Bring innovations into a low-power wireless sensor node dedicated to SHM

Sponsor: AFENDA (Association Française pour les Essais Non Destructifs dans l'industrie Aéronautique et spatiale)
French Association for Non-Destructive Testing in the Aerospace Industry

Prize: The team selected by the jury on this subject will win a **3 k€ prize** offered by AFENDA

1. Context

The large-scale deployment of Structural Health Monitoring (SHM) solutions currently faces a major physical limitation: the energy autonomy of sensor nodes. While detection algorithms are becoming increasingly powerful, dependence on the grid or batteries with limited lifespans is hindering the installation of dense, sustainable networks, particularly in areas that are difficult to access. The future of SHM therefore lies in the development of ultra-low power systems capable of self-powering or drastically optimizing their energy balance.

To address this issue, this challenge relies on the Alto hardware platform developed by Université Gustave Eiffel and Capturia. This electronic board, specifically designed for critical IoT applications, features a very low-power architecture. It is built around two key interfaces:

- A power management stage capable of harvesting energy to charge a storage device (supercapacitor or battery);
- An acquisition interface dedicated to querying analog sensors.

Figure 1: Alto platform

2. Objectives of this subject

The objective of this subject is to explore innovative hardware solutions to maximize the energy autonomy of a Structural Health Monitoring (SHM) sensor node based on the Alto platform by the implementation of a new energy source or the integration of an innovative sensing element.

Each team will start from a baseline configuration of the Alto board, which is provided with:

- a default energy source: a solar panel connected to the on-board power management system,

- a basic sensing element: a temperature probe,
- a reference firmware performing periodic data acquisition (one measurement per minute) and storing the data locally on a microSD card.

From this initial setup, teams are required to propose and implement improvements at the hardware level. Two main development strategies are offered:

- **Strategy A – Energy Source:**
  Design and implement an alternative or complementary energy harvesting solution based on energy sources available in the environment of a structure (e.g. mechanical, thermal, luminous, electromagnetic). The goal is to power the node and/or recharge its energy storage element (battery or supercapacitor), while improving overall energy autonomy.
- **Strategy B – Sensor Integration:**
  Integrate a new sensing element relevant to SHM applications (e.g. piezoelectric sensor, strain gauge, MEMS sensor), with particular attention to minimizing the energy consumption of the acquisition chain while maintaining exploitable signal quality.

In addition to these hardware modifications, teams are allowed to adapt the embedded software (e.g. acquisition strategy, sampling rate, duty cycle, data handling) in order to optimize the global energy balance of the system and ensure coherence between hardware choices and system-level performance.

3. Tools: The Alto Board

Participants will validate their solutions on the Alto development board, a hybrid platform designed for fine energy management and industrial IoT. It offers total flexibility thanks to its advanced architecture:

- Multi-Source Power Management: The board integrates three separate conversion stages to adapt to all potential sources:
  - Ultra-Low Power Harvesting (TI BQ25570): For very low sources (e.g., thermoelectric generator, piezoelectric, solar cells, rectenna), with cold start ability from 0.6 V (Vin < 5.5 V).
  - Standard Input (TI BQ24074): For conventional 5 V sources (USB) or regulated sources (4.4 V – 6.4 V).
  - Solar MPPT (TI BQ24650): A charger with maximum power point tracking for solar panels (5 V – 28 V, max 33 V).
- Acquisition Interface: The node has an Analog-to-Digital Converter input with specific technical constraints:
  - Voltage Range: 0 V to 3.3 V
  - Resolution: 12 bits
  - Sampling Frequency: 10 Hz to 1 MHz (enabling the detection of guided waves or high-frequency vibrations)
- Hybrid Storage: The system allows energy to be stored either in a Li-Ion battery (KeepPower 2600 mAh, 3.7 V supplied) or in a capacitive reservoir for fast cycles (10 F supercapacitor).
- I2C input
- Embedded Intelligence: Based on a programmable ESP32 and STM32 duo. Basic firmware will be provided to manage acquisition, allowing teams to focus on hardware innovation.

The teams will receive:

- an Alto card with a basic program for acquisitions
- the source code for the various elements of the card
- Alto Board Electrical Diagram

4. Steps

- Beginning of March: remote meetings gathering organizers and all teams on subject 3
- July 1st: deadline for submitting a two-page methodology and results summary
- July 9th: presentation of results and live demonstration during a plenary session

5. Expected results

The teams are expected to improve the hardware platform by increasing its energy autonomy through energy harvesting to enable long term deployment and/or by including new sensing capabilities without significantly compromising the energy efficiency. Any other additional proposals that enable a reduction in global energy consumption –with equivalent performance and functionality– will be appreciated.
The teams should propose metrics to evaluate the performances of their implementation.

The evaluation criteria are the following:

- 40 %: Quality of the scientific approach, clarity and effectiveness of the presentation, quality of the discussions with the jury
- 40 %: Quality of the results obtained and presented/demonstrated during the special session
- 20 %: Innovation and expected impact in the field

The teams are encouraged to share their work under open-source licenses and to publish their results after the conference. However, this is not mandatory and the organizers and other teams will not have access to proprietary element.

6. Organizers: Université Gustave Eiffel, Capturia and LAAS-CNRS

Contacts:

- Arthur Bouche: arthur.bouche@univ-eiffel.fr
- Vincent Le Cam: vincent.le-cam@univ-eiffel.fr
- Reunan Le Noc: reunan.le-noc@capturia.fr
- Gaël Loubet: gael.loubet@laas.fr