Giuseppe Pellizzi Prize
CLUB OF BOLOGNA

FEASIBILITY STUDIES AND ENGINEERING OF OPTICAL SIMPLIFIED AND STAND-ALONE DEVICES FOR AGRI-FOOD APPLICATIONS

Dissertation presented to University of Milan, ITALY

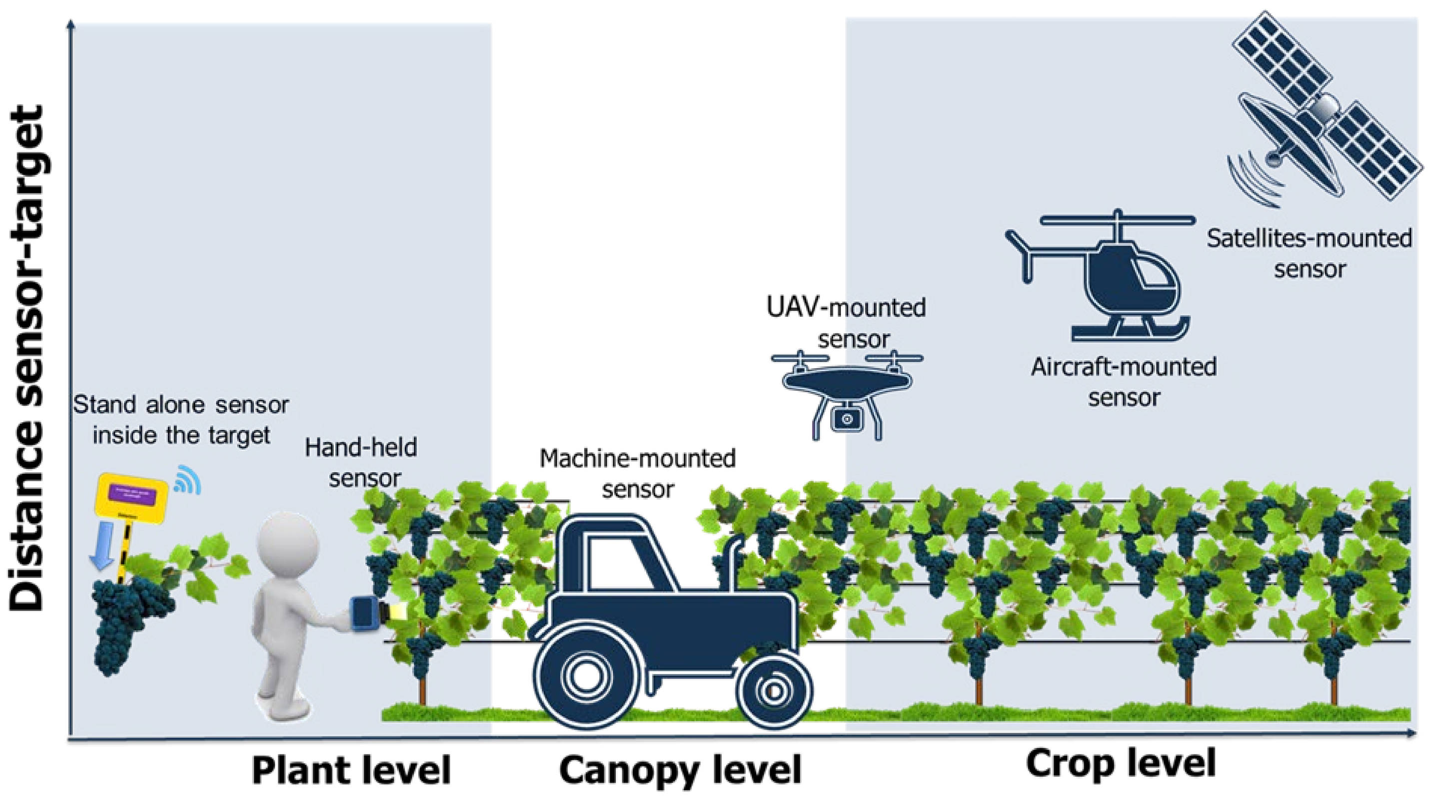
Alessio Tugnolo

Departmentof Agricultural and Environmental Sciences, Production, Landscape, Agroenergy (DiSAA). University of Milan, ITALY

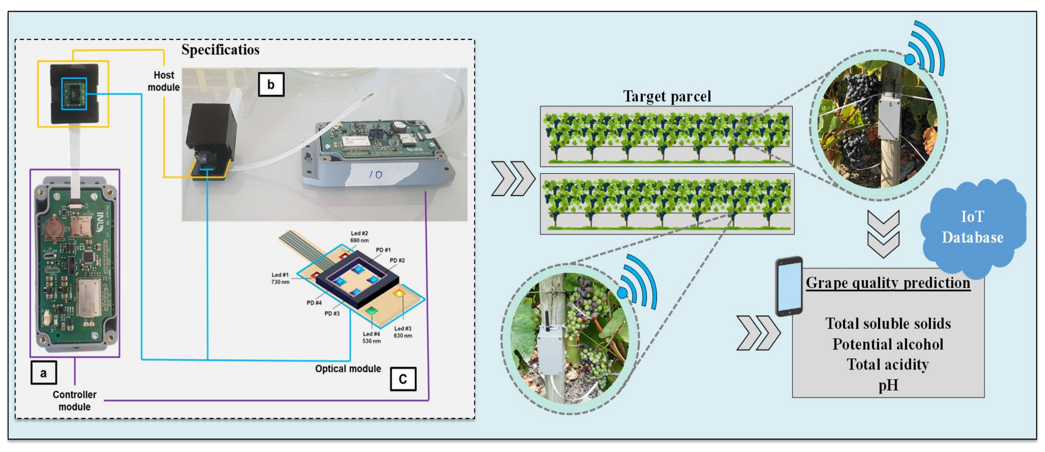
✉: alessio.tugnolo@unimi.it ☎: +39 3469442231

1 Introduction

Nowadays, the wineries' **trend is to bring the laboratory in field. Despite remote sensing (RS) is a landmark for the current agricultural sector, the latter has not been capable to fully embrace this technology in many real production circumstances**. Indeed, vineyards represent a real challenge for the application of RS technologies. This is due to the discontinuous nature of grapevine canopies and their moderate cover which causes noisy backgrounds and shadows influences on the measured reflectance signals. **Thus, the use of proximal sensing (PS) is still a convenient option. The consumer electronics industry** is driving the convergence of digital circuitry, wireless transceivers, and micro electro-mechanical systems (MEMS), which makes it possible to integrate sensing, data processing, wireless communication, and power supply into low-cost millimeter-scale devices. This **is leaving space to a completely new method of data acquisition and management using wireless sensor networks** (WSNs) **based on small battery-powered nodes**



2 Scope



This work focused on **the development of a fully integrated stand-alone optical device for grape quality monitoring directly in the field**. The main steps to fulfil the project purpose were:

a) Setting up of a miniaturized low-cost and stand-alone optical prototype composed by LEDs suitable for diffuse reflectance measurements, photodetectors (PDs, CMOS), sensors controller and power management;

b) Multivariate predictive models' development for the prediction of the main grape ripening parameters;

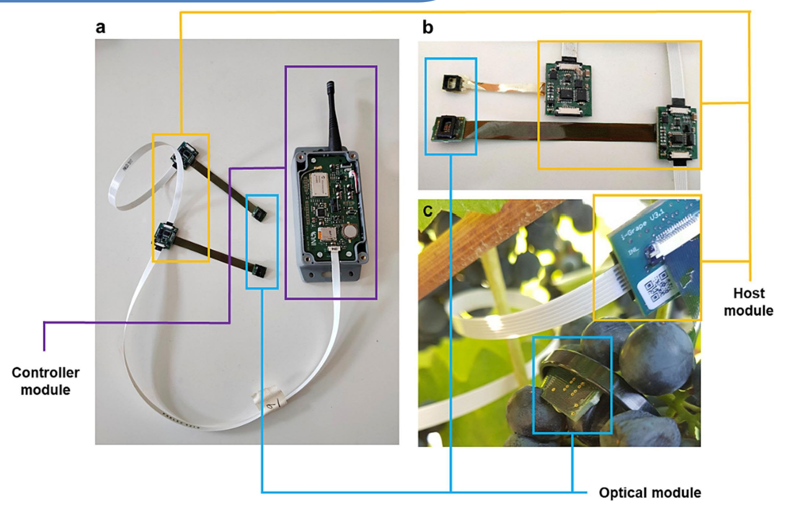
c) Test the prototype in field conditions.

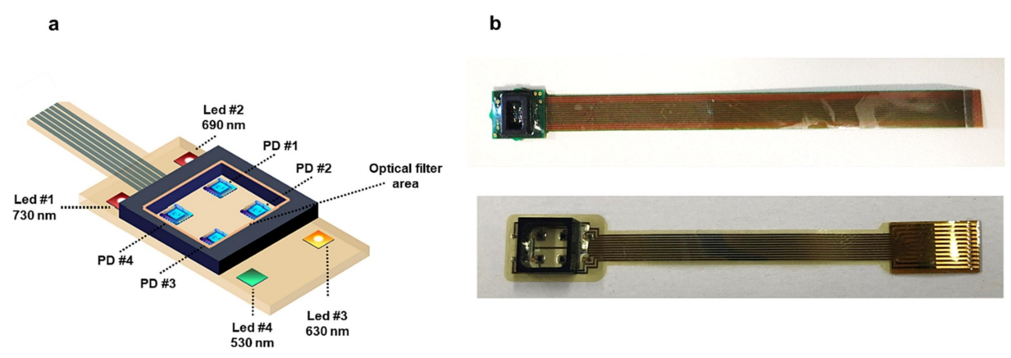
3 Materials and Methods

Sensor specs

The proposed autonomous spectral sensing system includes three complementary modules (Figure 2): (i) the **optical module**, which carried the optical sensing elements of the system, (ii) the **host module**, which carried the LED driver and the analog front-end, and (iii) the **controller modules**, which ensured the control, power management and IoT connectivity of the whole system.

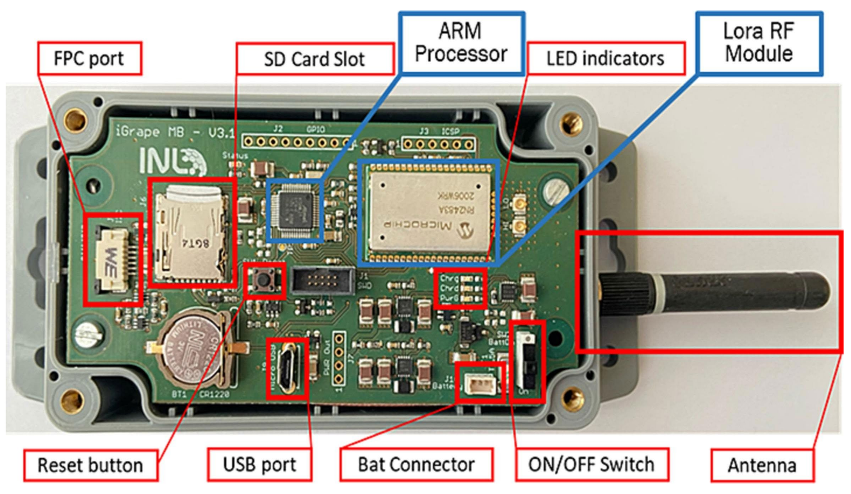
In its current version, each node configuration has a controller and two optical sensor sets, which include two optical modules and their respective host modules





Four light-emitting diodes (LEDs) were used for illumination of the grape (**530 nm, 630 nm, 690 nm and 730 nm**). Placed close to these, but optically isolated using an opaque barrier, **four photodiodes (with an active area of 520 × 520 μm2)** assembled to allow intensity measurements at the desired wavelengths (the relative spectra sensitivity is reported in figure 1b) have been used

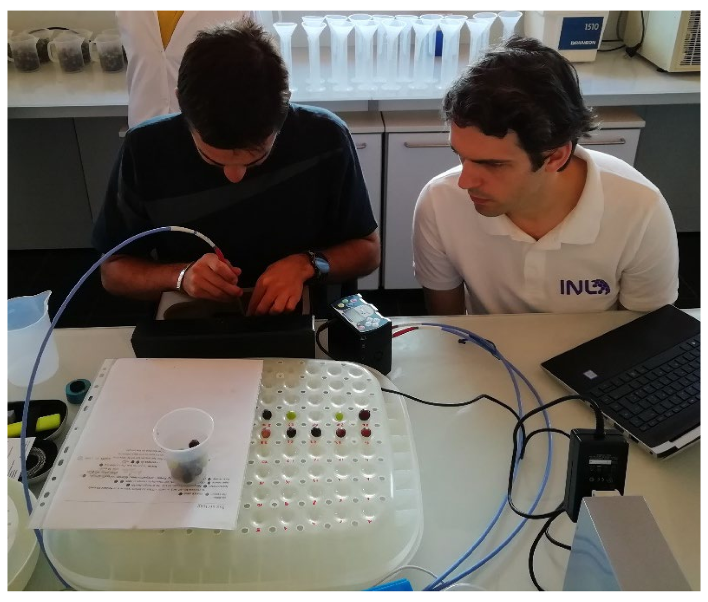
The controller module is powered by an ARM Cortex-M0+ microcontroller (ATMEL ATSAML21G) with 128 KB flash memory and ultra-low-power operation. It manages optical and host modules, system power, data readout, and supports low-power sleep modes. Communication with the host is via I2C bus, supporting up to four modules. For IoT connectivity, it uses the RN-2483A LoRaWAN module operating in the 868 MHz ISM band for long-range (10-15 km) data transmission. It includes a Li-Ion battery with charging via USB, DC-DC converters, and micro-SD storage for data backup

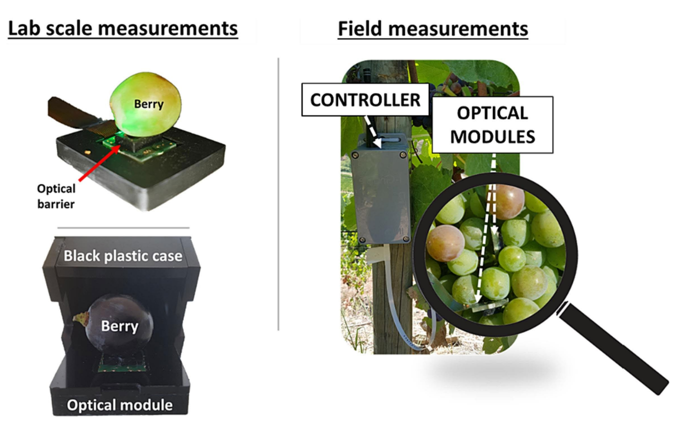


3 Reference

The sampling activity took place in the viticulture area of the Douro Valley from the end of July to mid-September on cv. Touriga Nacional (TN) and **Touriga Franca** (TF) (from 18 parcels) using the optical prototype without any sample preparation.

The reference analyses performed were: (i) **Total Soluble Solids** (TSS, °Brix), (ii) **Potential Alcohol** (PA, % vol), (iii) **Titratable Acidity** (TA, g of tartaric acid L-1) and (iv) **pH**.

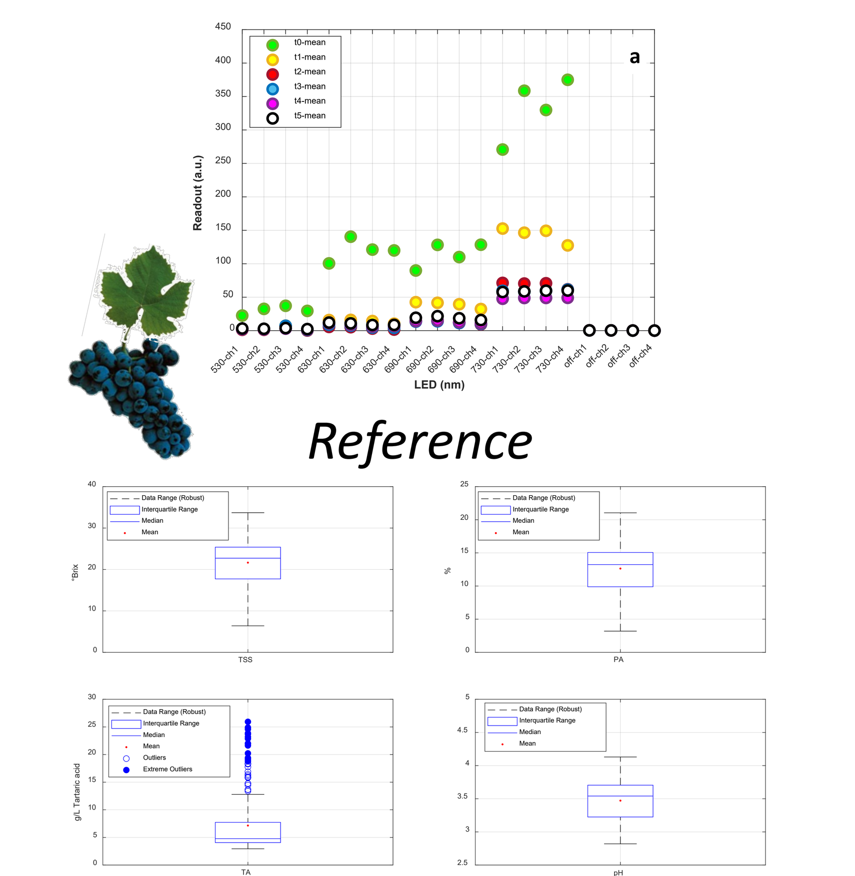




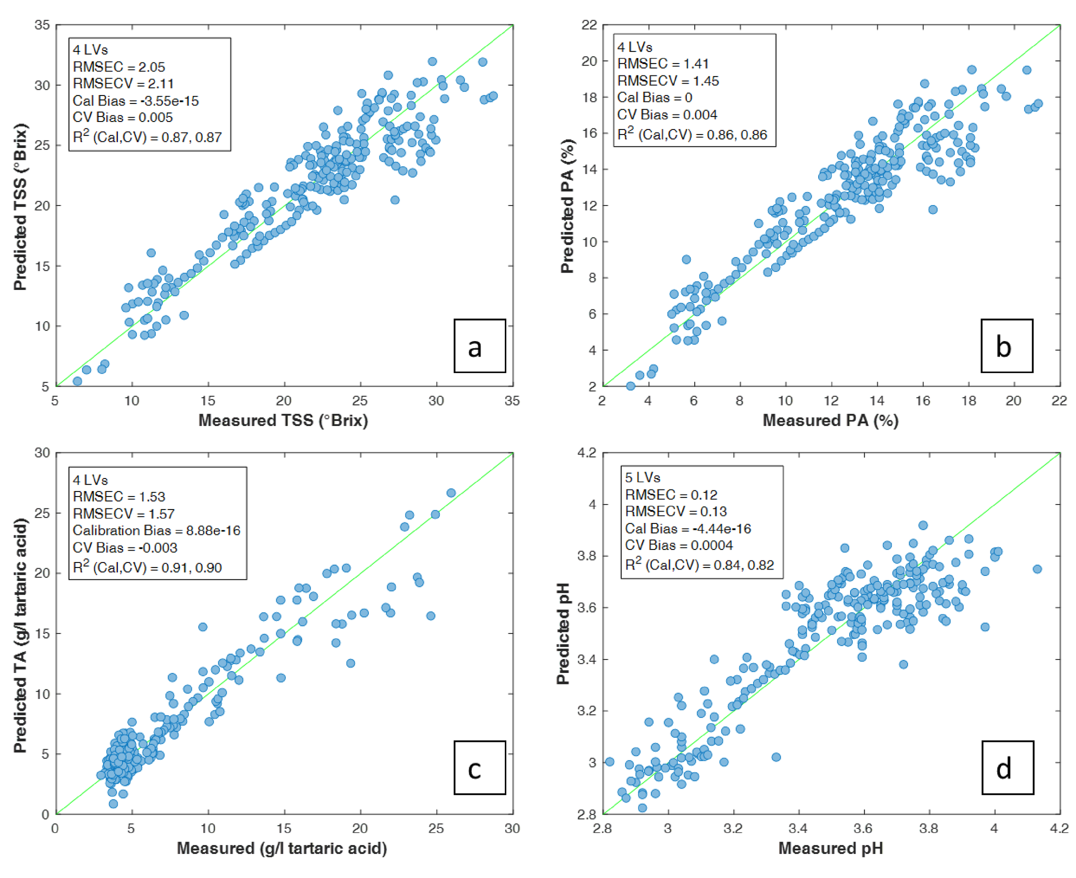
4 Results

Modelling

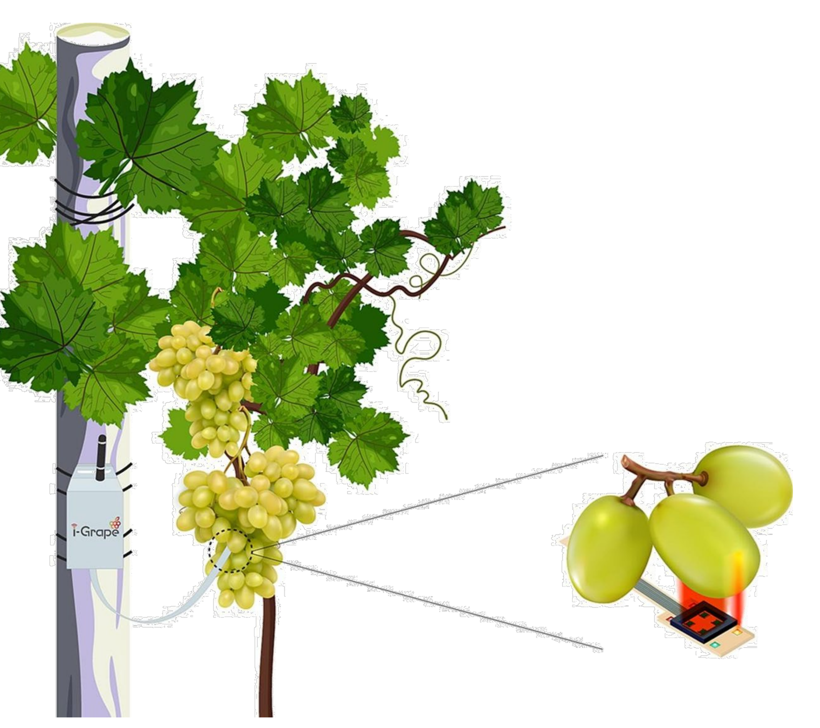
Sensor readouts mean optical outputs



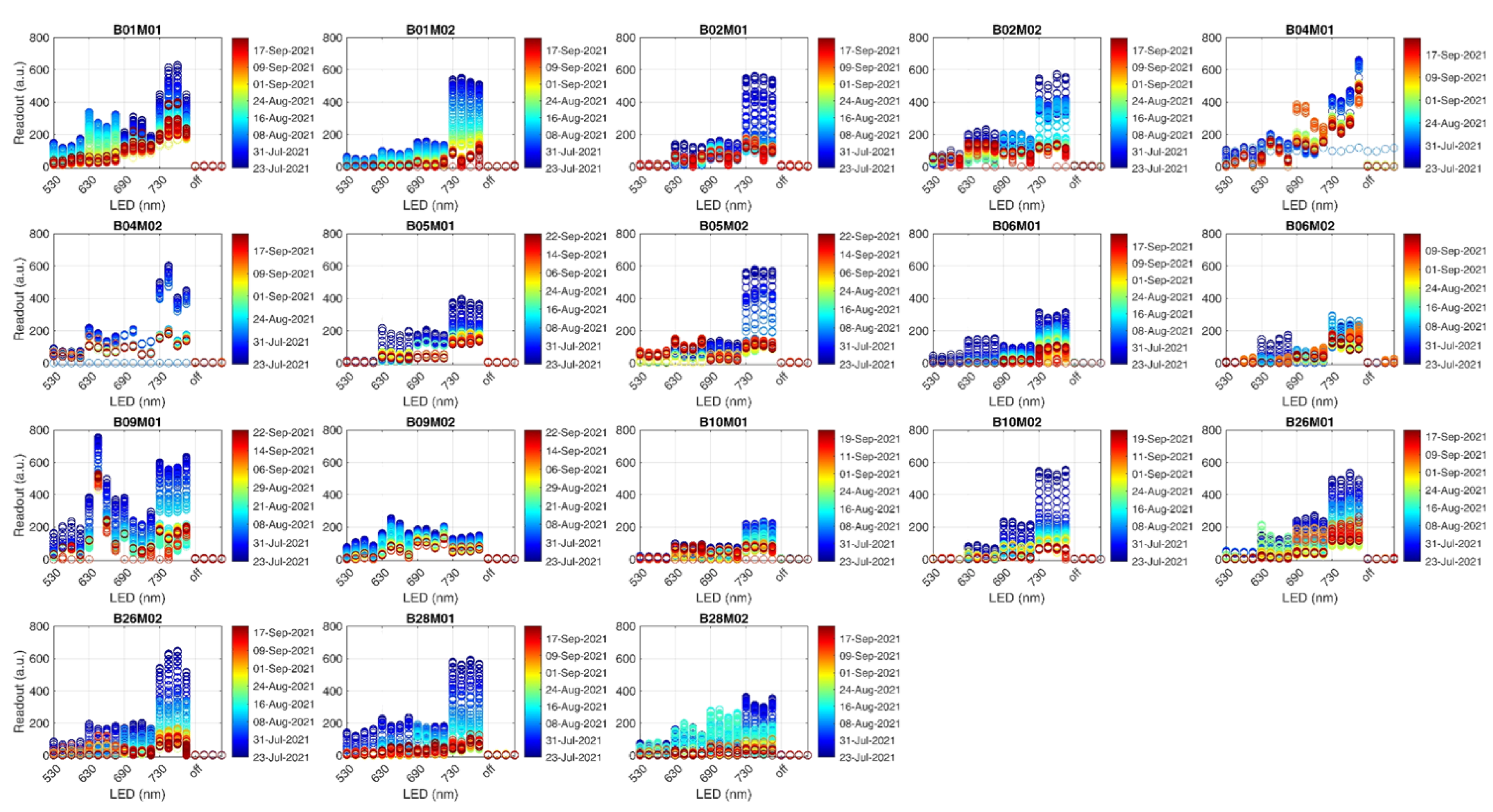
PLS Models



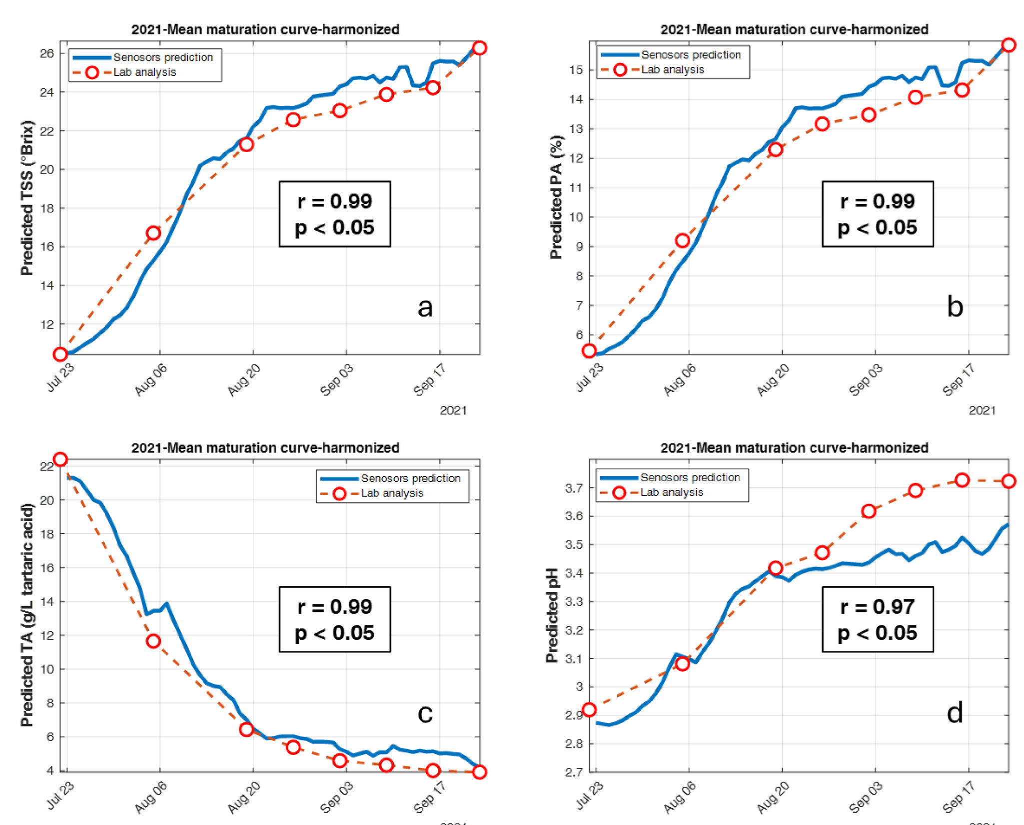
4 Field operation



Readouts of the 18 sensors deployed in the field



Real-time maturation courves



Final Remark

The Ph.D. thesis focuses on "Automation and Electronics," designing a standalone optical device for real-time grape monitoring. It offers the "Agricultural Machines and Mechanization" sector a new perspective via a wireless proximal sensing sensor network. **With its standalone design and affordable components, it suits viticultural areas where the use of bulky machinery is critical**. The method also aims to synergize with machines for precision viticulture, managing info remotely for more effective planning. Its transferability for assessing plant water stress is being explored. A paper titled "Optical specifications for proximal sensing to monitor vine water status autonomously" was published during the Ph.D. to pave the way for a dedicated sensor with the same concept.

In conclusion, **the general approach seeks to revolutionize vineyard management by bringing laboratory-level analysis to the field, replacing traditional wet-chemistry assays with a non-destructive, sustainable method**