SARMENTI: Smart multisensor embedded and secure system for soil nutrient and gaseous emission monitoring

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1 Introduction and objectives

Demand for sustainably produced food is driving current strategies for intensification of the agricultural sector worldwide. To meet these challenges farmers will need to adopt a whole-farm approach to resource efficiency. They will increase their productivity with a better application of knowledge per hectare. Optimising soil fertility will enable farmers to maximise their productivity and profitability with higher grass and crop yield and quality.

SARMENTI will deliver more accurate measurement of soil nutrient concentration and gaseous emission to improve nutrient use, maximise crop growth and minimise environment losses. The consortium will develop the next generation of reagent free sensor platform that will monitor in real-time soil nutrient supply. This platform will also measure local environmental conditions, especially harmful gas production just above the ground.

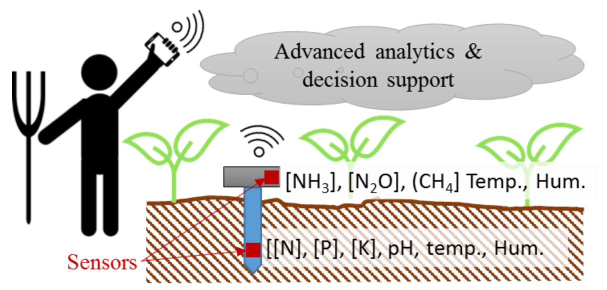

Figure 1: SARMENTI concept

With the SARMENTI system, farmers will collect in-situ digitised data to perform appropriate and timely actions regarding fertilisation leading to environmentally friendly and economically sustainable farming.

Besides soil nutrient and gaseous emission monitoring in farming, other applications include water quality monitoring for surface, ground and drinking waters.

2 SARMENTI system ambition

Today soil analyses are neither real-time nor in-situ, thus reducing the value of the soil test results back to the farmer. *SARMENTI nutrient sensors* will measure in-situ, high temporal resolution soil nutrient concentration that a farmer or advisor will interpret to implement fertiliser management strategies. SARMENTI primary use-case focuses on soil nutrient measurement for major nutrients (N and P) that can be calibrated with conventional extractive methods and translated into meaningful agronomic measures of plant available nutrients required by the crop.

Nitrogen is crucial to life on earth, and the nitrogen cycle is one of the most important nutrient cycles for natural ecosystems (cf. Fig. 2). Unfortunately, farming activities can disturb the equilibrium of this cycle: excessive application of fertilisers causes water pollution, eutrophication, acidification and greenhouse gas effects due to gaseous emissions, in particular, NH_3, N_2O and CH_4 that are greenhouse gases with higher warming potential than CO_2. Note that CH_4 released by the soil is generated by the decomposition of manure under anaerobic conditions. Nitrogen from inorganic fertilisers, animal waste, sewage sludge applications, biological N-fixation and crop residues can be converted to nitrous oxide in the soil [ES17]. By *monitoring the emission of NH_3, N_2O and CH_4*, at low cost, SARMENTI's end-users will *monitor the nitrogen cycle* to avoid losses via denitrification, and the proper decomposition of manure.

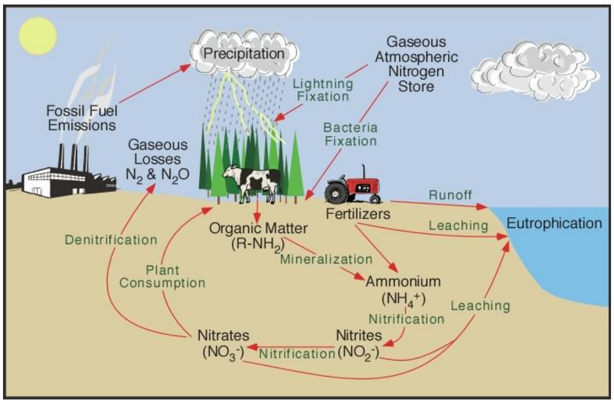

Fig. 2: Nitrogen cycle [PG09]

As the IoT Security Foundation states, "*Security is a critical element of IoT deployment, yet it is too often neglected in the development of systems*" (https://iotsecurityfoundation.org/). The European Union Agency for Network and Information Security (ENISA) highlights several threats in the "Baseline Security Recommendations for IoT, in the context of Critical Information Infrastructures" [ENISA17]. The ones with impact in agriculture sensing IoT systems are:

(i) nefarious activity/abuse on IoT devices, e.g., malware, exploit kits, modification of information;
(ii) eavesdropping/interception/hijacking on the interconnection network;
(iii) outages and failures/malfunction, e.g., failure of devices, software vulnerabilities.

SARMENTI addresses *cyber-security right from the start of the project*, taking into account the application and use-case requirements in terms functionality, cost, power, and of relevant threats and vulnerabilities that should be protected against. Instead of stacking-up countermeasures in the design, we will detect attacks and raise alarms, which is in line with the general trend of including detection and reaction as cyber-security protections.

3 First architecture attempt

The development of the SARMENTI system requires Research and Innovation in nano-electronics, electrochemistry, micro-electro-mechanics, biotechnologies, chemistry, data analytics, communication, embedded software, edge computing, and cyber-security for the IoT. The SARMENTI node consists of three devices (see Fig. 3):

(i) the *Soil Probe*, buried in the soil, contains electrochemical sensors – Nanowire sensors and potentiometric sensors, more precisely Ion Selective Electrodes (ISE). It also measures pH, moisture and ground temperature. The sensors are aggregated in a common multi-parametric miniaturised platform encapsulated in a membrane that will act as a passive microfluidic pump. This latter will be based on superabsorbent polymers coupled to a capillary flow water pump. This aspect constitute one of the major challenge of the project;

(ii) the *Air Probe* monitors environmental conditions just above the ground, including temperature, humidity and concentration of Ammonia (NH_3), which has an adverse impact on human health, and Nitrous Oxide (N_2O) and Methane (CH_4), both of which are Green House Gasses with a global warming potential 310 and 21 times higher than the Carbon dioxide (CO_2), respectively [ENV10];

(iii) the *Smart Data Logger* collects data from both probes and transmits them directly to the cloud either through a mobile device (via Bluetooth Low Energy – BLE) or a concentrator with LoRA or SigFox connectivity.

The *Smart Data Logger* will offer IoT capability to the SARMENTI system. Back-end servers will store the data collected by the node and analyse them with *advanced analytics*, taking into account weather forecast. The farmer will then receive advices about the best options for fertilizing the crops.

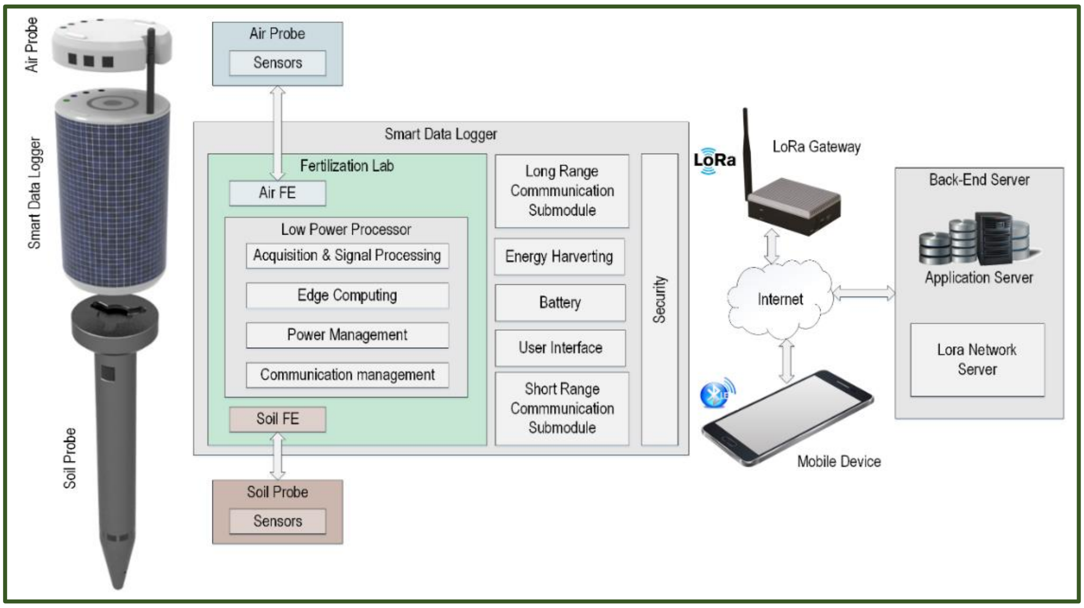

Fig. 3: Sarmenti smart integrated system architecture (first attempt)

A special attention will be paid to **Legal aspects** to ensure that the SARMENTI IoT node is consistent with EU and National regulations.

4 Sarmenti development

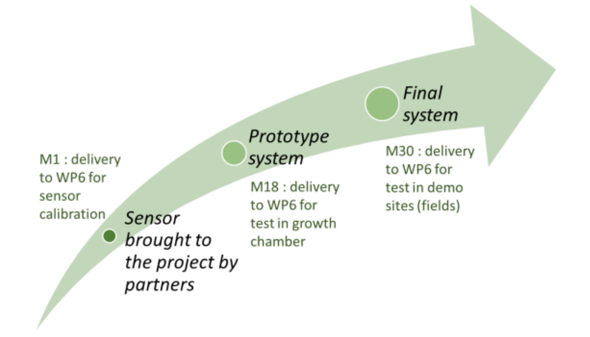

Fig. 4: SARMENTI development stages

End-users are part of the SARMENTI consortium to guarantee that the SARMENTI system truly answers their needs. SARMENTI is developed in two stages (see Fig. 4):

- the first stage has started with the collection of users' needs and requirements and the revision of the first architecture attempt. In parallel, the sensors brought to the project by partners are optimized for the application and, where necessary, new features and functionalities are added. This stage will deliver a first prototype at month 18 (June 2020) that will be **tested in laboratory-based growth chambers**;
- during the second stage, the test results will feed back the sensor developments and a second prototype will be delivered at month 30. Then, SARMENTI end-user partners – located in France, Ireland and Romania – will evaluate the SARMENTI system robustness and reliability at sensing soil nutrient concentrations and gaseous emissions **across a range of field sites** representative of pedoclimatic conditions and for different **crop types** in Europe.

5 Summary

The SARMENTI project will improve performance of fertiliser application in the field of environmental monitoring, providing significant benefits to the citizens and environment by developing a sensing solution for low-cost, low-power, *in situ real-time* detection of pH, phosphate, nitrate, nitrite and ammonium ions present in soil.

The system developed will also monitor environmental conditions over the soil including the concentration of ammonia and nitrous oxide, or other gases of interest.

At present, no commercial solution exists for in-situ real-time detection of nutrients in soil and monitoring of gaseous emission just above the soil.

6 Acknowledgements

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7 References

[ENISA17] "Baseline Security Recommendations for IoT", https://www.enisa.europa.eu/, ENISA, 2017

[ENV10] Fact Sheet on "The EU Nitrates directive", 2010, https://eur-lex.europa.eu/

[ES17] EuroStat http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_greenhouse_gas_emissions, "Agri-environmental indicator - greenhouse gas emissions", 2017

[PG09] http://www.physicalgeography.net/fundamentals/9s.html