DOI 10.5162/EUROSENSORS2025/T4.3.2

A low-power wireless sensor platform for real-time monitoring of pH and nitrate in the soil

Célia Boko[1], Elise Saoutieff[1], Paul Fourcade[1], Vincent Elhorga[1], Arthur Ohl[1], Iris Vogeler[2], Henk Smit[2], Nivedha Surendran[3], Axel Wille[3], Han Shao[4], Alan O'Riordan[4], Lukasz Kulas[5], Patryk Kalkowski[5], Henrique Trindade[6], Lukas Kohl[7], Safi Ullah[7]
[1] Univ. Grenoble Alpes, CEA, Leti, Grenoble, France
[2] Christian-Albrechts-Universität, Kiel, Germany
[3] Fraunhofer Institute for Electronic Microsystems and Solid State Technologies, Munich, Germany
[4] Nanotechnology Group, Tyndall National Institute, Cork, Ireland
[5] Gdansk University of Technology, Gdansk, Poland
[6] University of Trás os Montes e Alto Douro, Quinta de Prados, Portugal
[7] University of Eastern Finland, Kuopio, Finland
celia.boko@cea.fr

Summary:
The low-power sensing platform proposed by the FAMOSOS project is intended to be a wireless, low-power and multifunctional system for real-time soil monitoring. We developed a cost-effective *in situ* sensing system for nitrate concentrations in the soil solution along with soil moisture, pH and temperature. Soil water samples are collected through a porous ceramic probe with a piezoelectric micropump, analysed through on-chip electrochemical measurements, communicating with a LoRa-based underground network. This paper presents the system design as well as the results from the first field test.

Keywords: soil monitoring, innovative sensors, low-power, real-time, wireless underground sensor network.

FAMOSOS Background, Motivation and Objective

Soil is essential to human health, the economy, and environment, playing a crucial role in the water, nutrients, and carbon cycles. However, soil degradation is a growing concern, with significant implications for climate change, agriculture, and biodiversity. In response, the European Soil Strategy 2030 aims to restore and protect soil by 2050 through targeted actions and the proposed Soil Monitoring Law [1]. One of the main challenges in soil management today is the lack of real-time, *in situ* technologies for effective soil monitoring. The FAMOSOS (Farm Monitoring via Real-time SOil Sensing) [2] project addresses this challenge by developing a low-cost, real-time electronic system designed to help farmers optimise fertiliser use, reduce greenhouse gas emissions, and minimize water pollution. The system aligns with EU objectives for sustainable soil health and would equip farmers with essential tools to make informed decisions.

FAMOSOS System

FAMOSOS introduces an innovative IoT-based electrochemical sensor platform, known as the "beta system", designed for real-time, *in situ* data acquisition. This system consists of:

- an electrochemical sensor composed of gold and platinum nanowires with various electrodeposited overlayers, enabling selective and multiplexed detection of multiple analytes (NO_3^-, pH)
- a temperature and moisture sensor (TEROS 54, METER Group) for monitoring soil environmental conditions
- a porous ceramic probe combined with a piezoelectric micropump for extracting soil solution
- a low-power electronic board integrating an Analog Front End (AFE) for driving electrochemical and moisture/temperature sensors
- an antenna for wireless LoRa data transmission
- an SD card for storing sensor data

A schematic view of the FAMOSOS system, specifically the electronic architecture and its interface with other components, is shown in Fig. 1.

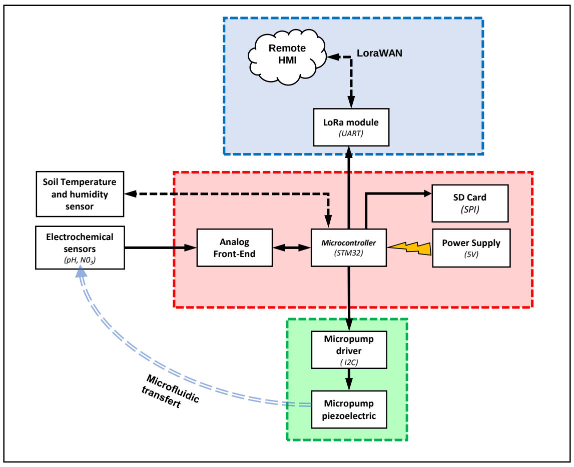

Fig. 1. Schematic beta-system design

AFE Electronic

The previous architecture features an Analog Front End (AFE) that integrates an STM32 microcontroller unit (MCU) and a portable potentiostat from CH Instruments. It was designed to support both innovative analog sensors (pH, NO_3^-) and commercial digital sensors (temperature and moisture) while also controlling the micropump. The electronic board enables sensor data acquisition, local data storage on an SD card, and LoRa-based data transmission. Fig. 1. highlights the board (indicated by the red rectangle), including its power management circuit for IoT and other connectable components. The beta system, embedded in a watertight casing and designed for outdoor field testing is shown in Fig.2.

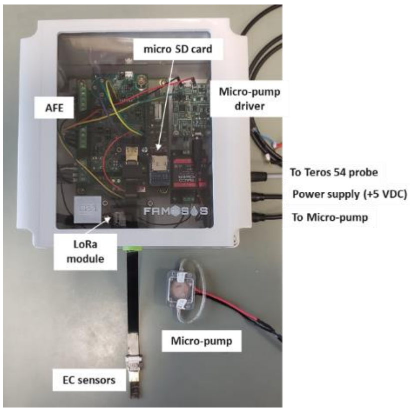

Fig. 2. watertight casing for beta-system electronic board

The AFE collects raw sensor data, which is then converted into physical values by the microcontroller. The data is formatted using a custom protocol and transmitted to the cloud via LoRa. The wireless system includes underground base stations and end devices. To minimize power consumption, sensors and peripherals remain in standby mode and wake up only when data transmission is required.

Results

The FAMOSOS concept was demonstrated through initial successful laboratory tests, followed by the beginning of the beta-system deployment in the field. Subsequent trials are being conducted on a site in Portugal, involving different crop rotations and various N fertilization levels.

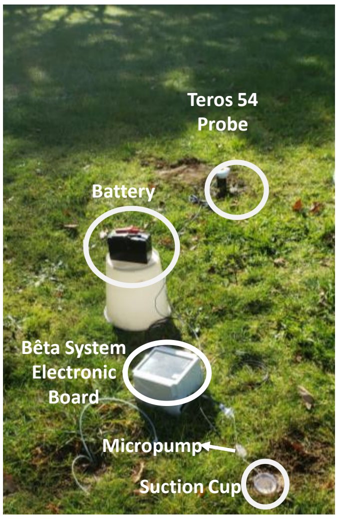

Fig. 3. Beta-system in Portugal test field

By developing a tool which provides farmers with real-time information on the soil N status, FAMOSOS will make a significantly contribution to enhancing soil understanding to improve management practices such as optimizing N fertilization strategies. This will enable more sustainable agricultural production through increased nitrogen use efficiency and supporting environmental health by decreasing N leaching and N_2O emissions

References

[1] EU Soil Health: [Online]. Available: https://environment.ec.europa.eu/topics/soil-health_en (accessed: Apr. 15 2025)

[2] E. Saoutieff, P. Fourcade, C. Boko, V. Elhorga, S. Boisseau, I.Vogeler et al., « Advanced sensor system dedicated to real-time soil monitoring», EUROSENSORS XXXVI 2024, pp 269-270

Acknowledgements

The project is funded as an EJP-SOIL external project by the French National Research Agency (ANR) under grant ANR-23-SOIL-0002-04, the Irish Department of Agriculture, Food and the Marine under grant agreement No. 2022EJPSOIL202, the Finnish Ministry of Agriculture (4400T-0569), and the German Federal Ministry of Education and Research BMBF under grant number 031B1377B.