Internal Radio-frequency Instrumentation System (IRIS) Overview

Homeland Defense and Security Information Analysis Center (HDIAC) Webinar

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• IRIS development arose from an Orion EM-2 Developmental Flight Instrumentation (DFI) need

• EFT-1 DFI:
  – ~60% of EFT-1 DFI mass due to wiring

• Wireless DFI effort:
  – implement and characterize the performance of a system to service low-data-rate (10Hz) thermocouple (TC) sensors w.r.t.
    • battery life
    • system mass
Wireless DFI sensors must be...

- **completely wireless**
  - data acquisition (DAQ) and communication powered by a battery or harvested energy

- **capable of operating independently for years**
  - switched on at time of installation
  - hibernate until required for mission

- **capable of being woken instantly**

- **extremely low mass**
  - large power sources cannot be tolerated

... which eliminates traditional “active” wireless solutions like ZigBee, Bluetooth, Wi-Fi.
Commercial Radio Frequency Identification (RFID) standards typically allow tags to report unique IDs to an interrogator:
But these same standards can transport sensor data as well:
RFID Sensing Architecture

- Communication power provided by interrogator, “for free” from sensor’s perspective

- Data acquisition (DAQ) power can come from several sources:
  - Stored power (e.g., batteries)
  - Harvested power (e.g., RFID, solar, thermal,...)
Using RFID to stream DFI data is a novel approach. To assess the feasibility, we must:

- design extremely low-power sensor front-end
- select candidate RFID serial-interface integrated circuits (ICs)
- build prototype hardware and assess:
  - system mass
    - tags, tag antennas
    - interrogator, interrogator antenna
  - sensor tag power requirements
  - achievable data rate
    - processor-to-tag interface
    - tag-to-reader interface
  - scalability
    - tags per interrogator
  - RF coverage
IRIS Thermocouple Tags

- **prototype TC tag (ODFI TC v. 1)**
  - 10.5 g.
    - 0.02 lbs.
  - 3.5 cm. x 4 cm.
    - 1.4 in. x 1.6 in.
  - BR2330A battery

- **e-textile (fabric) antenna**
  - direct textile mount
  - 11 g.
    - 0.02 lbs.
  - 10 cm. x 8.5 cm.
    - 3.9 in. x 3.3 in.

- **housing concepts:**
  - rigid housing + textile antenna
  - textile housing/antenna (pictured)
    - mass: 34.5 g. (inc. TC wire)
      - 0.08 lbs.
IRIS Interrogator

- **architecture:**
  - leverages Reduction RFID-Enabled Autonomous Logistics Management (REALM) Embedded RFID (EmbeR) interrogator
  - ThingMagic interrogator module
  - Gumstix single-board Linux processor
  - supports up to 4 antennas

- **mass:**
  - 473 g.
    - 1.04 lbs.

- **size:**
  - 15.5 cm x 11 cm x 4.5 cm.
    - 6.1 in. x 4.3 in. x 1.8 in.

- **power dissipation:**
  - 0.43A at 28 VDC (~ 12W)
Interrogator Antenna

- **REALM-1 antenna**
  - low-mass 900 MHz RFID antenna
  - custom designed for ISS inventory management work
  - harvests most of mass reductions through housing re-design

- **mass:**
  - 377 g.
    - 0.83 lbs.
System Diagram

Vehicle
Power/Data
(28VDC/Ethernet)
• **sensor tag programmed in two modes:**
  – hibernate until commanded to active mode
  – sample at 10 Hz and write to tag memory every 15s

• **currents measured:**
  – $\sim 3.1 \mu A$ hibernation current (2.7 V)
  – $\sim 47.5 \mu A$ active current (2.7 V)

• **battery life calculated:**
  – BR2330A (255 mAh):
    • hibernate: 9.4 years
    • active: 223 days
• **Orion aft-bay sector mockup:**
  – derived from Orion CAD
  – populated with sensors and representative obstructions
    • 50 tags
    • 2 “propellant” tanks
    • 1 “coolant” tank
Scaling/Throughput Test Environment

REALM-1 antenna
TC sensor tag
Hydrazine tank mockup
Data Rate, Tag Population Analysis

• **Average error rate measured over 100 hours of experiments:**
  – 0.00% average packet loss observed
    • excludes progressive hardware failure in 1 tag as outlier
    • results verified over second 100-hr set (inc. similar HW failure)
    • work to characterize HW issues ongoing

• **Average interrogator-to-tag interface characterized to guide scaling estimates**
  – measured for 50 sensor tags
  – theoretically allows for ~480 10Hz tags/reader
    • retry overhead ~0.00% so should not impact limit
  – scales gracefully as tags added
  – should support in excess of 100 tags per interrogator (conservatively), provided:
    • processing burden does not become too great as tag population scales
    • all tag locations have adequate RF coverage from interrogator
• initial assessments conducted on EFT-1 vehicle to establish feasibility of coverage
  – used commercial RFID interrogators/tags
  – required approximation of missing backshell/heatshield

• CEM analysis initiated to assess coverage in operational environment
  – Orion CAD used to build CEM models
  – Maxwell’s equations solved on model assuming:
    • tag/interrogator antenna positions
    • tag/interrogator sensitivities
    • interrogator power level
Aft Bay Sector D: “least cluttered”
Sector D Heat Shield Modeling

Source Antenna (1)

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Sector D Heat Shield Modeling (cont.)

Source Antenna (1)

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Tag 6 (7)
Sector D Heat Shield
1W Coverage

Source Antenna (1)

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Tag 6 (7)

- write coverage
- read coverage
Sector D Heat Shield
100mW Coverage

Source Antenna (1)

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Tag 6 (7)

write coverage
read coverage
Sector D Heat Shield
30mW Coverage

Source Antenna (1)

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Tag 6 (7)

write coverage
read coverage
Sector D Backshell
100mW Coverage

Tag 11 (12)
Tag 9 (10)
Tag 7 (8)
Tag 5 (6)
Tag 3 (4)
Tag 1 (2)
Tag 12 (13)
Tag 10 (11)
Tag 8 (9)
Tag 6 (7)
Tag 4 (5)
Source Antenna (1)

write coverage
read coverage
Sector D Backshell
30mW Coverage

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Tag 6 (7)
Tag 7 (8)
Tag 8 (9)
Tag 9 (10)
Tag 10 (11)
Tag 11 (12)
Tag 12 (13)
Source Antenna (1)

write coverage
read coverage
Aft Bay Sector E: “most cluttered”
Sector E Heat Shield Modeling
Sector E Heat Shield
1W Coverage

Source Antenna (1)

Tag 1 (2)
Tag 2 (3)
Tag 3 (4)
Tag 4 (5)
Tag 5 (6)
Tag 6 (7)
Tag 7 (8)
Tag 8 (9)

write coverage
read coverage
Sector E Heat Shield
100mW Coverage
Sector E Heat Shield
30mW Coverage

Source Antenna (1)

Tag 1 (2)

Tag 2 (3)

Tag 3 (4)

Tag 4 (5)

Tag 5 (6)

Tag 6 (7)

Tag 7 (8)

Tag 8 (9)

write coverage

read coverage
Summary of Accomplishments

- **Extremely low-mass sensor architecture demonstrated:**
  - tag mass (textile antenna/housing): 34.5 g./tag (0.08 lbs./tag)
  - infrastructure mass (1 IRIS interrogators + 2 REALM-1 antennas): 1.2 kg (2.70 lbs.)
    - plus cabling/fasteners
  - mass trade scales well as tags added
    - e.g., 150 tags $\rightarrow$ ~ 0.1 lbs./channel

- **Extremely battery-efficient sensor architecture demonstrated:**
  - 9.4 years hibernation time (BR2330A battery)
  - 223 days 10Hz TC streaming (BR2330A)

- **Scalable architecture demonstrated:**
  - 50 10Hz tags/interrogator shown to date
  - approach can deliver data with approx. 0% packet loss (50-tag population)
  - >100 10 Hz tags/interrogator seems likely based on experiments to date
    - further scalable with planned improvements in RFID hardware

- **RF coverage risk significantly bought down**
  - CEM analysis confirms coverage from 100mW – 1W interrogator output power
  - mockup testing ongoing to confirm
Project Status and Forward Work

• Preparing IRIS for commercialization / flight demonstration opportunities

• Environmental testing completed to date:
  – Electromagnetic Interference / Electromagnetic Compatibility
  – Vibration
  – Thermal/Vacuum

• Higher data-rate extensions have been explored/prototyped

• Flight demonstration opportunities are being sought

• Development will continue to:
  – decrease system mass
  – increase battery lifetimes, explore harvested power
  – increase data rate
  – increase reference designs for sensors of interest
    • e.g., optical recession sensors
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