Ability to Produce a Complete System Concurrently
Flexible Hybrid Electronics- What Can it Enable?

“Electronics on Everything”
• products that fit the natural forms of our world
• Soft, electronic interfaces on /in body
• Sensing systems designed for their environment through materials and design
• Large format sensing & communication systems

Application Areas:
• Wearables/Implantables for Healthcare
• Wearables for Workers
• Enhanced mechanical edge sensing for GE Products
• Electronics and Sensing Integrated with Structure
• Smart Tracking for Manufacturing, Inventory, Service
• Soft Robotics
• Sensing of prosthetic arm to give sensory feedback

What’s in it for GE:
• Size weight and power reduction 1/10 size
• 80% reduction in part complexity
• Digital Scaleable Manufacturing
• >10 X cost reduction
• Reliability enhancement
Manufacturing USA

- A network of regional institutes, each with a specialized technology focus.
- Secure the future of manufacturing in the U.S. through innovation, collaboration, workforce development, and education.
- Focused on FHE
- $75M DOD Invest over 5 years
- Lead: Flextech Alliance, AFRL, ARL
- NYS ESD Match through Binghamton University
NEXTFLEX AND FLEXIBLE HYBRID ELECTRONICS

• NextFlex is leading a consortium of 100 members across the US to develop and mature this new form of electronics based on additive manufacturing and incorporation of thin, bare die.
Change in Form Factor of Sensors: Rigid to Flex to Soft

Conventional ECG

untethered

disposable

BrainGate Neural Interface enable control of robotic

Soft electronic implants for low profile chronic Implantation

http://www.terasemmovementfoundation.com

Neural
COMPONENTS of FUTURE FACTORIES

- People
- Machines
- Digital

- Monitor Asset Health
- Detect Hazard
- Optimize Maintenance
- Contextualize Information
- Boost Productivity
COMPONENTS of FUTURE FACTORIES

- People
- Machines
- Digital

Detect Hazard
Monitor Asset Health
Optimize Maintenance

Industrial Data
Boost Productivity

Contextualize Information
EHS Event Data
Performance Data

COMPONENTS of FUTURE FACTORIES

- BRILLIANT FACTORY
  - Modern Design Practices
  - Manufacturing Production Planning
  - Production Process Optimization

- PEOPLE- ONEHS Digital
  - Safety
  - Productivity

- Ongoing Field Support - PREDIX
  - SHM
  - PHM
  - Optimized Control for Efficiency or Life
  - Feedback to Design and Manufacturing

- Monitor Asset Health
- Detect Hazard
- Digital EHS Platform
- Digital Data
- Performance Data
- Boost Productivity
- Contextualize Information
- EHS Event Data
- Industrial Data
- Performance Data
- Detect Hazard
- Digital EHS Platform
- Digital Data
- Performance Data
- Boost Productivity
- Contextualize Information
- EHS Event Data
- Industrial Data
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- Manufacturing Production Planning
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- Safety
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Ongoing Field Support
- SHM
- PHM
- Optimized Control for Efficiency or Life
- Feedback to Design and Manufacturing

The rise of robots, automation, data analytics and additive technologies are transformative.
Brilliant Factory

A “digital thread” forms the 21st Century Assembly Line for Smart Manufacturing

The “Brilliant” Factory

Virtual Product Design

Virtual Manufacturing

Service/Repair Shop

Supply Chain Network
Advanced Manufacturing Transforms the Entire Value Chain

Industrial Internet meets manufacturing

**VIRTUAL DESIGN & MANUFACTURING**
- Should-cost
- Producability advisors
- Virtual manufacturing
- Collaboration

**SMART FACTORIES**
- Sensor Enabled Automation
  - Novel process prototyping
  - Informatics
  - Model-based manufacturing
  - Condition Based Maintenance
  - In Line Inspection
  - Process Optimization

- Factory Optimization
  - Tracking of parts, product
  - Real time optimized factory and optimized system design
  - Bottleneck detection
  - Data-driven manufacturing models

**SUPPLY CHAIN OPTIMIZATION**
- Real-time analytics
- Visibility
- Predictive maintenance
- Connected systems

- 10-50% cost out
- 20-70% ↓ cycle time
- 10-50% ↑ yield

- 2-4X ↓ cycle time
- 50-70% ↑ intros
- 2X yield

- 7-15% ↓ inventory
- 3-5X predictability
- 40% ↓ downtime
Challenges of Renewables Manufacturing

- Longer, lighter blades
- Increased blade performance
- Lower cost of energy
- Production increase
- Off-shore sites
- Repowering and extension of Service Life
- Damage assessment
- Adaptive control: performance, asset life, weather, wildlife
FHE Enabled Cradle to Grave Composite Structural Health Monitoring

A scalable network of passive sensing patches that can be embedded or placed on composite structures and provide input on process during manufacturing.

Temp, strain, dielectric measurements inform:
- Infusion process
- Cure process
- Prevent rework

Image from TWIN Engineers
https://www.youtube.com/watch?v=tu5ycxL0Avs

Sensor embedded into or onto composite
Sensor Embedded into Structural Composite for Operation

Sensors provide state awareness enabling:
- closed loop operational control
- structural health monitoring
- reduce costs and improve safety.
- Many applications possible

Passive Sensor Advantages
- Simple, low profile sensor
- Inexpensive
- No battery or wiring required
- Relieves Lightning strike issues
- Eliminates complexity of wiring
- Reader can be integrated into structure
- Very large dynamic range of measured strain (5-10,000+ ustrain)
- Rugged operability near conductors and/or clutter
- Easy integration with “zero-power” backscattering techniques
Printed RF Systems
Interconnect, Passives and Embedded Die
Nextflex PC1.0 & 3.2

PC 1.0 - Topsite Print Only

- Lower Cost
- Digital Design = Quick Turn
- Affordable Antenna in Package
- Affordable Ultrathin Packaging
- Conformal Active Arrays
- Deployable Arrays

PC 3.2 - Double side printed RF circuitry with printed vias and embedded die

Embedded die performance to >25Ghz

GE Proprietary
Limitations of existing sensors

- Poor sensitivity prevents prognostics
- Cannot discriminate oil aging (total acid number, TAN) vs external contaminants (water, fuel)

Value proposition of GE solution

- Independent quantitation of oil aging and external contaminants by sensor design + analytics
- Electrical resonant sensor for early diagnostics of industrial fluids

Potyrailo, R. A.; Tokarev, I.; Go, S.; Ottikkutti, P.; Kuzhiyil, N.; Mihok, J.; Anzini, C.; Shartzer, S. accepted, 2018
Reference Shaft Method

T700: System Accuracy ~ 3-5%
interlocking shaft & torque tube,

Measuring Torque allows optimized operations, and extended life

OC 1.0 Peel and Stick Sensor on Asset
Wider Adoption, Scalable, Reliable
Rotating or reciprocal shafts
• >2X improvement in G capability
• 70% profile reduction
• >10X increase in asset size supported
• Reduce Assembly steps from 19 to 4
• Reduce part count by 80%
• Reduce Shaft Rework by 20%
• Reduce qualification costs & time by 80%
• Reduce NRE time by 50%

SAW Torque Sensor
• passive: no battery or wired power
• Improved accuracy
• Only sensors in harsh zone
• Electronics in benign zone
• Low Mass –does not affect engine dynamics

Developed for Helicopter Engine Program
for Military Use
• Requires Torque sensing with >1.5% accuracy
• SAW method ~ 2X as accurate as previous solutions
• 3.5 lbs wt savings
• Eliminates 9% of unplanned engine removals
PRINTING ON 3D SURFACES:
CREEP SENSOR IN POWER

- 3D Sensors Condition-Based Maintenance
  - Fully Automated Robotic WorkCells
  - Printing Serialized Strain Sensors
  - Collected Data Analyzed on GE Predix Cloud
  - Few dollars to print, potentially saves $10,000’s in reducing maintenance Costs
  - Production Capacity: ~1 Million Sensors/year

Industrial IoT
COMPONENTS of FUTURE FACTORIES- Focus on People

**BRILLIANT FACTORY**
- Modern Design Practices
- Manufacturing Production Planning
- Production Process Optimization and Control

**PEOPLE- ONEHS Digital**
- Safety
- Productivity

**TESTING/Quality Assurance**

**Ongoing Field Support**
- SHM
- PHM
- Optimized Control for Efficiency or Life
- Feedback to Design and Manufacturing
5 Year Digital EHS Roadmap - Industrial Safety

EHS SMART ECOSYSTEMS

Predictive Analytics
Digital Twin
HiPo

Hazard Identification
Event Modeling

Artificial Intelligence
Vision
Language

Virtual Assistants
Planning

Intelligent Machines
Block Chains
Brilliant Factories

UAVs
Smart Materials

WEARABLES & BOTS
Exoskeletons
Smart Glasses
Lone Worker Wearables
Hazard-Sensing Bands

EHS PLATFORMS
Gensuite Simplification & Integrations
Spotfire EHS Performance Dashboards
IOT IH Monitoring
Inspection Robots

People
Environment
Equipment
Site Mapping
DYNAMIC HAZARD ZONE
PERSISTENT HAZARD ZONE
LOCALIZED SENSORS
ENVIRONMENT SENSORS

Private/Public Cloud

Insights
- Dashboards
- Personal Alerts
- Hazard Prediction

Models
- Environment
- Person
- Hazard Event

Example Sensors / Information Source
- GE: Gas, Voltage, Sweat, Biometric
- Non-GE: Watch, Camera, Exo-suit, Smart Glasses, Weather Data

• Accurate & reliable Sensors
• Flexible SW Platform
• Robust Connectivity
• Outcome based Analytics
Occupational Safety Wearable: Voltage Sensing Wristband Designed to Alert Users of AC Voltage Sources

A wristband that:
- Senses and alerts user to the presence of electrical fields
- “Wear and Forget”
- Supplement to safety procedures and LOTO
- Prevents incidents and accidents
- Designed as added safety function for service and repair
- May be useful for first responders

- Power consumption/battery life: >16 hours
- Rechargeable
- User adjustable Sensitivity Settings
- Omnidirectional Detection
- Sensitivity: min 80cm @110 VAC
- Voltage to detect: Required 100 VAC to >1kVAC
- Frequencies: 50Hz, 60 Hz
- Alert mode: audible, visible, vibratory
- Sensitivity Adjustment

- Next Generation Band has:
  - Wifi/Bluetooth connection to allow notification and mapping
  - Worker Down Function

Detection Distance in Electrical Cabinet
Main available sensors for gaseous pollutants

- Exhaust gases and industrial emissions
- Workplace atmosphere
- Ambient rural and urban air

- Photoionization
- Electrochemical
- Metal oxide semiconductor
- Nondispersive infrared
- Pellistor

Concentration of pollutants (from ppb to % volume in air)

0.1 ppb 10 ppb 1 ppm 100 ppm 1% 100%

Szulczynski, Gebicki, Environments 2017
Designs of resonant RF and RFID sensors

Exploring fundamental capabilities of multivariable RF and RFID sensors for diverse applications
Gas sensors for occupational safety: $\text{CH}_4$

Example of sensor operation over 8-h period = one work shift

Statistics of sensor performance

$\text{CH}_4$ LEL = low explosive limit
Robots for Dangerous and Repetitive Tasks

Factory and Field Deployment of Robots and Drones

• Deploying a companion robot with a human worker
• Augmenting the worker with an exoskeleton
• Utilizing robots and drones for inspection of factories

Approach depends upon hazardous the task is and how you need the human brain involved in the process.

https://www.suitx.com/
Soft robotics for manufacturing and industrial services

- **Unique capabilities of soft robots** for delicate manipulation, environmental compliance, confined navigation, variable stiffness, reconfigurability and self healing.

- **Transformational productivity improvements possible for industrial services:**
  - On-wing maintenance & repair for the $80 billion Aviation MRO industry.
  - In-situ repairs for large industrial assets, reducing outage duration & cost
  - Automated handling of delicate products for agriculture and e-commerce order fulfillment ($5 trillion industry by 2021.)
  - Active exosuits for human capacity augmentation on the shop floor.

- **Major advancements will be needed to make fabrication of soft robots accessible, reliable and scalable.**

**GE application examples**

- Aircraft Engine Coating Restoration Soft Robot
- Aircraft Engine Shroud Inspection and Spray Device
- Gas Turbine Hot Gas Path Inspection Flexible Robot
- Flexible Snake Robots for Inspection and Repair

**Future concepts - MRO example**

- **Novel locomotion modalities**
- **Large force capability with flexibility**
- FHE technology integration*
  - Temperature capability for in-situ welding, additive repair

* Flexible sensors for strain, temperature, radiation, force, cracks, chemical concentration, contact, etc. Flexible batteries, microcontrollers and interconnects. Flexible actuators for movement, heat, light and sound.
Adoption of Industrial Digital Technologies in Manufacturing

• Faster more predictable cycle times
• Higher quality
• Lower cost

FHE Technologies well suited for

• Tracking
• “cradle to grave” sensing of asset
• Single use sensors
• Wearable technology for digital assist, hazard identification, biometric assessment
• Robotic assist to augment human capabilities
• Soft Robotics for service, repair, inspection, remanufacturing
• Light weight sensors on inspection robots