Energy harvesting based sensor network for industrial monitoring
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Outline

1. Company introduction
2. System architecture
3. Piezoelectric technology for energy harvesting (EH)
5. Climatic chamber and real industrial environment tests
1 Company introduction
Meggitt - overview

» Provides high technology products and systems for the aerospace, defence and other specialist markets, including: medical, industrial, energy, test and automotive
» 60 years experience in extreme environment engineering
» Annual sales (2012), £1,605.8 million, 10% growth in comparison to 2011
» Listed on London Stock Exchange (MGGT)
» FTSE100 company

Civil aerospace 46%
Military 43%
Energy and other 11%
OE 52% / Aftermarket 48%
A global presence

North America
Employees: 5,790
Locations: 31
USA, Canada and Mexico

UK
Employees: 2,090
Locations: 13

Mainland Europe
Employees: 1,450
Locations: 7
Denmark, France, Germany, Spain and Switzerland

Asia and RoW
Employees: 650
Locations: 8
Australia, Brazil, China, India, Singapore, UAE and Vietnam

Over 10,000 employees worldwide
Meggitt Sensing Systems Denmark

- Meggitt A/S is a manufacturer of piezoelectric materials, components, devices
- 2-3 million units produced annually
- Major markets
  - Medical ultrasound
  - Underwater acoustics
  - Acceleration sensors
  - Flow meters
  - Energy Harvesting
2 System architecture
Kinetic energy harvesting – basic principle

The kinetic energy is transformed into electrical energy.

The kinetic energy can be in the form of the following:

- Harmonic vibration
- Non-harmonic vibration
- Rotation
- Displacement
- Torque
- Acoustic wave
- Etc.
Energy harvesting based wireless sensor network

- Star topology
- Unidirectional transmission
- 16 sensor nodes
- 2.4 GHz radio link
- Proprietary protocol
- Distance (3-10 m)
General features of the system

» Micro generator level
  - Highly integrated
  - Small (millimeter scale)
  - Sourcing energy from vibrations

» System level
  - Low weight
  - Energy autonomous
  - Wireless
  - Long life
  - Wide range of working temperatures
Sensor node architecture

» Harvesters convert kinetic energy in electrical energy
» Electrical energy is stored and conditioned
» When electrical energy is sufficient the load is powered
» Microcontroller repeats acceleration measurement and data transmission at fixed time intervals
Piezoelectric technology for energy harvesting
Energy Harvesting micro-generators – thick film based bimorph

» Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
» Single clamped cantilevers with a silicon proof mass at the free end
» Bimorph configuration
» 10x10 mm² lateral dimensions
» Higher voltage and power compared to unimorph
» Si/PZT fabrication + middle electrode + 2nd PZT layer + Si membrane removal

DTU Nanotech and Meggitt A/S
Fully assembled generator board

» Four EH devices are combined in order to assure the proper power level/bandwidth
» Fully assembled board delivers approx. 100 µW of continuous power at 0.3 g RMS, resonance (e.g. 300 Hz)
4 Sensor nodes and Wireless Sensors Networks
Sensor Node

» Operation temperature
  - Range: -40 – 70 ºC

» Acceleration measurement
  - 3D acceleration measurement
  - Sampling frequency = up to 3200 Hz
  - Resolution = 13 bits

» Ambient temperature
  - Accuracy ±0.4 ºC (10 ºC - 60ºC)

» Relative humidity
  - Accuracy ±3.0 %RH (20% - 80%)

» Sensor nodes are linked using 2.4 GHz wireless communication forming star-like network architecture
Operation principle of the sensor node

- Due to low energy level the nodes operate with low duty cycle
- The microcontroller alternates acceleration and temperature measurement and data transmission with sleep intervals
- The minimal acceleration level is approx. 0.3 g RMS, working frequency is tunable in a broad range
Working network of wireless and battery-less sensor nodes

- Several wireless sensor can operate at the same time
- Base station receives and forwards the incoming packets to the web server
- Sql client collects the incoming data and stores them in the database
- Web database interface shows the stored data to the users
- Intercompatibility of the different EH sensor nodes
Climatic chamber and real environment testing results
Climatic testing

- 400 N Shaker
- Climatic chamber
  - Temperature
  - Humidity
- Shaker shaft
- Energy harvesting based sensor nodes
  - Excitation: 300 Hz, 0.5 g RMS
- Battery powered sensor node
500 hours test

Figure 1: Test started: 2013-05-17 16:17:01

- Normal conditions test:
  - 30°C (night) and 60°C (day)
- 4 hours => 1 day
- 500 hours => 125 days of operation
- At 250 hours:
  - 30°C for 24 hours
Industrial environment setup – an example

» Energy harvesting powered sensors have been placed on hydraulic pumps located outside of the factory building
» The base station together with the data server was placed inside the factory building
» Operating harvesting frequency was 220 Hz
» Battery powered sensor node was used as the reference
Results – example of data trends

Energy harvesting wireless sensor network
Conclusions

- The EH devices are capable of generation of 15 to 20 μW of power at moderate accelerations of about ~0.3 g RMS
- The PZT thick film micro generators can successfully power sensor nodes, enabling energy autonomous, wireless measurement of acceleration, temperature and humidity at low levels of vibration e.g. 0.25 g RMS
- The data is easily accessible through number of standard network interfaces: LAN, WiFi, 3G
- The climatic testing indicated good performance in real environment conditions
- The wireless and battery-less sensor systems have been successfully applied in monitoring of industrial equipment
- The presented network of sensors can be applied in permanent as well as temporary monitoring in e.g. difficult to access locations
- Energy harvesting based sensor nodes enable systems that are:
  - Energy autonomous
  - Maintenance-free
  - Very easy to deploy
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Thank you
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