Doctoral Program in Electrical, Electronics and Communications Engineering (37th cycle)

Smart Electronic Systems for Precision Agriculture

Summary

Candidate: Mattia Barezzi

Supervisor: Danilo Demarchi

The agrifood sector is responsible for 26% of global greenhouse gas emissions, representing a significant contribution to climate change. Furthermore, careful management of resources and agricultural techniques is crucial to mitigating the effects of this phenomenon.

This dissertation provides an overview of state-of-the-art electronic systems for crop monitoring, covering both remote and proximal solutions. A brief review of commercial and research-grade sensors capable of directly detecting the health status of plants from within the plant itself is also presented.

The main focus of this doctoral work is the development of electronic systems for precision agriculture. In particular, one branch is focused on optimizing water usage. The other branch aims to explore a novel technique based on in-vivo electrical stem frequency measurement, where the plant becomes an active component of the feedback loop and exploits the conductive channels of the plant itself. This innovative method estimates plant health by measuring in-vivo electrical stem frequency, a value that is highly correlated with the stem impedance of the plant, offering a simple indicator of plant status.

One section details the development of a fully automatic drip irrigation system for high-yield professional orchards, utilizing advanced capacitive matric potential sensors (Fig. 1). This approach has been facilitated by advancements in the internet of things field, where cost-effective electronic devices equipped with sensors and processing capabilities can communicate over the Internet.

The study addresses the mitigation of abiotic stress caused by improper watering, delivering quantitative results (water withdrawals, stem growth variations, crop yield/tree, crop size, firmness, dry matter, starch) and establishing a framework to demonstrate how agritech solutions can significantly reduce water consumption while maintaining fruit yield and organoleptic quality.

Other sections introduce the novel stem frequency measurement technique for precision agriculture. This method offers several advantages: the output is a simple square wave where the frequency variation encodes the health status of the plant. As a result, the need for analog-to-digital converters is eliminated, enabling the creation of low-power, low-cost, and easily integrable electronic systems.

The development of embedded electronic systems based on in-vivo electrical stem frequency measurement is described. The sensor (also called WAPPIMP) was deployed in an observation campaign (Fig. 2) to monitor in-vivo electrical stem frequency alongside environmental and soil parameters in one of the professional orchard fields previously discussed, enabling the chance to observe the sensor in the most harsh environment in the agrifood context: open field. A discussion of the results is presented. Additionally, an evolved sensor (Fig. 3) was developed to estimate not only the in-vivo electrical stem frequency but also the signal amplitude in other points of the plant using the conductive channels of the plant itself, both serving as indicators of plant health. In a more advanced configuration, multiple in-vivo electrical stem frequency sensors could operate simultaneously using different carrier frequencies. A single receiver positioned, for example, at the base of the plant could then collect frequency data from all sensors and assess the signal attenuation along each path between the individual sensors and the receiver. The results of the experiment are discussed. This system was also prototyped on a new electronic platform comprising two boards: a core board, named LoRaTO, intended for future research activities, and a shield printed circuit board, named Global Plant Status Shield (GPSS), designed to extend the application of the technique beyond the laboratory. A description of the main features is discussed and a photo is shown in Fig. 4.

A separate section explores a simplified circuit topology (Fig. 5) to make in-vivo electrical stem frequency measurements even more integrable onto a microelectronics platform. This capability is not only valuable for research demonstrations in agriculture but also represents a fundamental requirement for practical applications. Achieving full integration would significantly reduce both size and power consumption, paving the way for a true plant-wearable system. The preliminary design steps for a low-power integrated circuit, employing a relaxation oscillator based on an inverting Schmitt trigger in a feedback loop with the plant stem, are presented, together with simulation results and a comparison of the potential energy-per-measurement savings against other techniques.

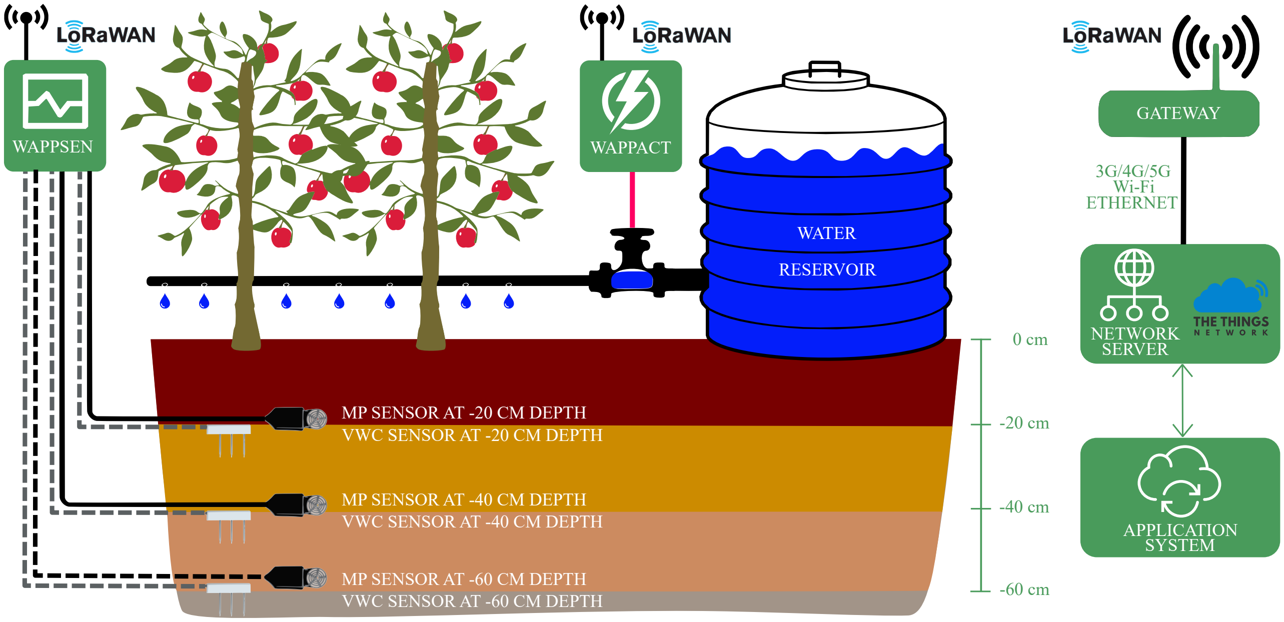

Figure 1: General system architecture for WAPPFRUIT project.

Figure 2: Stem frequency sensor installed in F1 farmer where the electrode distance is 5 cm. Exactly the same configuration has been used, except for an electrode distance of 15 cm in the two sites of F2 farmer. (Left) Zoom on electrodes connected in the stem of the apple orchard. (Right) Zoom on WAPPIMP stem frequency sensor board in the field.

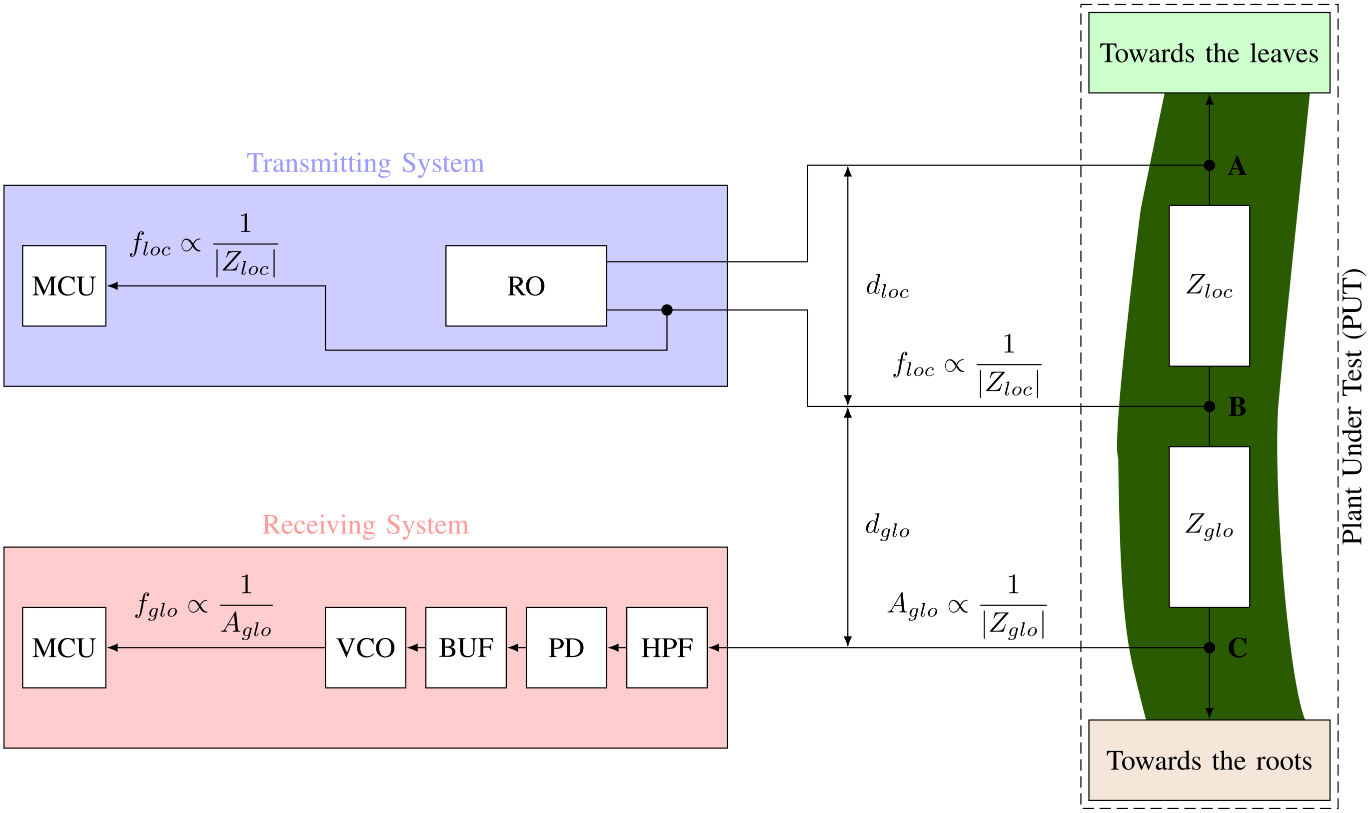

Figure 3: Block diagram of the sensor system used to measure both local and global impedance moduli of the Plant Under Test (PUT).

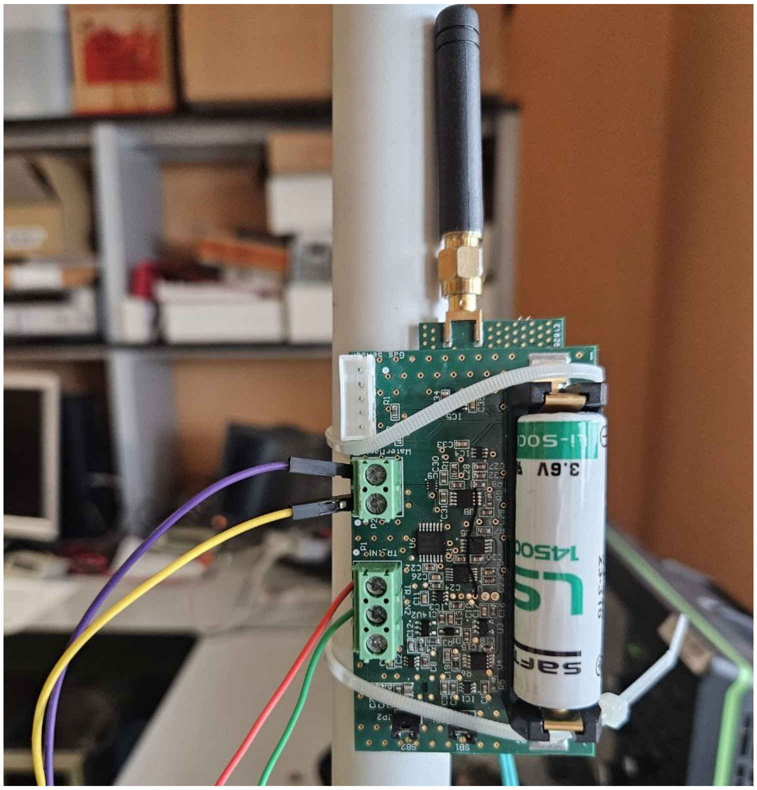

Figure 4: Detail of the new stem frequency sensor (LoRaTO+GPSS) in a test.

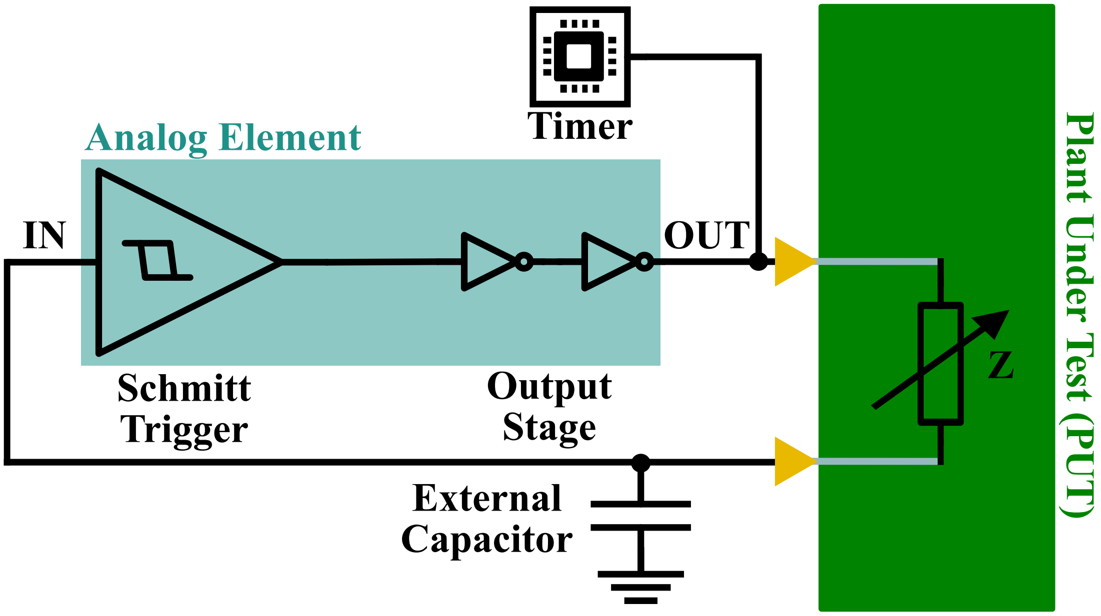

Figure 5: Relaxation oscillator scheme in a climate-smart agriculture application.