Self-triggered ECObattery TAGS for instant and ubiquitous event detection - ECOTAGS

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ABSTRACT

The Internet-of-Things (IoT) entails the deployment of a wide network of wireless nodes continuously consuming energy to monitor their surroundings. Contrarily to the current IoT paradigm, ECOTAGS consumes zero power until an alarming event takes place, as it takes advantage of the phase transition of a material to monitor a relevant physical events. A fire-detecting prototype has been developed as a demonstrator of this new concept. ECOTAGS reacts to a temperature rise by using a material that triggers the activation of a single use paper-battery, whose power is used to send a wireless alarm signal to a remote receiver.

Keywords: Internet-of-Things, self-powered sensor, fire detector, temperature sensor

1. INTRODUCTION

ECOTAGS project aims to develop a new paradigm of assessing alarm monitoring in wireless nodes with a zero-energy consumption strategy.

Despite all the efforts directed to develop low-power sensing and communicating electronic devices, the upcoming implementation of the Internet-of-Things (IoT) scenario will entail a dramatic increase in the energy needs that will not be met with the solely use of portable batteries. Moreover, many of the IoT systems are intended to surveil single unwanted events such as water flooding, fire, vacuum breaks, toxic gas presence, etc…that take place seldomly along the operational life of the device. This means that most of these systems make use of electrical power to monitor continuously the absence of relevant events.

The disruptive character of the ECOTAGS is based on the transformation of current power-consuming continuous monitoring of a physical magnitude - such a temperature – to a self-triggered strategy that consumes absolutely no power until relevant information from the ambient is needed to be either stored and/or reported.

As a realization example of the zero-power monitoring strategy, a prototype of a small tag able to detect whether the ambient temperature rises above a pre-determined threshold has been developed. The surpassing of the target temperature activates the system, which releases a wireless signal that can be received at a distance of several meters. This configuration makes the system ideal as a fire detecting device although other interesting applications such as temperature monitoring along the cold chain are also promising.

2. STATE OF THE ART

It is undeniable that the fulfilment of the Internet-of-Things scenario, which is enabled by multiple energy autonomous systems that are comprehensively capable of sensing, diagnosing, deciding and actuating in a communicative and collaborative way, is leading society towards a digitalized new era. [1] Although IoT is still in the early stages of growth, current estimations point to more than nine billion connected devices around the world. This number is expected to increase exponentially, with estimates ranging from 25 billion to 50 billion devices in 2025. [2] Energy autonomy of sensing nodes has been largely identified as a key enabling feature of digital scenario and till now, significant financial and technological efforts to obtain sustainable power sources able to harvest energy from the environment (light, heat and movement) have been invested during the last decade. Yet, state-of-the-art autonomous sensing devices make use of batteries, as they are the sole candidates to provide sufficient power output in a reliable manner. However, it is unclear whether the energy needs of billions of power hungry devices are to be satisfied with current battery technologies as demands forecasts in growing sectors like transportation and computing seem to compromise the availability of lithium and other key battery materials.

3. BREAKTHROUGH CHARACTER OF THE PROJECT

ECOTAGS proposes a paradigm change in environmental monitoring. State-of-the-art monitoring systems still rely on the sensor – electronics – battery paradigm, in which the devices constantly drain power from the battery to function. Although the development of ultra-low power micro and nanosystems has allowed reducing significantly the energy required per device, the expected proliferation in the near future of millions of devices renders an unsustainable scenario both energetically and environmentally.

ECOTAGS proposes the use of physical/chemical responsive materials to sense relevant changes in the environment at zero power consumption. In this approach, absolutely no power would be consumed by the electronic modules of the system, as it is the material itself that gathers information from the surroundings. In the particular case presented in ECOTAGS, phase transition from solid to liquid of different materials is used to monitor a temperature threshold that would account for the ignition of a fire. This transition is used as a physical barrier to activate a liquid-activated paper battery that starts to function upon the arrival of the fluid. It is clear that this simple idea has the potential to be transferred to monitor temperature in many application sectors as well as to monitor other physical/chemical parameters that require constant surveillance.

4. PROJECT RESULTS

The implementation of ECOTAGS prototype during ATTRACT Phase 1 consisted of three main developmental stages: (i) the temperature sensitive-battery, (ii) the IoT module, and (iii) integration of components into an operational demonstrator.

4.1 Temperature sensitive-battery

The key component of the ECOTAGS system is a liquid activated paper-based battery (from Fuelium) customized with a blister containing the liquid for the battery activation (Fig. 1a). The blister is sealed with a thin layer of a temperature responsive material that interface with the battery inlet membrane. When the ambient temperature crosses the phase transition temperature of that material, the blister releases the liquid content and activates the battery, triggering-on the IoT

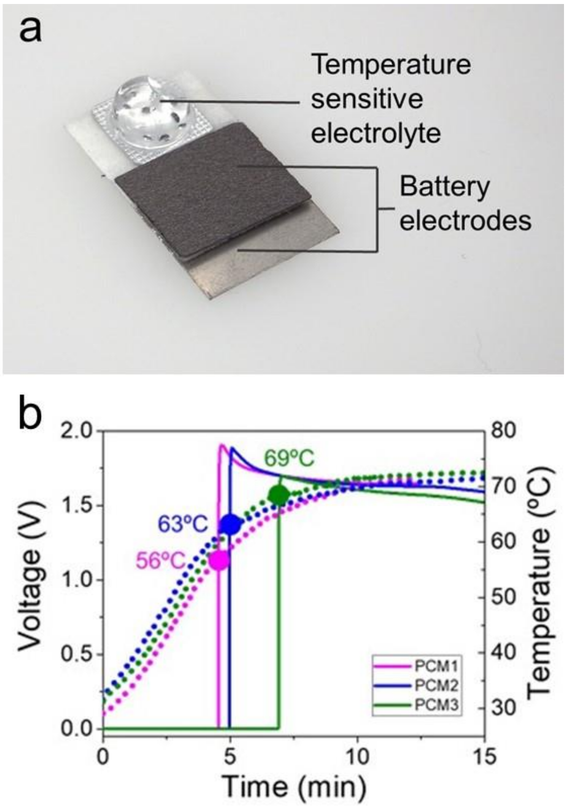

Fig. 1. (a) Picture of the temperature sensitive-battery element. **(b)** Output voltage of temperature sensitive-batteries triggered at different temperatures. Solid lines represent battery voltage evolution; dotted-lines account for the measured temperature near the battery. Colored temperature values indicate the ambient temperature at which the batteries with different PCM's were activated.

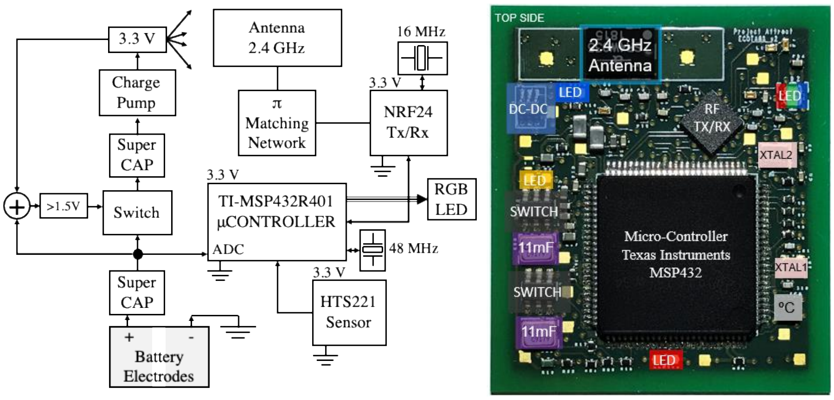

Fig. 2. Diagram of the different electronic components integrated in the final version of ECOTAGS protype (left) and picture of the electronic assembly as-mounted on a PCB.

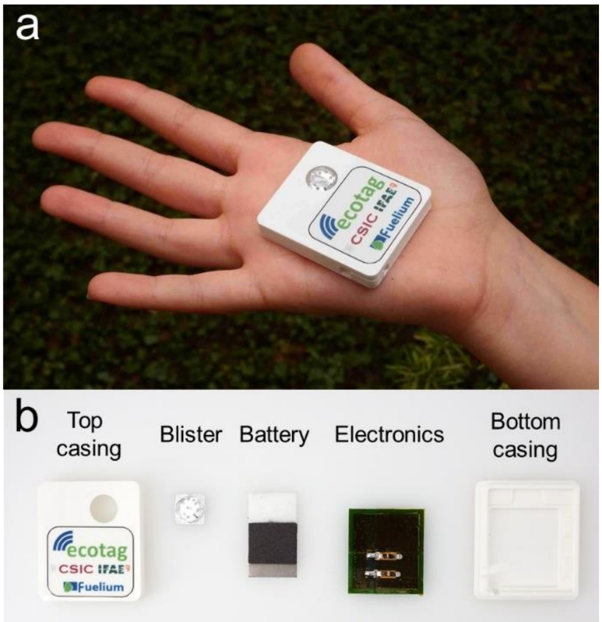

Fig. 3. Photograph of all components in the ECOTAGS demonstrator.

electronics module. The phase change material (PCM) can be chosen to operate at different temperature ranges, with different phase transition temperatures, as shown in Fig. 1b. The figure presents the operation of temperature sensitive-batteries customized to activate at three different temperatures. As it can be seen, the measured battery voltage in each device rises when the surrounding temperature reaches the PCM phase transition. The capability to define the trigger temperature based on the selection of the PCM makes this approach a versatile solution for different applications where temperature is a key factor (see Section 5.3).

4.2 Electronics module

The electronics module realizes three main functions: first, the battery's voltage regulation and boost up to 3.3 V in order to bias the commercial components of the system; second, the monitoring of the temperature and the humidity of the tag; and third, the connection to a master station using a dedicated point-to-point communications protocol. The battery management section includes a delayed and battery-level enabling switch to accommodate for the battery's activation dynamics and to provide power supply to all the electronics synchronously. A microcontroller from Texas Instruments' MSP432 series manages the operation of the complete module. Every two seconds, it reads the measurements of a HTS221 temperature and humidity sensor located in the board and sends the readout to an RF transceiver from Nordic Semiconductors' NRF24 series that communicates to a master in the ISM band of 2.4 GHz. Figure 2 shows a diagram of the different electronic modules developed and/or integrated in the project and a picture of the final version of the PCB.

4.3 ECOTAGS demonstrator

The temperature-sensitive activated battery and the electronics module have been assembled manually in a plastic package of several squared centimetres. Figure 3 shows a picture of the demonstrator (a) and exploded view of all its components (b).

The validation of ECOTAGS device operation is shown in Figure 4. An ECOTAGS was place inside of an oven that was set to increase its temperature from 25 ºC to 70 ºC (oven temperature plotted as red line). For testing purposes, the battery voltage was measured and an external thermocouple was inserted inside the ECOTAGS device to record the temperature evolution (magenta line). The ECOTAGS was customized to be triggered when temperature inside the device exceeds 55 ºC. As it can be seen, the battery voltage rises when the device reaches the set temperature. Once activated, the sensors embedded in the ECOTAGS electronics module start recording the temperature, processing information and sending data wirelessly. A custom-made data receiver processes the information sent by the ECOTAGS. The dotted blue line represent the temperature data received, which coincides with the temperature recorded with the external thermocouple. The figure insets show the fluctuations of battery voltage due to the power consumption of the circuit during standby, data acquisition and data transmission.

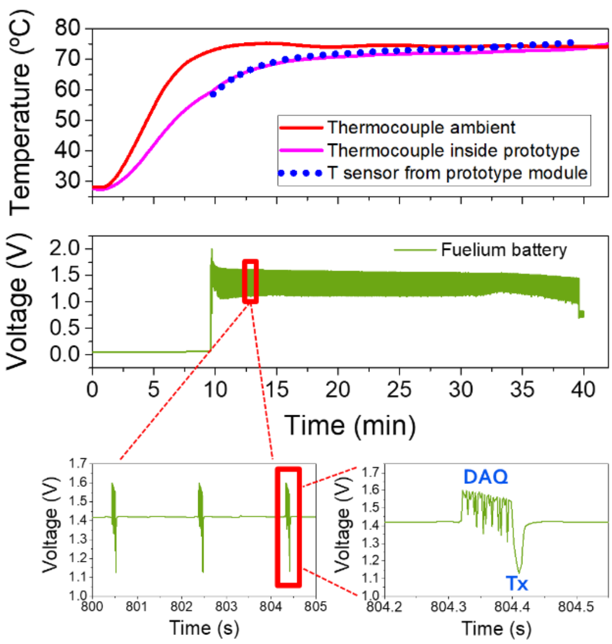

Fig. 4. Experimental validation of ECOTAGS activation upon an alarming rise of ambient temperature.

5. FUTURE PROJECT VISION

5.1 Technology Scaling

ATTRACT Phase 1 funding has allowed the ECOTAGS concept to reach TRL 4. In a next step, state-of-the-art manufacturing technologies will allow obtaining a self-triggered sensor with a tag format that will be composed of a flexible substrate, the PCM in a thin laminate format, an encapsulated electrolyte, a paper-based battery, a RF antenna and a microelectronics module. All the tag components will be fabricated with printed and roll-to-roll manufacturing including hybridization of the electronics module, which will be integrated into a single microelectronics chip to reduce cost, area, consumption, complexity and environmental impact upon disposal. Figure 5 shows a schematic representation of a product-like vision of the ECOTAGS device.

The simplicity of the concept and the manufacturability of the final device would allow the consortium to reach a TRL 8 during ATTRACT Phase 2. As subsequent steps, and in parallel to manufacturing industrialization, the consortium plans to validate the correct performance of the current prototype in a relevant environment such as detecting the occurrence of a controlled fire in dedicated premises.

5.2 Project Synergies and Outreach

Our consortium consists of three partners with strong expertise in microelectronics (IFAE), flexible paper batteries (Fuelium SL) and rapid prototyping and printed electronics techniques (CSIC) that are perfectly capable of assessing the technical aspects required to take ECOTAGS to TRL7-8. Prototype design freeze and production line design will be outsourced to a local manufacturing processes consulting office. Silicon chip design for the electronics scaling up will be handled by an European industrial design house under the supervision of the microelectronics expert in the consortium (IFAE). Definition of product specs will be assessed in collaboration with experts and end-users. Fire Detection Tag specs will require assistance of technical consultants on Fire detection like the Fire Lab of the Polytechnic University of Catalonia [3], a multidisciplinary team with dedicated facilities that allow testing materials and devices under relevant conditions. Temperature monitoring in logistics specs are already being analysed in collaboration with the Catalan Packaging Cluster [4]. The cluster gathers the most relevant stakeholders in all of the packaging value chain (including manufacturers and end-users).

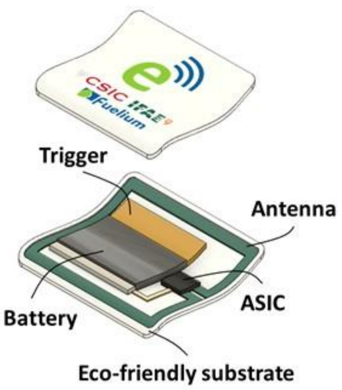

Fig.5. Schematic representation of a roll-to-roll mass manufactured ECOTAGS device.

The envisaged dissemination activities of ATTRACT Phase 2 project are the following:
Conferences: consortium team members will present the results of the project at international conferences of relevance, such as LOPEC, CES or IOT World Congress.
Scientific publications: wide dissemination of relevant research results in the scientific community can most effectively be reached by publications in high-ranked journals relevant for the field. Open Science policies will be encouraged.
Press releases: Details regarding project achievements will be disseminated via press releases through the participating institutions.
ECOTAGS website: a public website will be developed to provide information for stakeholders.

5.3. Technology application and demonstration cases

ECOTAGS can be applied to different areas beyond fire detection. The areas in which the device could make an impact are cold-chain monitoring in retail sector (pharma, chemical, food) and temperature monitoring on individuals for safety purposes (firemen or other workers under severe thermal stress). These applications will bring clear benefit to different Societal Challenges such as *Health and Wellbeing* and *Security of Food and other Perishable Goods*. The demonstration cases that are to be developed in ATTRACT-Phase 2 are the following ones:

1. Object-centred fire detector
2. Cold-chain monitoring tag for perishable goods
3. Temperature alarm monitoring for individuals safety

5.4. Technology commercialization

The startup company Fuelium, already in the project consortium, will drive the market uptake of the ECOTAGS technology. Once TRL7 is achieved, the consortium aims to seek for co-development contracts with industrial partners already stablished on the application sectors described before. These early commercial alliances are expected to short time-to-market and deliver a product that fulfils specific needs of a client. This route will eventually be reinforced by nondilutive funding and venture capital if setting up fabrication facilities is needed. Ideally, VC should be connected with the business sectors in which Fuelium would like to enter as it is important that they offer not only financial investment but also strategic/networking support.

5.5. Envisioned risks

The Project consortium has identified two different risks that could prevent the ECOTAGS prototype to reach the market:

- *Regulatory entry barriers*: collaboration with students (see 5.6) has allowed identifying significant regulatory requirements in the fire detector sector. For this reason, the consortium will consider to enter in applications with a less demanding regulation where the device offers immediate advantages (packaging). New applications like personal safety where there are no competing solutions (and therefore regulations are still to be defined) are more likely to succeed.

- *IP Protection*: the consortium will file a patent application to the EPO. Despite a preliminary patent search has not yielded significant pre-existing devices such a ECOTAGS, the uncertainty of achieving IP ownership of the technology will not be removed until the final patent granting.

5.6. Liaison with Student Teams and Socio-Economic Study

During Phase 1, ECOTAGS project was selected as a case study for the Young Innovator & Entrepreneurs program. The consortium obtained assistance from the Fusion Point Spanish hub, with students from business and law (ESADE), engineering (UPC) and design (IED Barcelona Design University). The team carried out market research and customer discovery activities, and provided the consortium with some interesting insights like the identification of the regulatory barriers in the fire detection arena as a future project threat or the suggestion of the application of ECOTAGS technology to a personal temperature alarm tag for firefighters. In view of the potential of this initiative, during ATTRACT Phase 2, ECOTAGS aims to get further support in business model definition and product design activities.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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