HIGH PRECISION LOW – COST SPECTROPHOTOMETER FOR AGRICULTURAL APPLICATIONS

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II Simposio Universitario de Ciencias para el Desarrollo Sostenible

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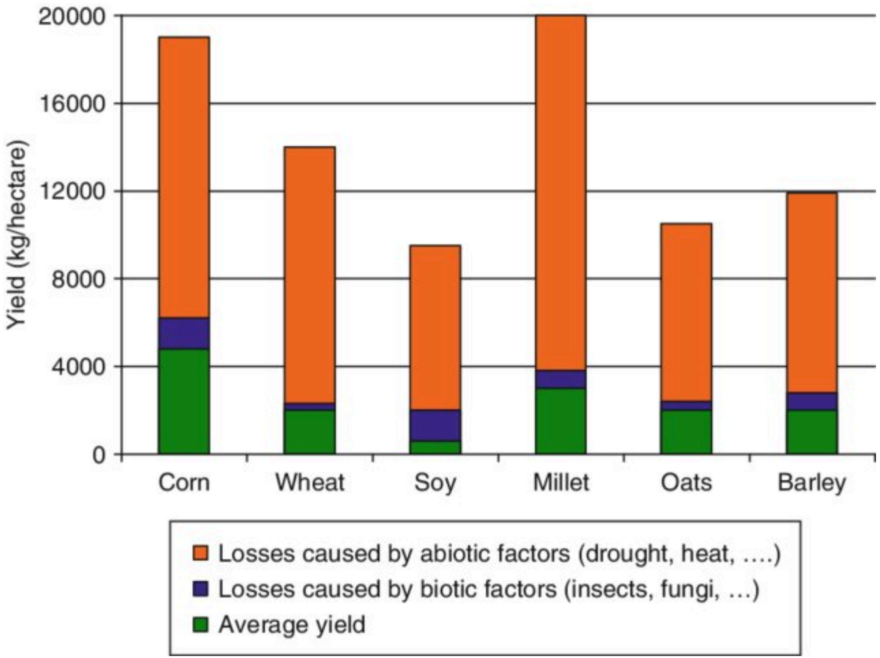
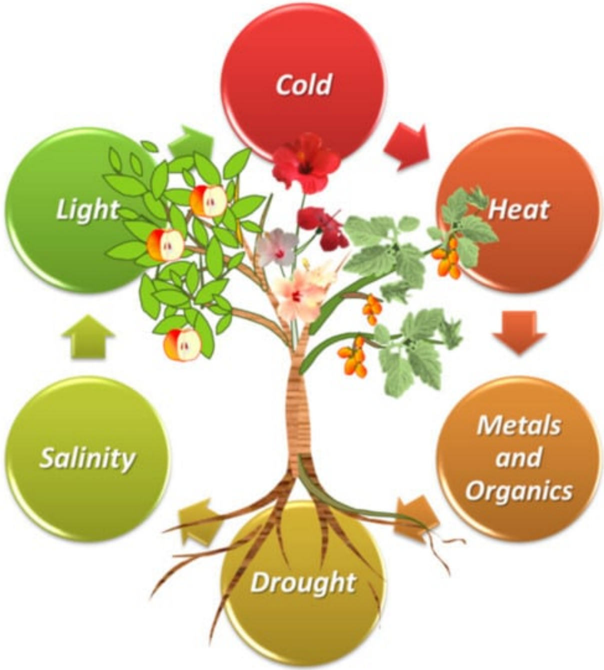
Motivation



Source: *Crop Improvement Through Different Means: Challenges and Prospects*



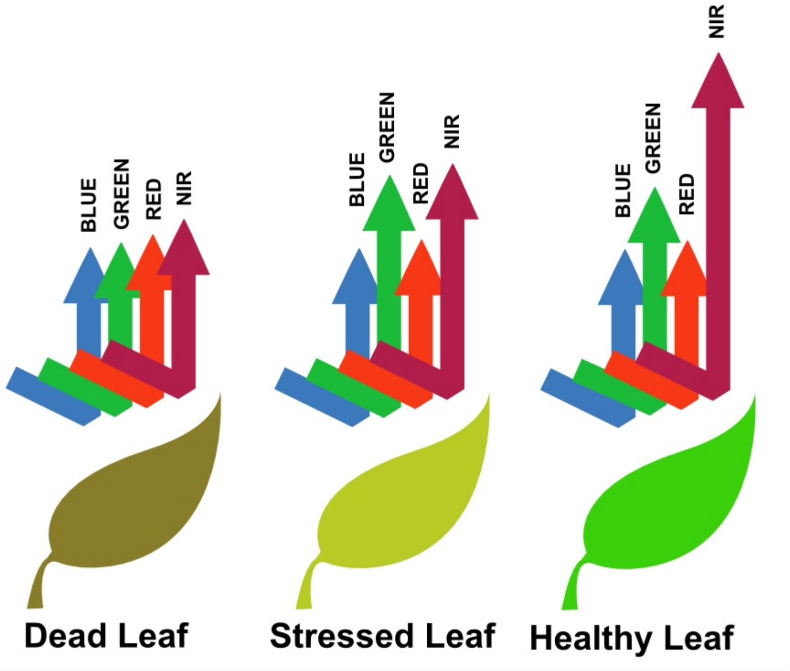
Source: *Horticulturae* **2019**, *5*(4), 67

More than **70% of production is lost** due to abiotic factors

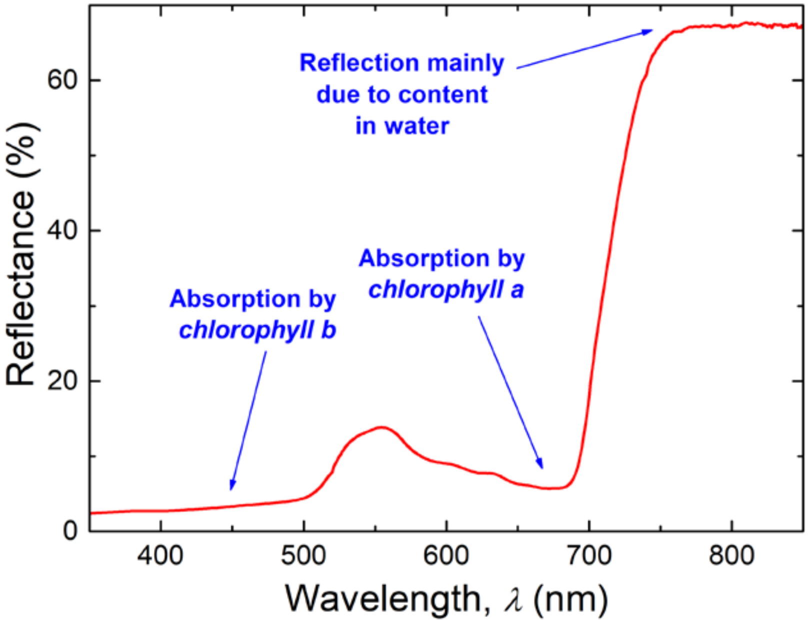
Motivation

- Losses can be reduced by taking appropriate measures on time. It is necessary to **develop instrumentation** that **allows us to anticipate the loss of production.**

Introduction



Source: PhysicsOpenLab



Reflectance spectroscopy allows us to know about the **physiological state** of the plant.

Introduction

- The most widely used is the normalized difference vegetation index (NDVI):

$$\mathrm{NDVI} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{RED}}}{\mathrm{R_{NIR}} + \mathrm{R_{RED}}}$$

- Other indexes:

$$\mathrm{NDVI_g} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{GREEN}}}{\mathrm{R_{NIR}} + \mathrm{R_{GREEN}}} \qquad \mathrm{NDVI_b} = \frac{\mathrm{R_{NIR}} - \mathrm{R_{BLUE}}}{\mathrm{R_{NIR}} + \mathrm{R_{BLUE}}}$$

State of the art

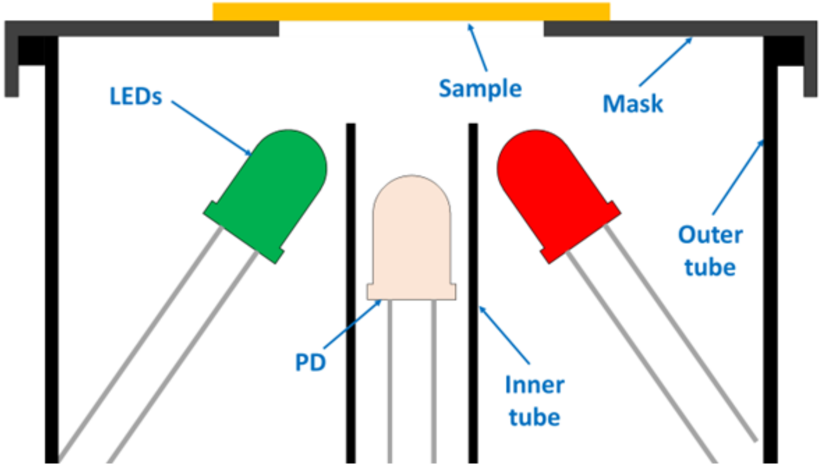
- There are available devices to measure vegetation indexes. However:

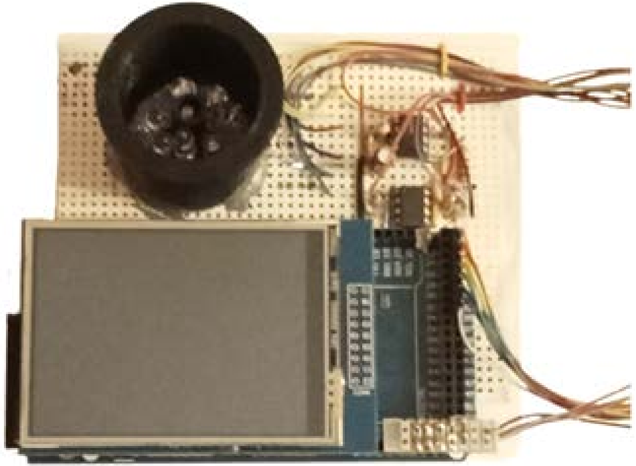
    - They are **very expensive** (> € 2000).
    - They only measure **one or two indexes.**
    - Their **geometry** does not allow measuring objects other than leaves.

Source: AlphaOmega Electronics

Source: Spectrum Technologies, INC.

Optical design

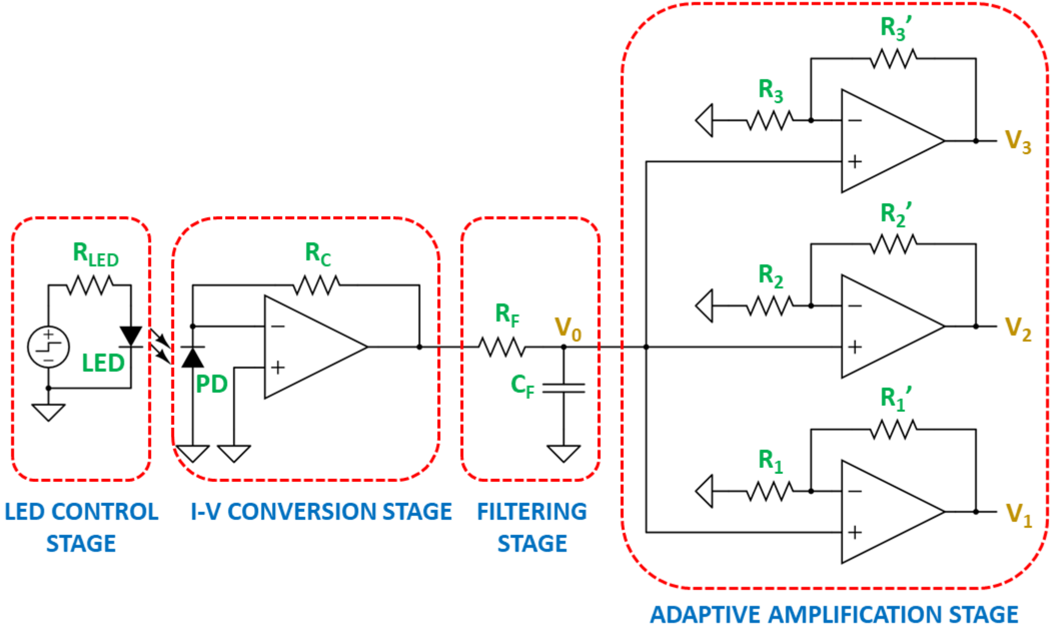




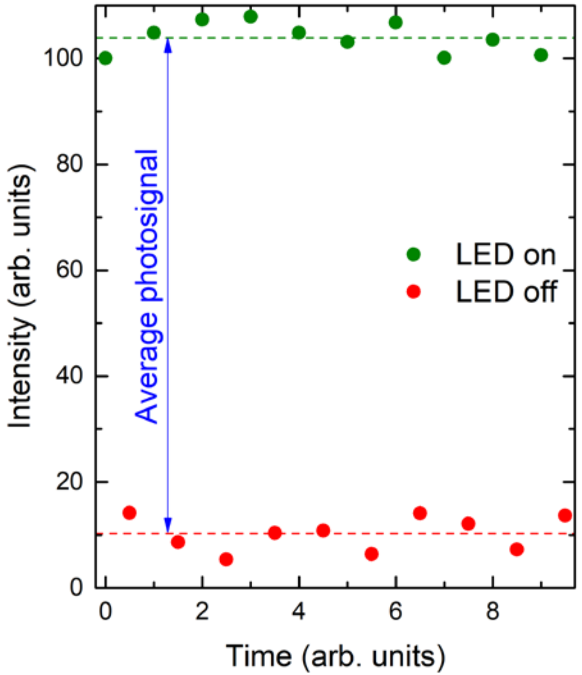
Bill of materials:

< €65

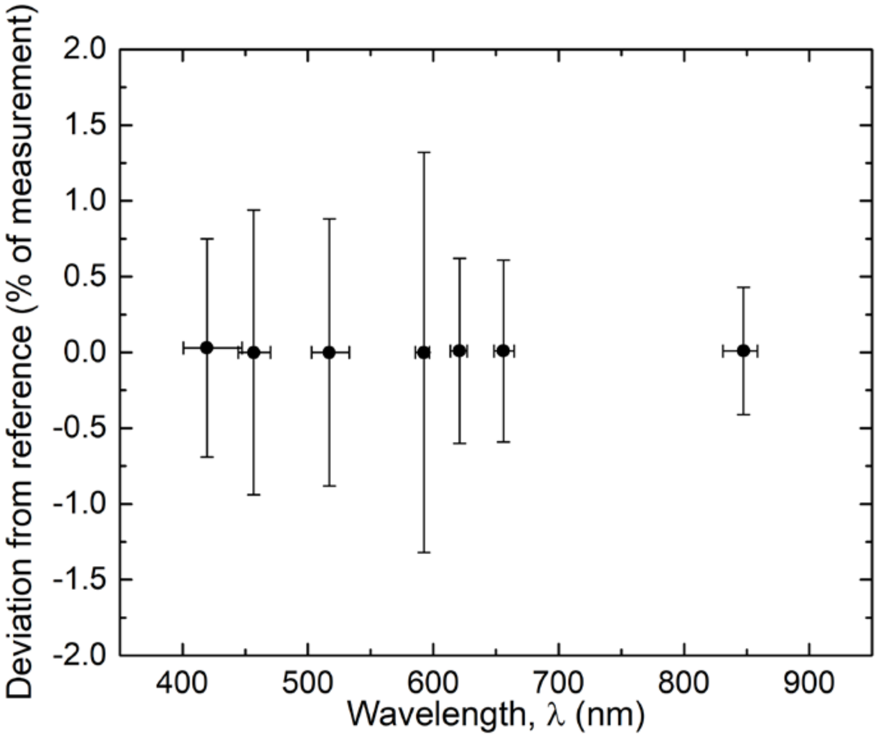
Signal acquisition



Synchronous digital filter

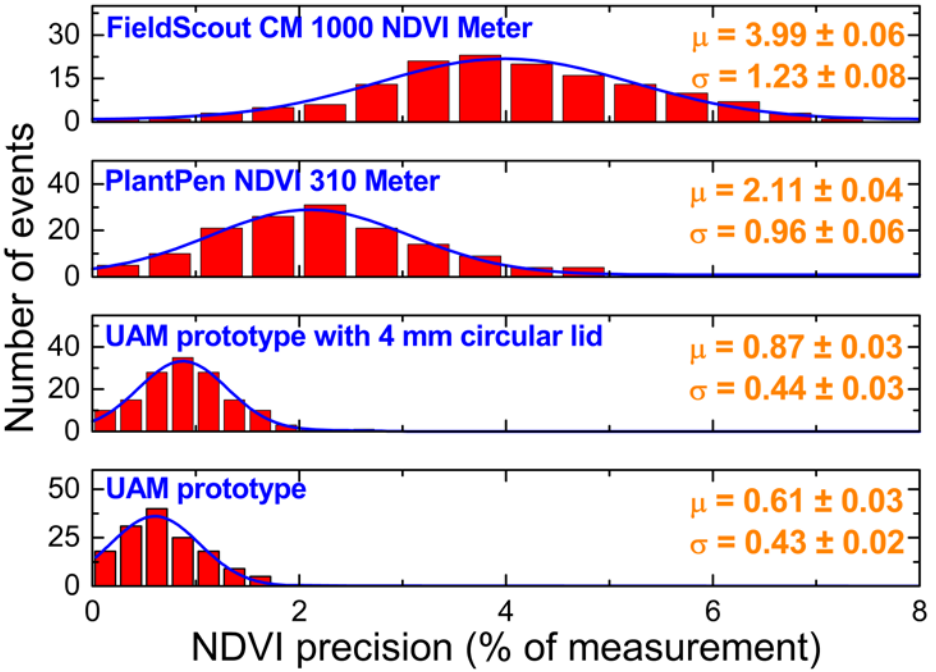


Accuracy determination



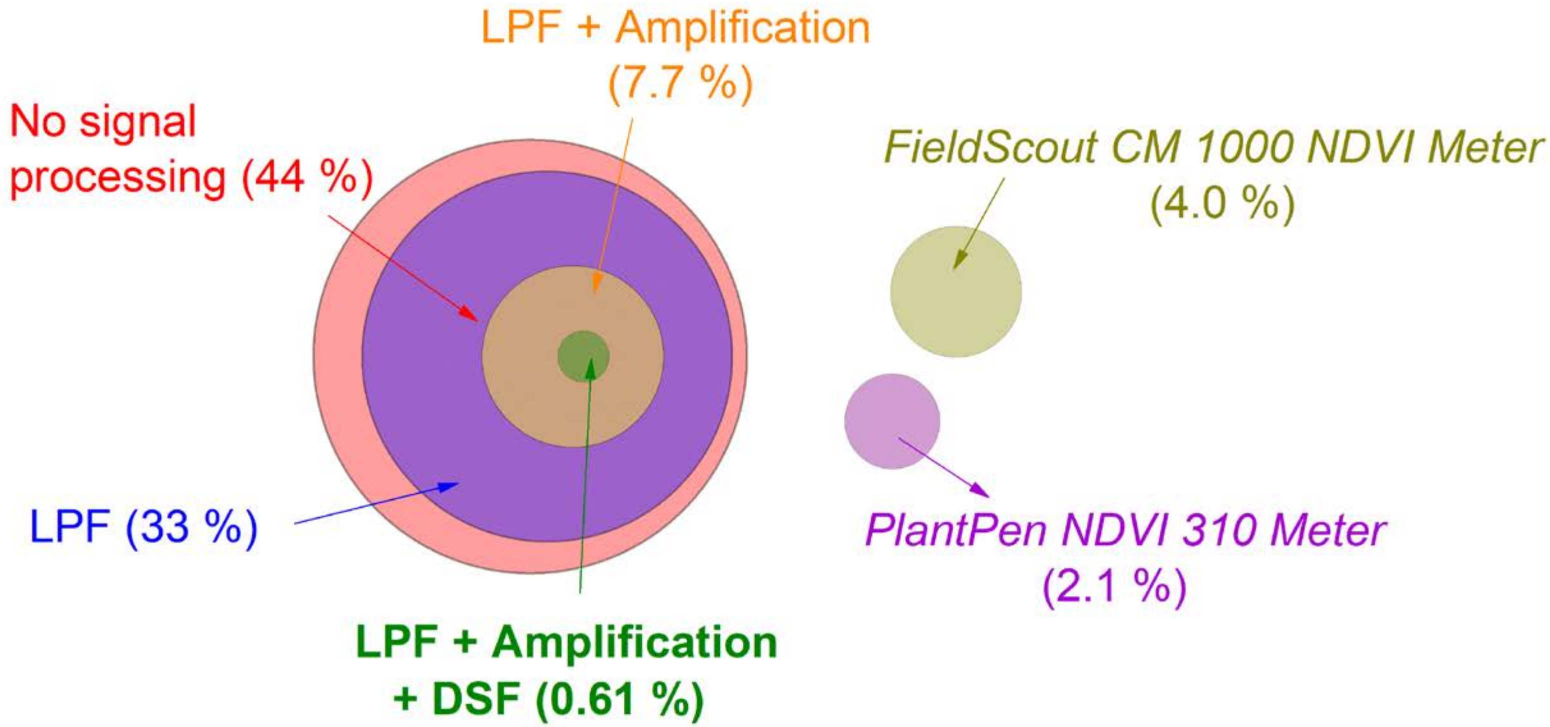
Accuracy between 0.4 % and 1.5 %. Just **two to four times worse** than **high-end comercial spectrophotometers.**

NDVI precision determination



NDVI precision **three to six times better** with our device than with high-cost comercial ones.

Uncertainty budget



Our device presents **a better precision.**
However, **all the signal processing** stages must be applied.

Field test: Monitoring changes with exposure to sunlight

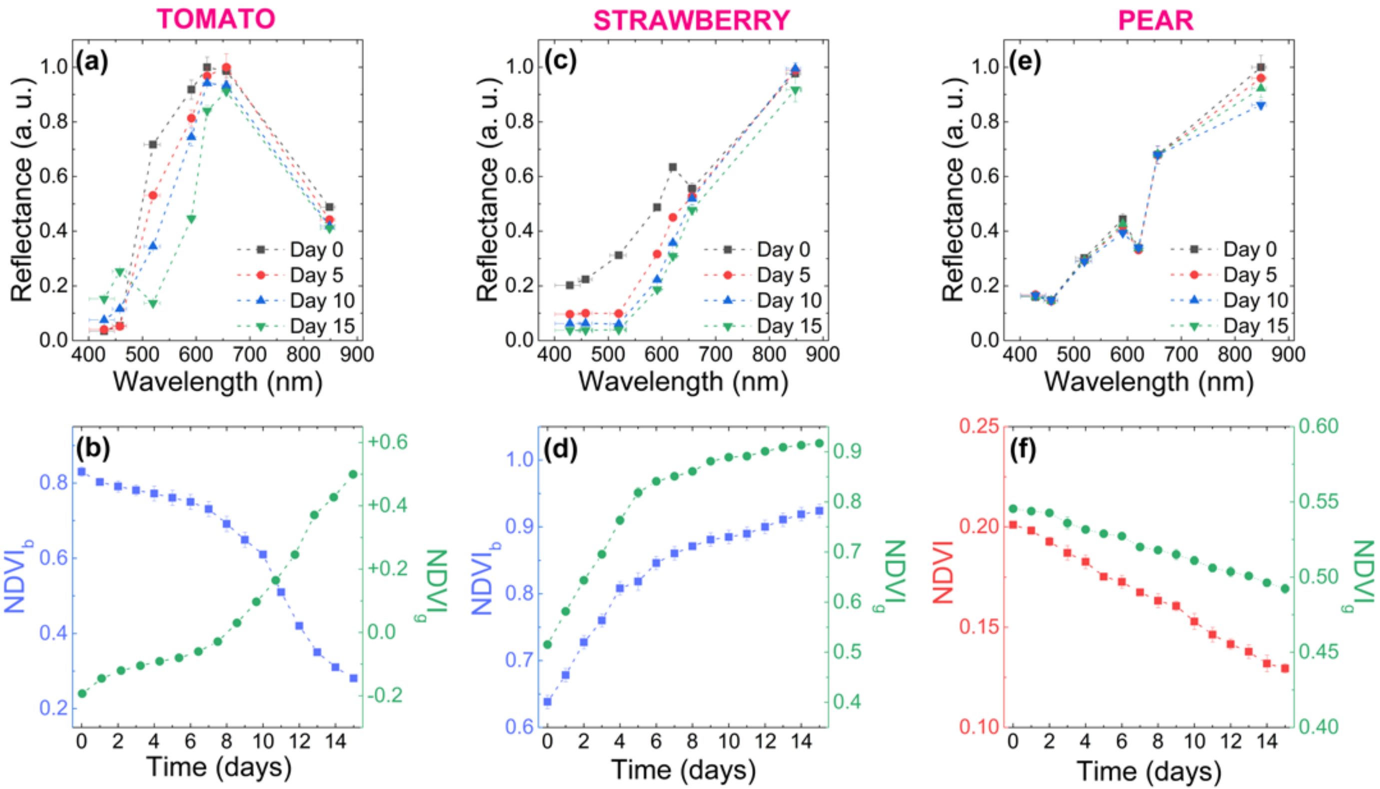
Our device presents a **better accuracy and precision.**
This would allow **changes** to be applied to farms **quickly** and **effectively.**

Field test: Monitoring changes with hydrigation level

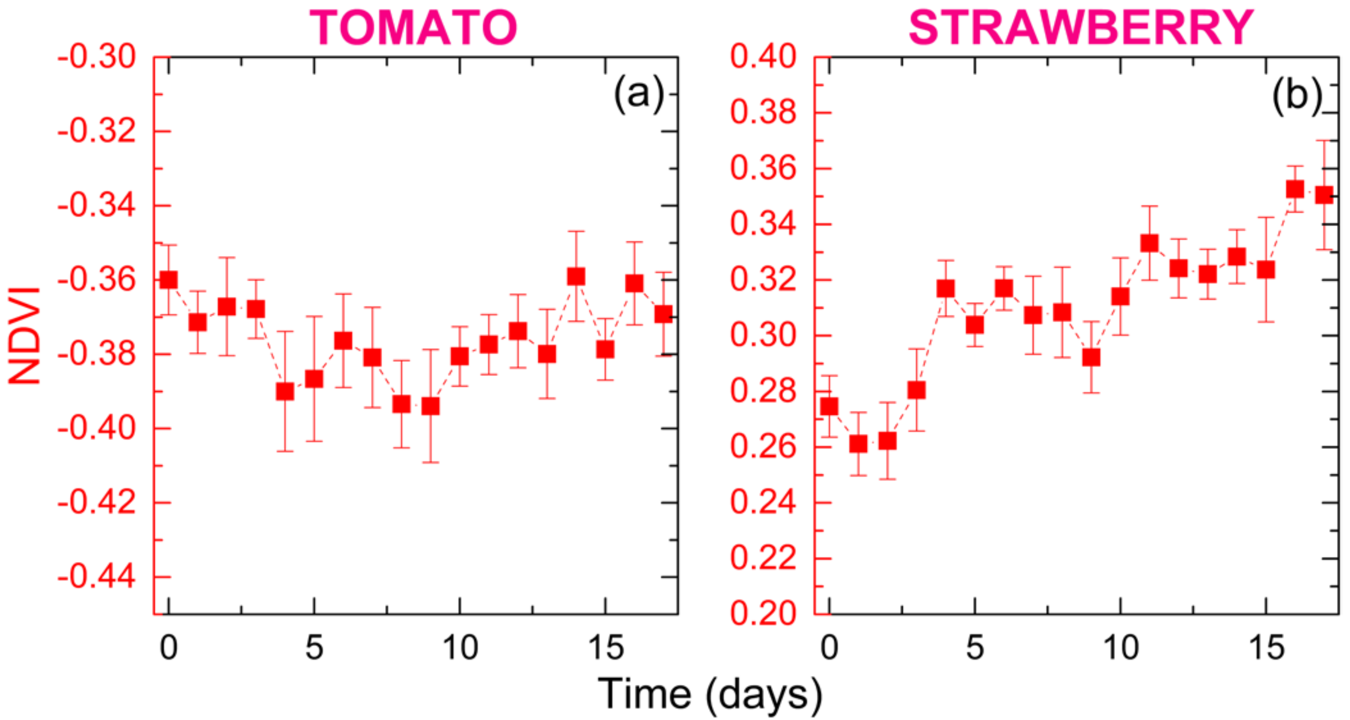
UAM Prototype

Our device presents a **better accuracy and precision.**
This would allow **changes** to be applied to farms **quickly** and **effectively.**

Field test: Monitoring ripening of fruits

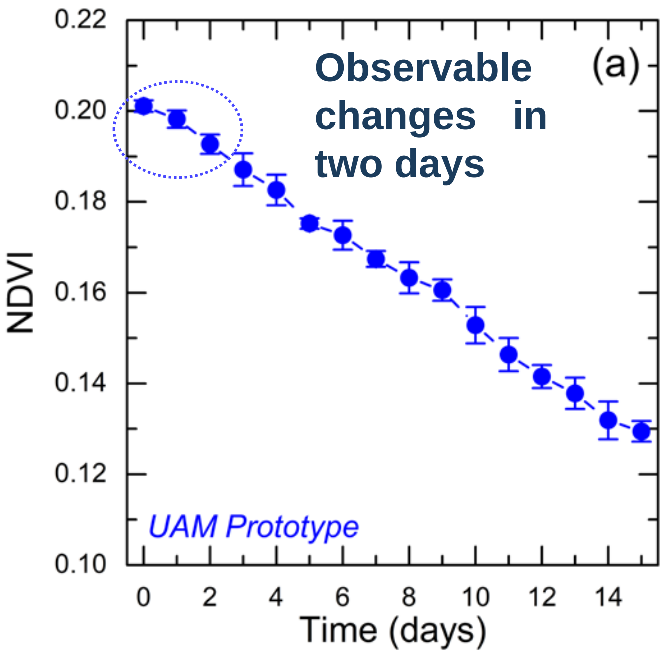


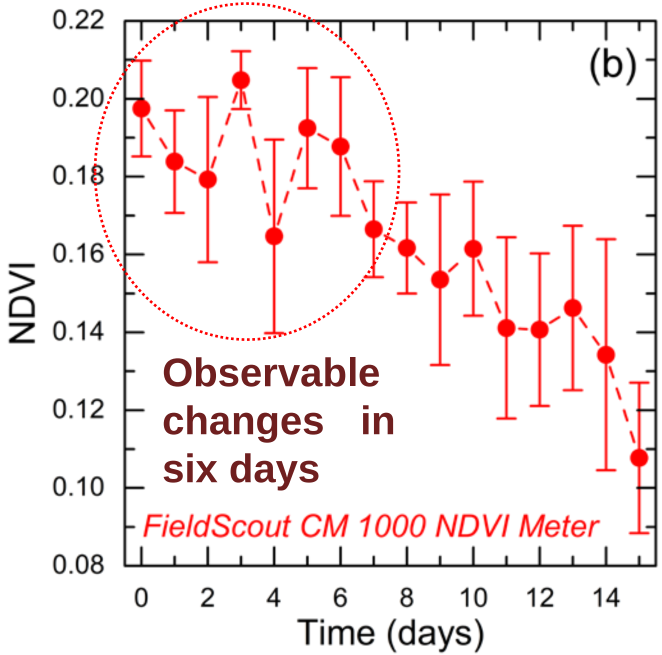
Field test: Monitoring ripening of fruits



NDVI not suitable for monitoring changes in **tomato** and **strawberry.**
Commercial devices not applicable.

Comparison with a commercial device





Our device allows us to monitor changes **before** they are **visible** to the **naked eye.**

Conclusions

- A **low-cost spectrophotometer (< €65)** capable of measuring reflectance in seven bands and determining up to 9 vegetation indices has been implemented.
- An **accuracy value** of between **0.4 % and 1.3 %** was obtained. A **NDVI precision** value of **0.61 %** was obtained, **better** than that of **high – cost similar devices.**
- The **applicability** of the device was verified in two field studies.
- Possible applications in farms, especially in **developing countries**, favoring compliance with **SDGs No. 2 (zero hunger) and 12 (responsible consumption and production).**

Thank you very much for your attention!

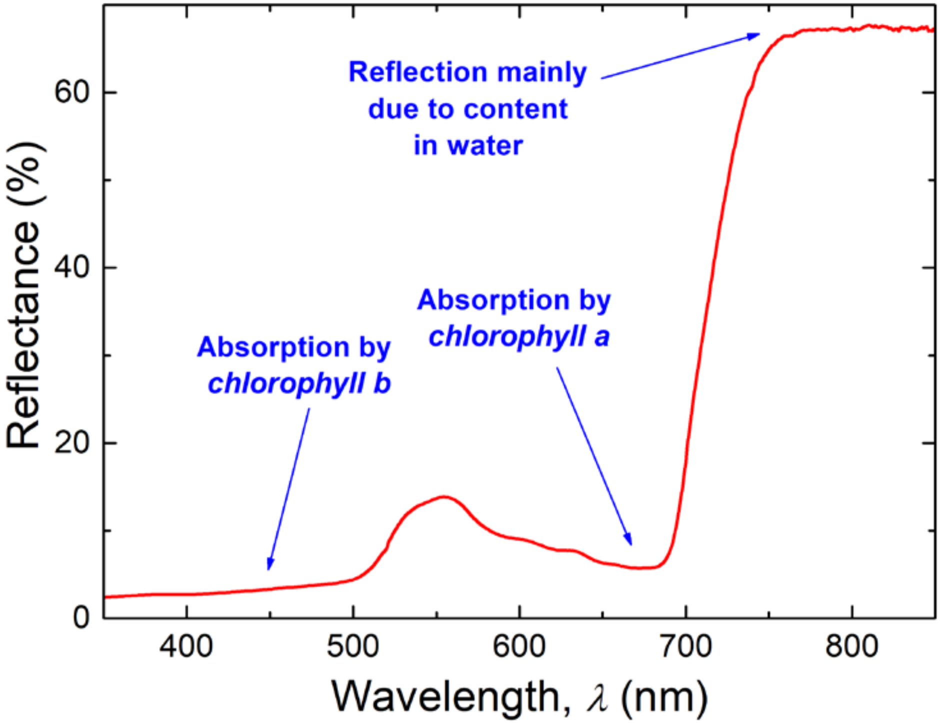
Questions?

Acknowledgements

Part of this work was awarded with the prize to the best Bachelor Theses in the "*II Convocatoria de Premios a la Investigación en el Ámbito de la Agenda 2030 de la Universidad Autónoma de Madrid*"

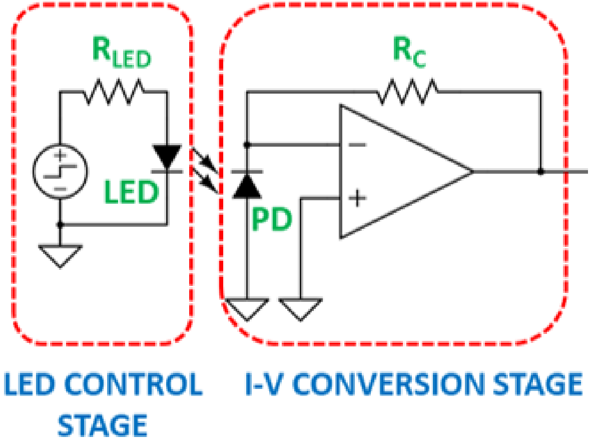
Introduction

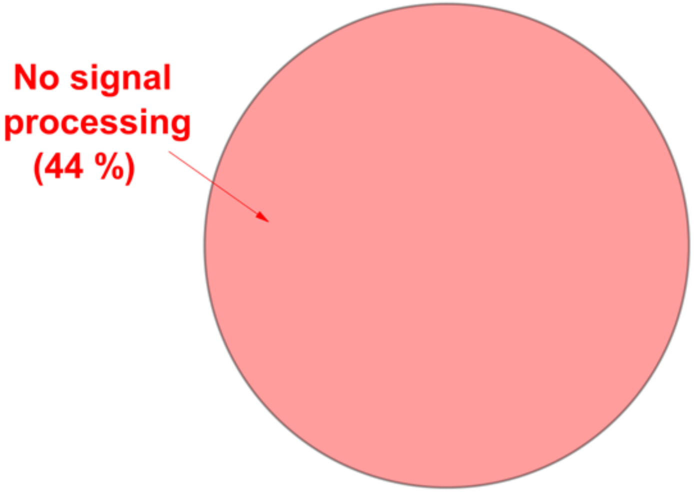
Reflectance spectroscopy is a **non – destructive technique** with multiple applications in food and materials quality control and in **precision agriculture.**



Uncertainty budget

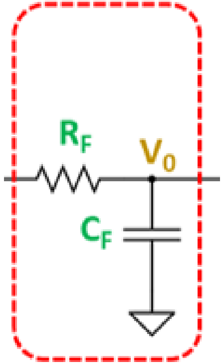
No signal processing



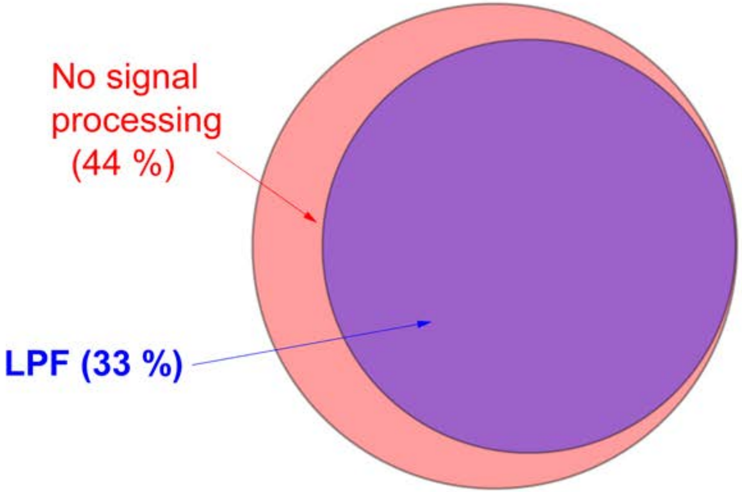


Uncertainty budget

Adition of
low-pass filtering (LPF) stage

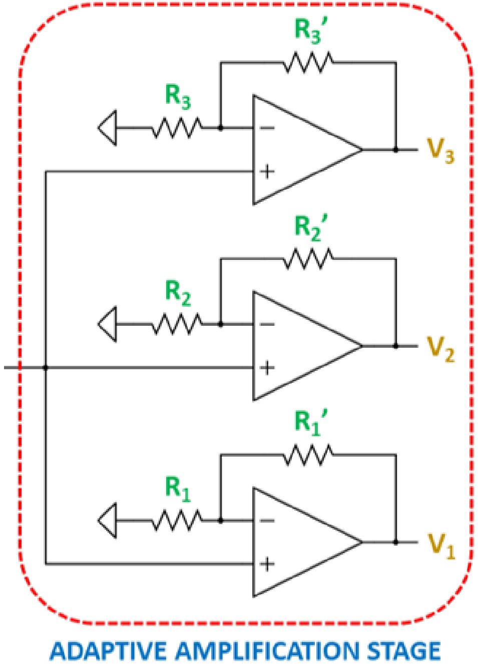


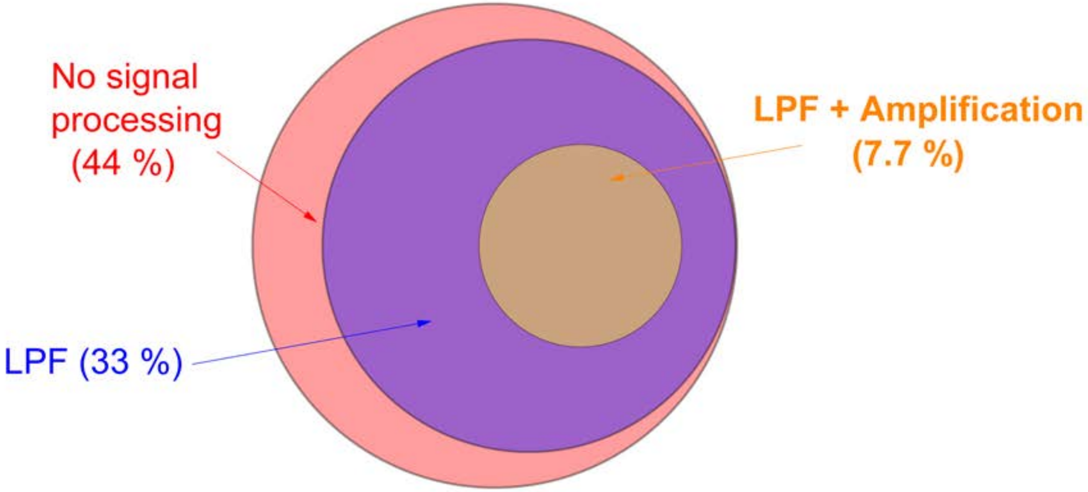
FILTERING
STAGE



Uncertainty budget

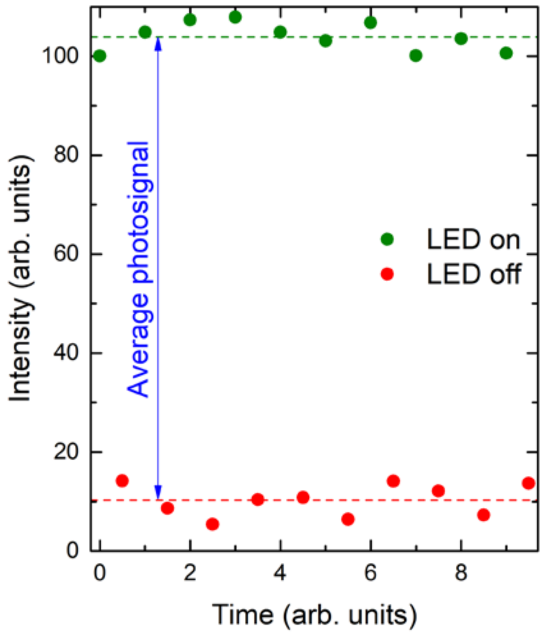
Adition of
adaptive amplification

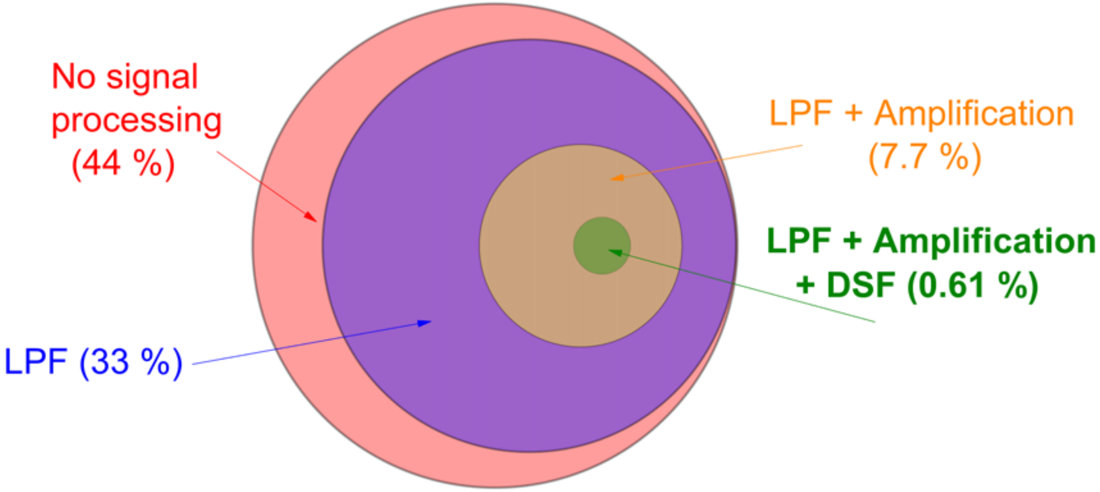




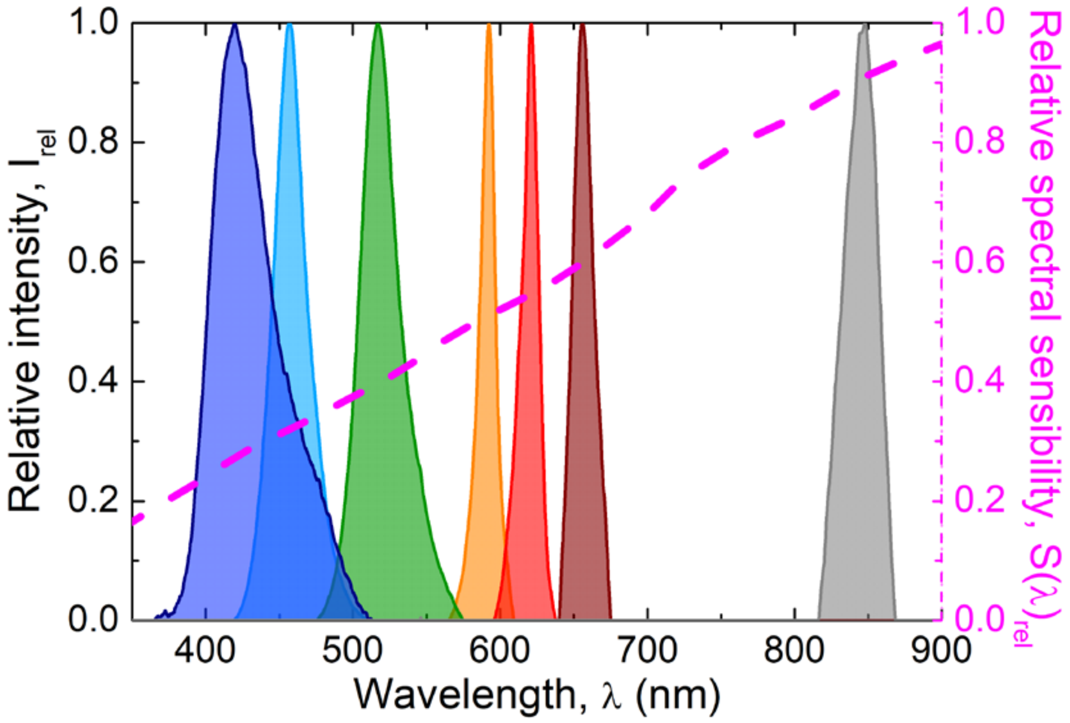
Uncertainty budget

Adition of
Digital synchronous filter





Optical design

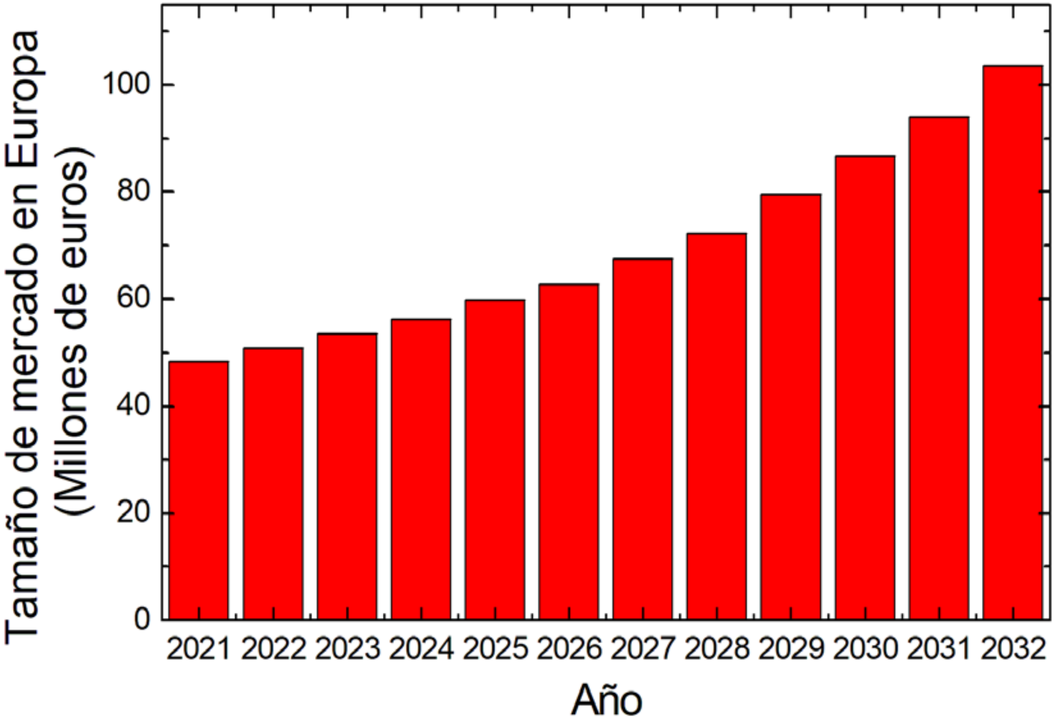


Operation mode

1. It is neccesary to **calibrate** with respect to **white** and **black reference.**
2. Determination of the **proper gain** to be considered for each particular band.
3. Data collection. **Implementation of DSF.**
4. One data has been taken for all bands, the **displayed values are updated.**

All this process takes 1 to 4 seconds.

Tamaño de mercado



Métodos disminución incertidumbre

- Eliminación **lock – in: Aumento de la incertidumbre** en un **factor entre 5 y 20** según la muestra.

- Eliminación **ganancia selectiva**: **Aumento de la incertidumbre** en hasta **un factor 10**, según la muestra.

- Realización de **medida de "negro"** con **superficie especular** plana. **Aumento de incertidumbre** en un **factor 2.**

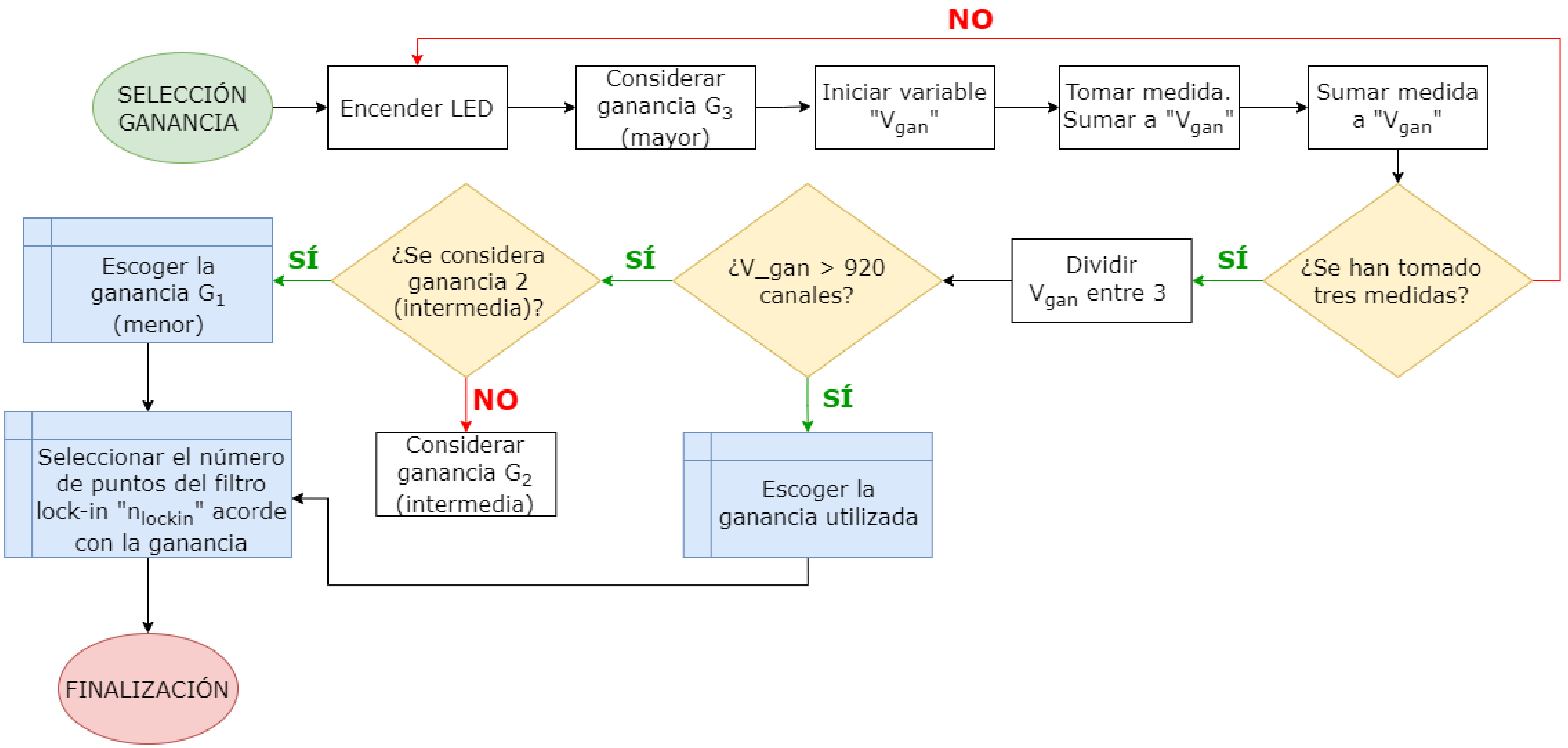
Selección ganancia óptima

- **La tensión registrada puede variar hasta en un factor 50, dependiendo de su carácter difuso o especular de la muestra y del LED considerado.**

- **Objetivo**: Medir una **señal notablemente superior** a la **resolución del microcontrolador** (5 mV)

- Se escoge el **amplificador** que arroja una **mayor señal**, pero **sin encontrarse en saturación**, en cada caso.

Selección ganancia óptima



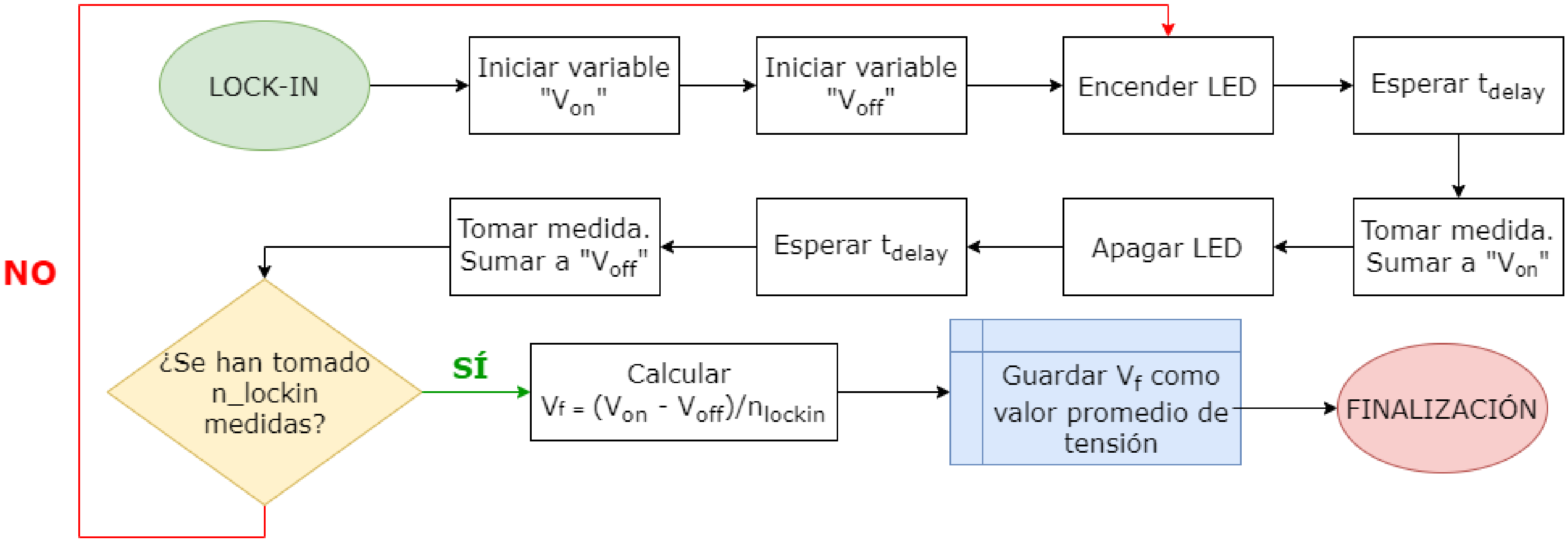
Algoritmo lock - in

- Se **promedian** las medidas realizadas con el **LED encendido.** De este modo, **se eliminan** posibles señales de **ruido electrónico periódicas**.

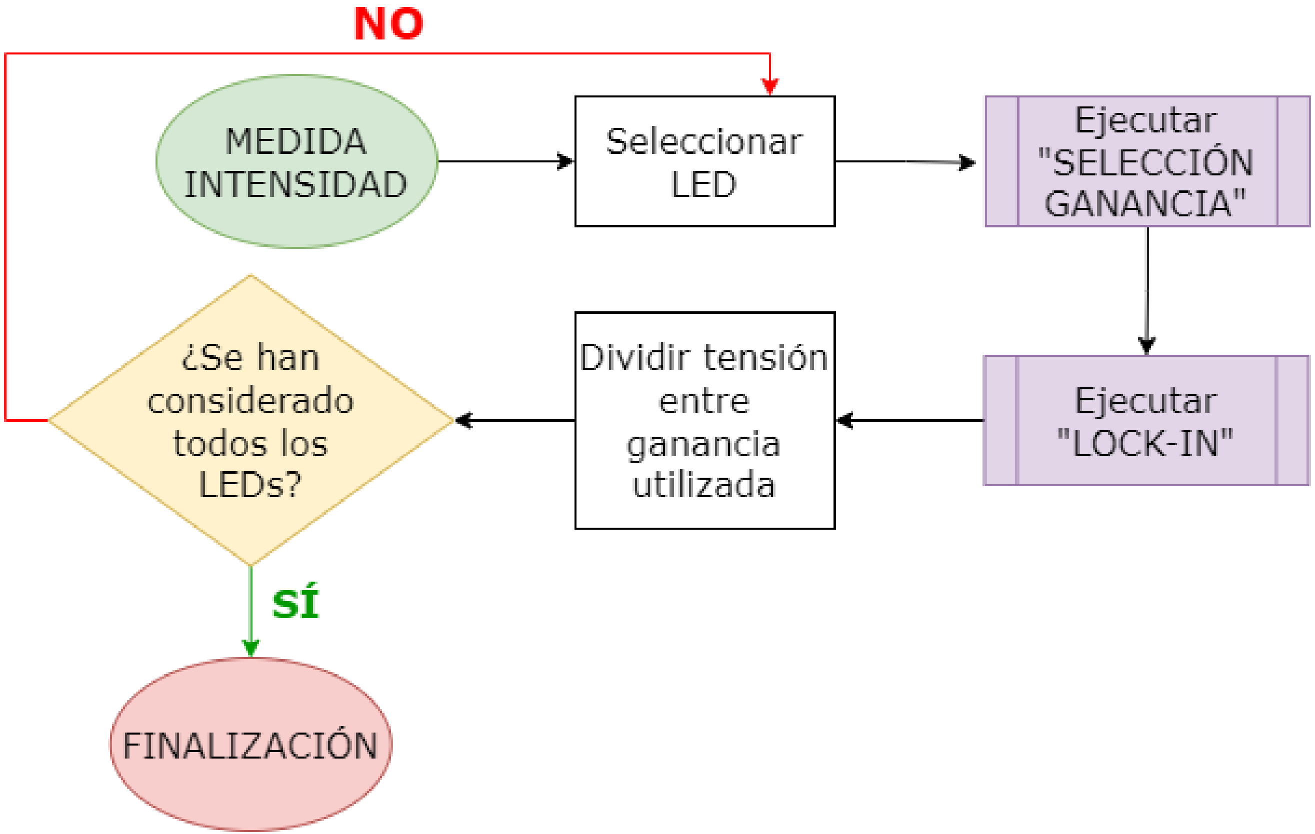
- Se **promedian** las medidas realizadas con el **LED apagado.** De este modo, se obtiene la parte de la señal debida a otras **posibles fuentes de luz.**

- Se **resta** el p**romedio de las medidas realizadas con el LED encendido y apagado**, obteniendo la **señal neta** debida a la luz reflejada por la muestra, con un nivel de **ruido electrónico y lumínico muy reducido.**

Algoritmo lock - in



Medida continua



Correlación con dispositivo de referencia

- Es necesario considerar que el **dispositivo de referencia** mide la **reflectancia a cada longitud de onda**, mientras que **nuestro dispositivo lo mide en una banda continua.**

- Es necesario considerar que la **sensibilidad del detector depende** de la **longitud de onda de la luz incidente.**

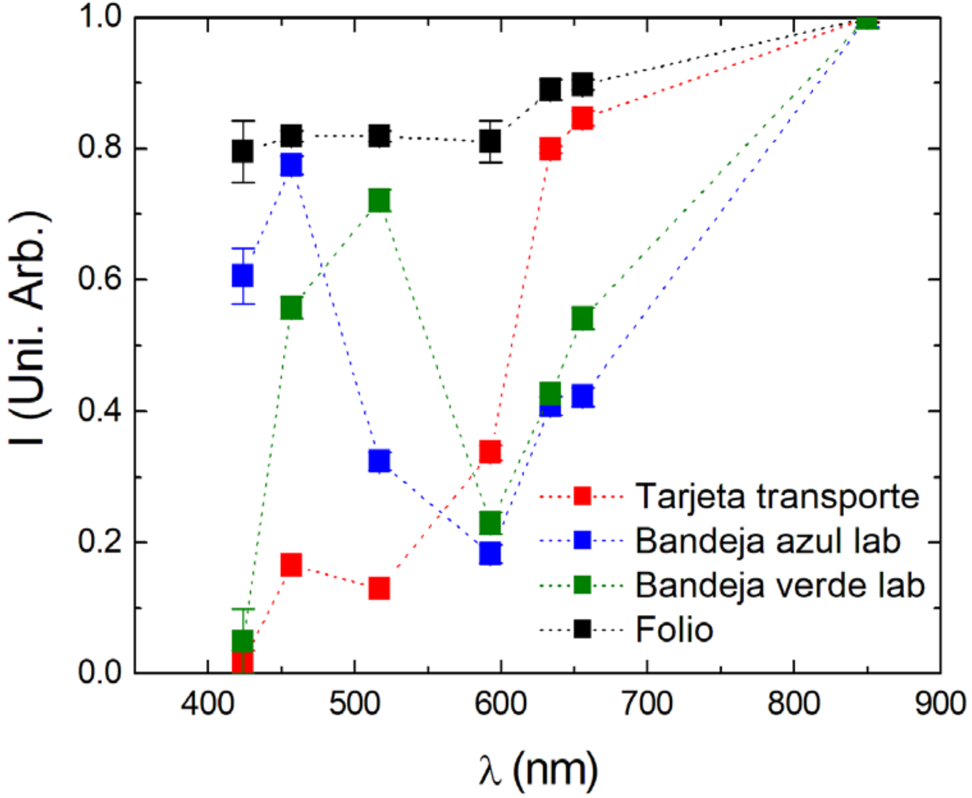
$$\mathrm{R_i} = \frac{\sum \mathrm{R}_\lambda \mathrm{I}_\lambda \mathrm{S}_\lambda^{\mathrm{rel}}}{\sum \mathrm{I}_\lambda \mathrm{S}_\lambda^{\mathrm{rel}}}$$

Ajuste realizado con dispositivo comercial

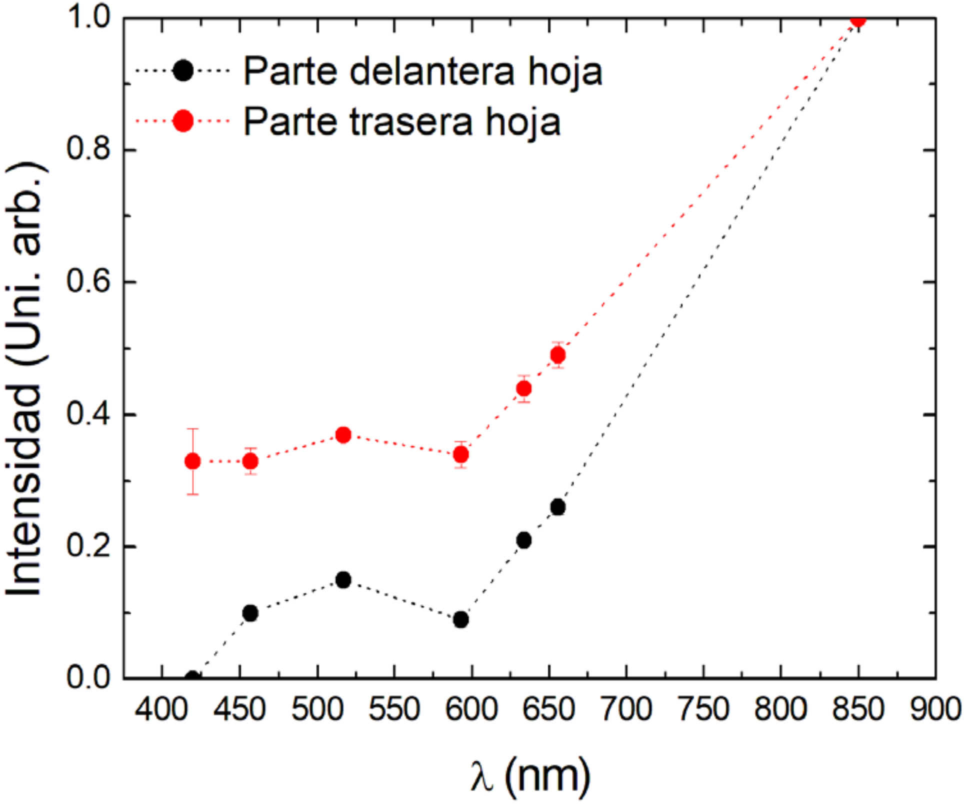
- Se considera que la reflectancia en la banda infrarroja prácticamente no cambia para los distintos dispositivos, así como que la reflectancia registrada por los diferentes dispositivos está relacionada por una constante.

$$\mathrm{NDVI}_{\mathrm{comercial}} = \frac{\mathrm{R}_{\mathrm{NIR}} - \mathrm{R}_{\mathrm{RED}}}{\mathrm{R}_{\mathrm{NIR}} + \mathrm{R}_{\mathrm{RED}}} = \frac{\mathrm{SR}-1}{\mathrm{SR}+1} = \left[\frac{\alpha\left(\frac{1+\mathrm{NDVI}_{\mathrm{UAM}}}{1-\mathrm{NDVI}_{\mathrm{UAM}}}\right)-1}{\alpha\left(\frac{1+\mathrm{NDVI}_{\mathrm{UAM}}}{1-\mathrm{NDVI}_{\mathrm{UAM}}}\right)+1}\right]\mathrm{NDVI}_{\mathrm{UAM}}$$

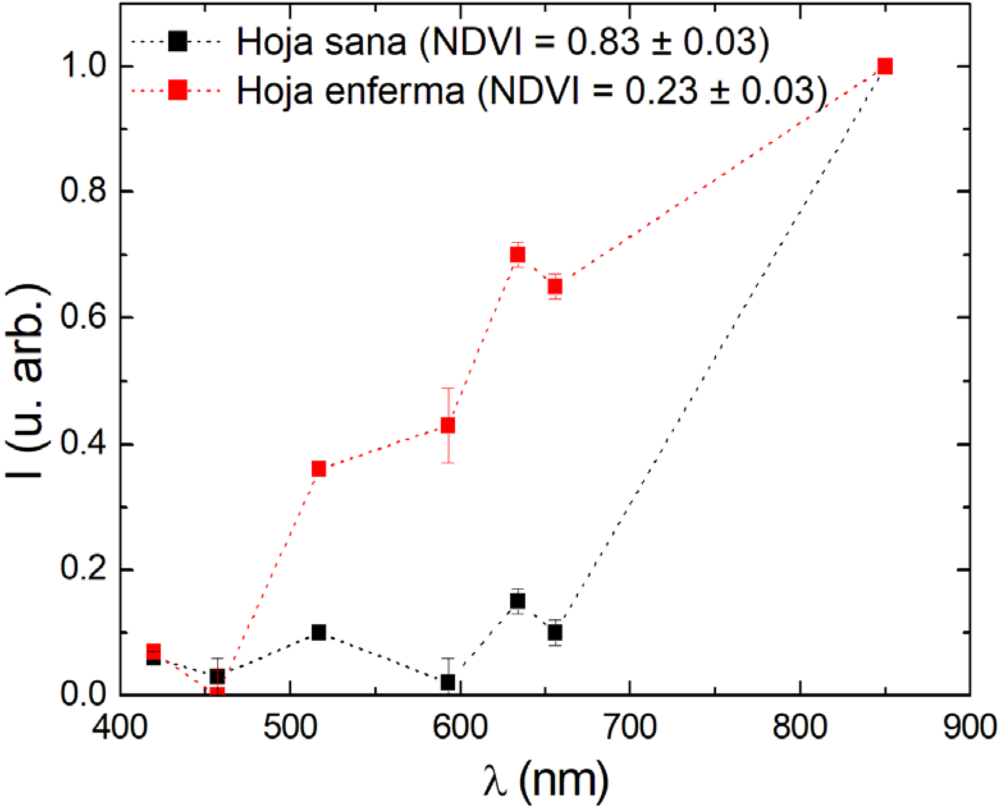
Otros espectros



Otros espectros



Otros espectros



Otros espectros