altice labs

Agrotech – sensing use cases

IoT; Agrotech; Machine learning; Banana crop; Service platftorm

White paper

Version 1.0, May 2023

Introduction

Agriculture is changing, and innovation is more important than ever. Farming agriculture is facing huge challenges, from a labor shortage, supplies rising costs, and changes in consumer preferences such as food traceability and food safety [1]. New precision agriculture and the implementation of developing technologies are extremely important to farmers to maximize their yields by controlling important variables of crop farming, such as moisture levels, soil conditions, fertilization levels, and micro-climate changes.

In Madeira island, banana cultivation has a major impact in several areas, such as economic, social, and environmental, and in the region's landscape, with its commercialization growing over time [2]. Currently, the banana business moves millions of euros to the region and employs thousands of people on the island [3]. Since Madeira has many singular producers of bananas, there was a need to create an organization that manages the production, collection, and distribution of the banana to be a sustainable and continued business [4].

The Banana Sector Management Company of Madeira Island (GESBA) was founded in 2008. While seventy percent of the bananas on the Island are produced in the summer, only thirty percent are in the winter. Therefore, the large volume of production in the summer ultimately affects the market values. So, the company's main aim is to improve bananas' quality and market value.

GESBA recognizes that new agriculture solutions are needed to face these challenges. In collaboration with the University of Madeira (UMa), Regional Agency for the Development of Research, Technology and Innovation (ARDITI), Altice Labs, and Altice Portugal, GESBA is sponsoring an ongoing project named 'BAnana SEnsing' (BASE), approved and co-founded by 'Programa de Desenvolvimento Rural da Região Autónoma da Madeira' (PRODERAM 2020), Regional Government of Madeira, Portugal 2020 and by the European agricultural fund for rural development (EAFRD). The BASE project started on 1 July 2022 and ended on 31 March 2023. This project will bring significant technology innovation practices to the banana sector by applying sensor technology to monitor the crop growth of banana cultivation in the field.

Using of IoT technology

The agrotech revolution is emerging and aims to use advanced precision technology, such as real-time analysis of soil nutrients and weather conditions using sensors to meet the future demands for food in a more sustainable, efficient, and eco-friendly way [5].

The internet of things (IoT) is remodeling agriculture enabling farmers with a wide range of techniques, namely precision and sustainable agriculture, to face challenges in the field.

IoT technology enables collecting information about conditions like weather, moisture, temperature, and soil fertility, helping farmers increase yields and have better crop management.

There has been a significant rise in research and development of precision agriculture technologies to monitor pH, salinity, moisture content, organic matter, and texture. However, in situ monitoring of soil macronutrients, nitrogen (N), phosphorus (P), potassium (K), and other nutrients remains a challenge. Moreover the sap flow sensors for banana plants are under the research domain.

The BASE project has deployed a set of IoT sensors in two sites with different climatic and edaphic conditions (Ponta do Sol and Lugar de Baixo sites), where the development of a representative sample of banana plants is monitored using morpho-agronomic traits during three phenological stages, shown in **Figure 1**.

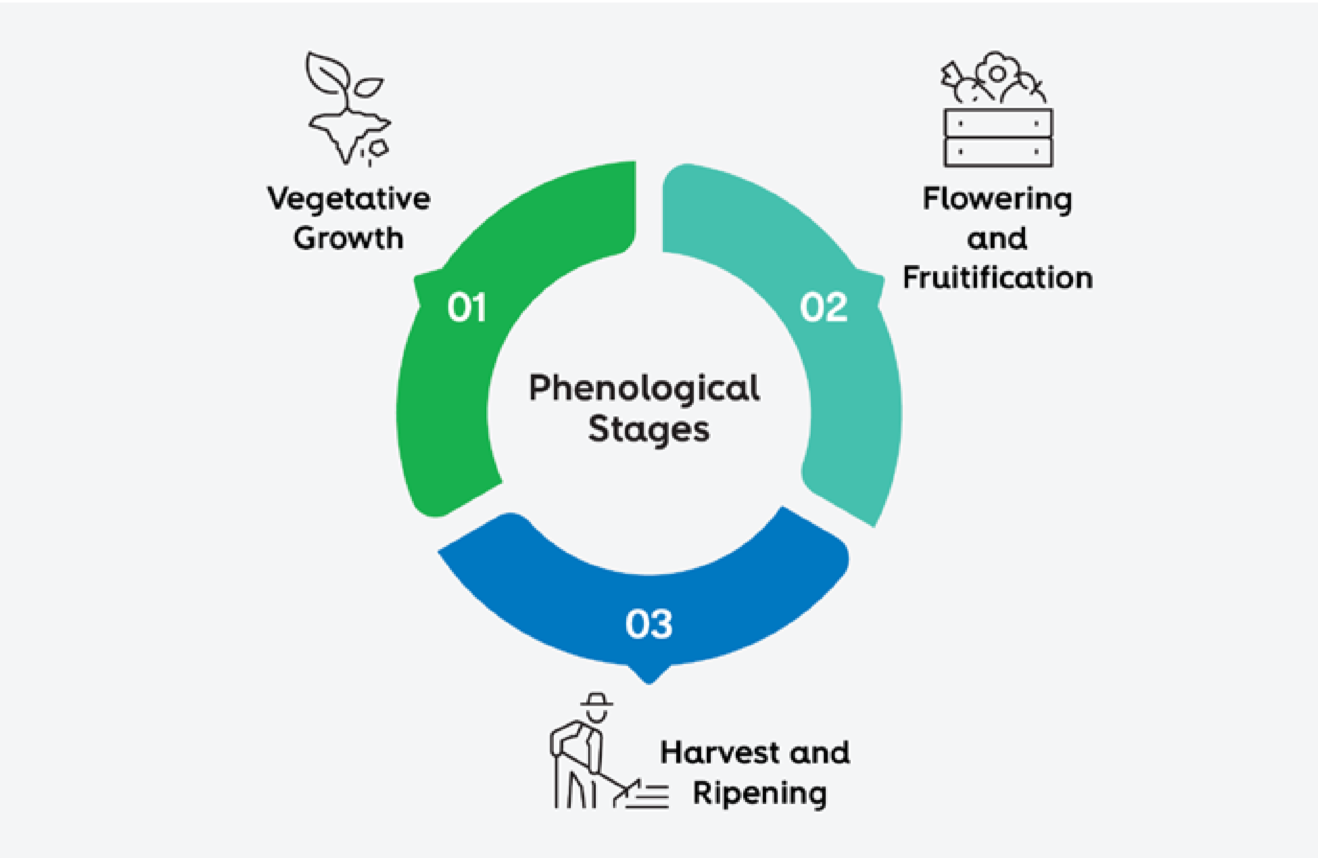


Figure 1 – Phenological stages

To perform these studies, the cultural practices, irrigation, and fertilization management of the banana plots are recorded in the field using a cloud monitoring platform.

The project has successfully implemented this monitoring platform able to collect a set of soil, weather, and leaf parameters with near real-time updates that are also of extreme importance since the stored data can provide historical values of those parameters for future studies.

Having this technology applied to the field is of the utmost importance in understanding how to increase crop yield, especially under different weather and soil parameter conditions.

The overall system architecture is presented in the next section.

High-level system architecture

The overall system architecture designed for the project is represented in **Figure 2** and is divided in four layers:

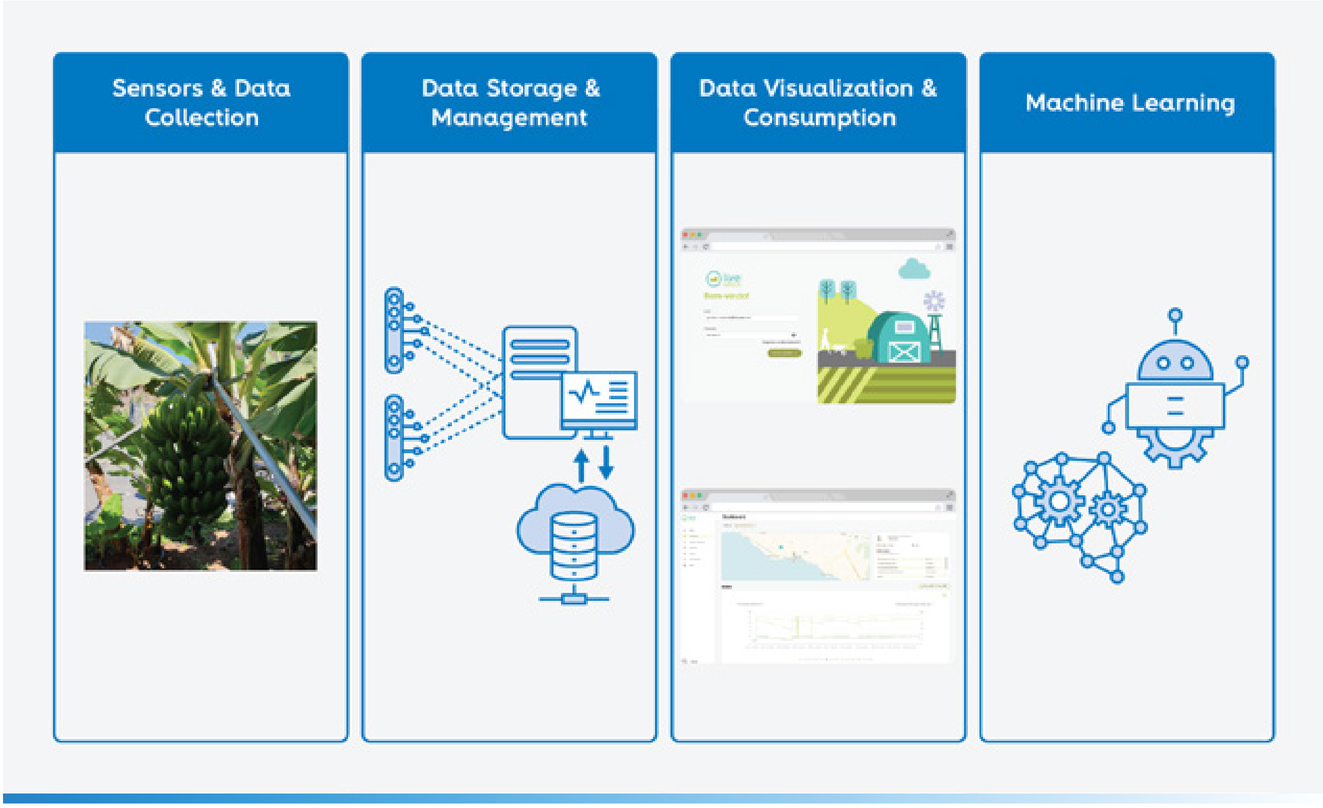


Figure 2 – High-level system architecture

1. Sensors & data collection: In this layer, the system collects data from several types of sources. Banana plants have sensors to measure several parameters from air and soil, which communicate with the data storage & management layer through the gateway adapters using a SIM card with 4G mobile data. The user may also insert morpho-agronomic data collected manually.
2. Data storage & management: This is the layer where the data is transformed and stored in Altice Labs' Live!Data service platform [6]. This platform consists of a backend server and several gateway adapters that communicate with the sensors, receive the data, validate it and parse it into a format compliant with the database. The backend server exposes an API to retrieve the data, get analytics, and process the data.
3. Data visualization & consumption: Altice Labs' Live!Green application, which runs on top of the Live!Data service platform, provides the user with a dashboard where it is possible to see the last values read by the sensors, some historical information, and the geolocation of each sensor. In this dashboard, the user can compare the values read by the sensors over time and analyze the historical information to make the best

decisions and learn from the data collected. Another feature available in this platform is that the user can write the readings of each state about the morphological data and store photos from each plant in the field. Also, in this layer, authorized entities may access the data through a representational state transfer (REST) API from the backend server (in the middle layer). The data is available in JavaScript object notation (JSON) format or as a comma-separated values (CSV) file.

4. Machine learning: This layer is responsible for recognizing patterns and getting hidden knowledge from the data stored on Altice Labs' Live!Data platform, and for predicting events from the data collected. This layer is where the user will get the benefits from the work and the investment in the previous layers (sensing, storing, and displaying the data). Data is read from the data storage layer and processed with adequate machine learning algorithms to retrieve knowledge from it. This layer is being developed in partnership with the University of Madeira (UMa): LARSyS [7] and ISOPlexis [8].

Sensors & data collection layer

To monitor the development of the banana plant, a set of deployed sensors can read soil and climate parameters. To gather this information, the sensors connect to a 4G communication node (namely, the Waspmote Plug & Sense! Smart Agriculture Xtreme [9]) to transmit data to the Live!Data service platform.

These sensors and nodes are deployed in two sites: Ponta do Sol and Lugar de Baixo. Each site has four communication nodes with the following connections:

One node is connected to a MaxiMet GMX-240 weather station [10], providing the following climate air parameters: air temperature, air pressure, air humidity, wind direction and speed, and total precipitation and precipitation intensity.

Each one of the other three nodes is connected to the following sensors:

- The TEROS 12 soil sensor [10] provides the following soil information: soil temperature, electrical conductivity, dielectric permittivity, and volumetric water content;
- The NPK sensor [11] provides information about nitrogen, phosphorus, and potassium;
- The Pythons 31 leaf surface wetness sensor [10] simulates the behavior of a plant leaf, where it is possible to gather the humidity information from one leaf.

Data from the above sensors are fed automatically into the service platform.

Besides this sensing data, conventional laboratory methods, such as the manual collection of morpho-agronomic data, can be uploaded to the service platform. This morpho-agronomic data is classified into three different development stages and nutritional evaluation, shown in **Table 1**.

Vegetative Growth	Flowering and Fruitification	Harvest and Maturation	Nutritional Evaluation
• Pseudo-stem height • Diameter of the base of the pseudo-stem • Perimeter of the middle third of the pseudo-stem	• Flowering time • Number of fruits in the bunch • Peduncle length	• Crop cycle • Number of hands • Number of fruits/ hand • Fruit length • Fruit diameter • Fruit weight • Bark thickness • Pulp color at ripening • Texture	• Ripeness coefficient • Water content • Total minerals • Crude fiber • Sugar content • Protein content

Table 1 – Morpho-agronomic data classification

In this study, the plant development in the different phenological stages uses a statistically significant number of plants (n=40). Photos from each banana plant are taken regularly and uploaded to the platform for analysis.

To develop a robust growth model for the Madeira banana plant, it is necessary to evaluate two production cycles of the banana crop in two edaphic conditions (summer and winter periods).

Data storage & management layer – Live!Data service platform

Altice Labs' Live!Data is the service platform that gathers data from various sources and provides several tools to enrich, process, and get analytics of the data collected. This platform serves different sectors such as industry, agrotech, smart cities, etc.

The platform has virtual representations of the actual sensors that allow the users to manage the devices and organize the information to send through the API. It also enables the user to collect processed data such as averages, maximums, minimums, etc.

Data visualization & consumption layer - Live!Green application

Live!Green is an end-user application providing data management and visualization tools for data gathered from the Live!Data underlying service platform.

Figure 3 depicts the main page of the Live!Green application, showing each site location, Ponta do Sol and Lugar de Baixo, represented by a circle with the number of nodes inside each circle.

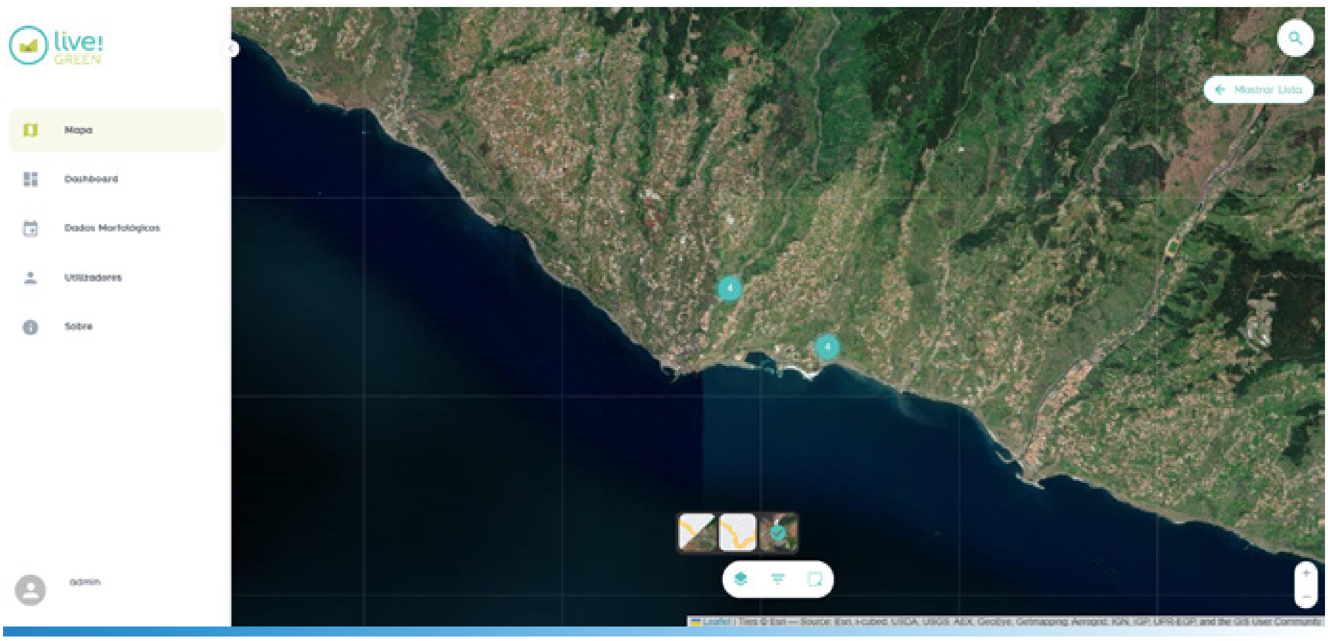


Figure 3 – Sensors location in the two sites

After choosing a given site, detailed information is presented to the user within all the different site nodes. By selecting each node, it is possible to get all values from all the sensors present on this node, within a given time slot (**Figure 4**).

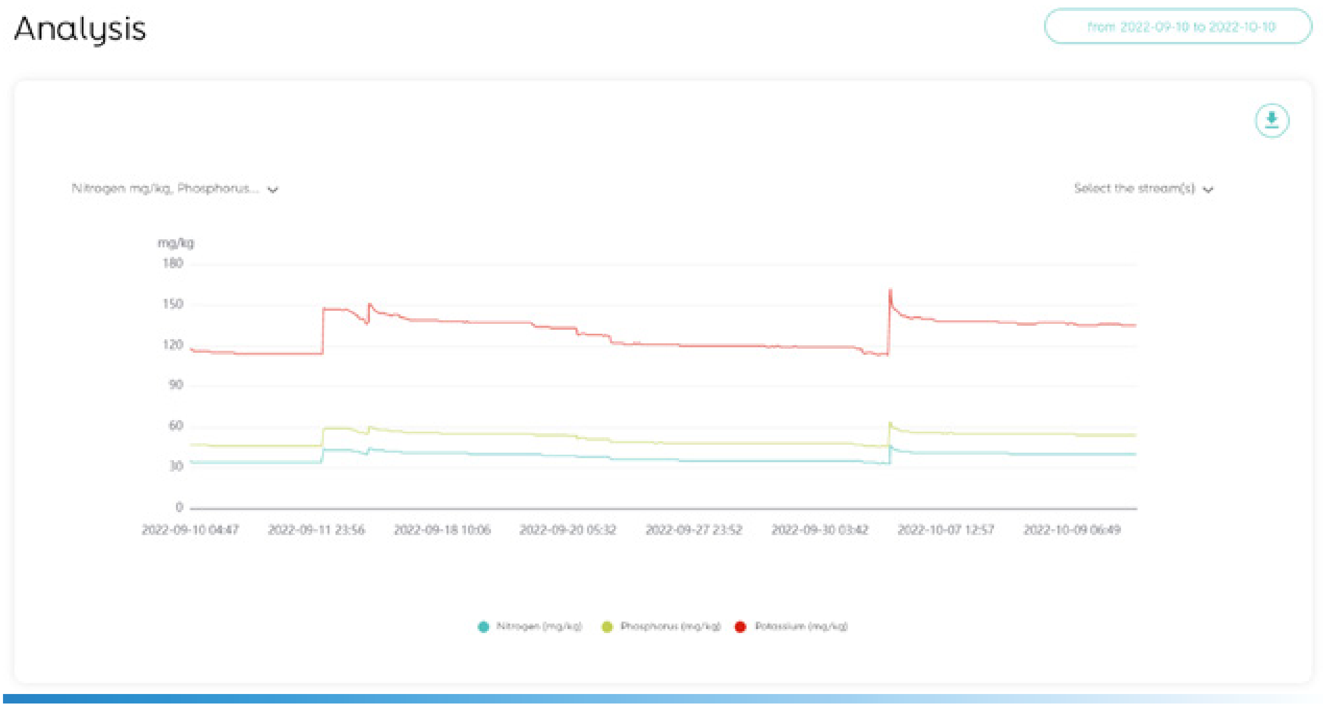


Figure 4 – Graphic with sensor comparisons

Machine learning layer

The sensing of the banana plantation, and collecting and storing this data in the Live!Data platform allowed the use of machine learning techniques to analyze and study the data collected during the growth of bananas. Two approaches using data-driven and machine-learning techniques were developed for analyzing banana cultivation.

The first approach considered a long period of tracking to identify which factors can contribute the most to banana maturation and to assess which information in the data can be used to follow the development of the banana bunches. For this purpose, the developed model was based on examining the data collected by the sensors, used as features to be fed to a machine learning model. When the banana bunches are harvested, the sensor's data will be used to backtrack the changes over the months to determine which information correlated the most with the maturation period of the banana. For this purpose, the feature selection procedure will be used to determine the most relevant sensor while removing redundant information, reducing the total number of needed sensors. Afterward, a heuristic optimization procedure will be employed to optimize the regression model architecture. As the volume of data is limited to only one banana maturation cycle, the use of conventional machine learning models is needed, testing different methodologies to determine which is more suitable for this problem. Subsequently, the developed model will be connected to the Live!Data platform to allow forecasts to be available for the user. The combination of both machine learning and the Live!Data platform potentiates the examination capability in agrotech. The proposed methodology is presented in **Figure 5**.

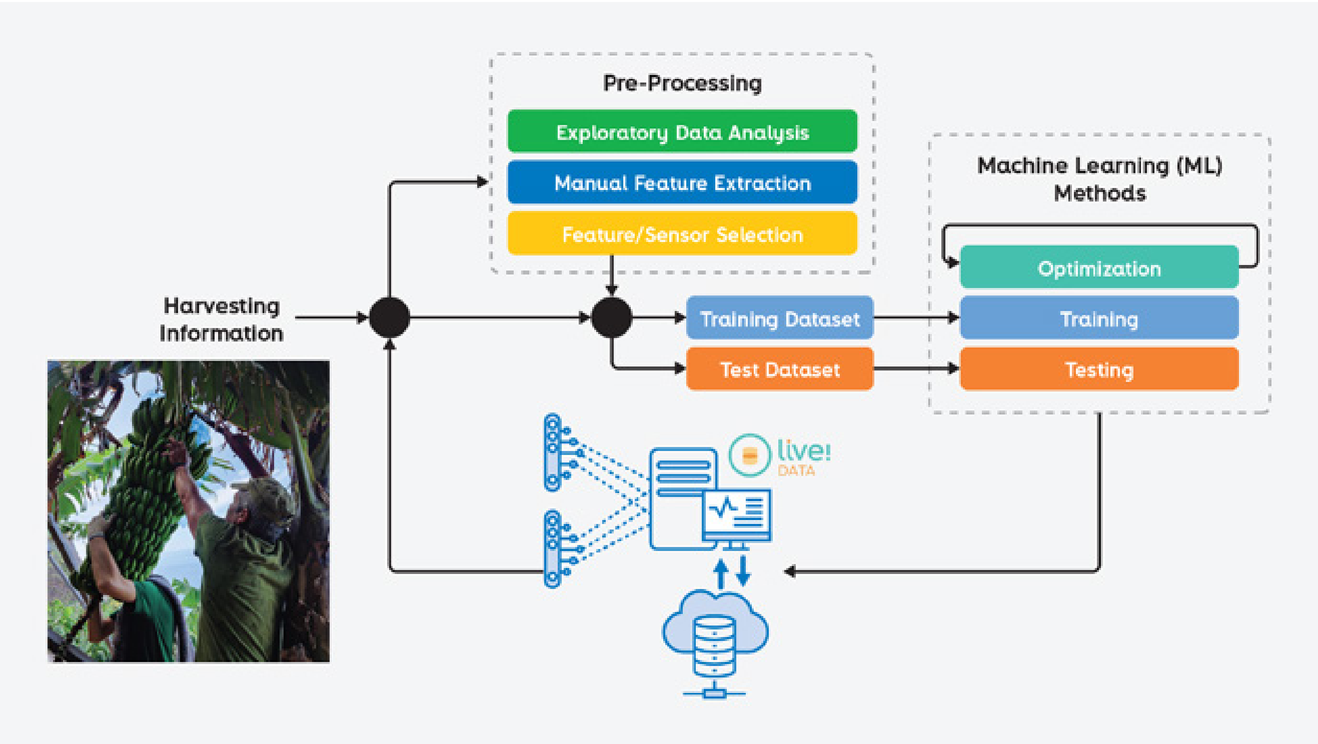


Figure 5 – Developed procedure for automating the banana maturation prediction using a combination of machine learning and data from the Live!Data platform

The second approach aimed at creating a contactless tool to help identify the banana harvestability and automate the banana analysis.

The central concept was segmented into three steps:

1. Target detection, where the goal was to identify the banana bunch in the images successfully. Such was accomplished using a machine learning model trained for object detection, isolating the image pixels corresponding to a banana bunch.
2. Identify the harvestability of the bunch by consulting the expert opinion, leading to the production of a second dataset, where each bunch was labeled with a unique number. This second dataset was then used to build the primary machine learning classifier, which evaluates the harvestability of the bunch.
3. Implement both machine learning models in a smartphone application, capable of automatically identifying the banana bunches and detecting their harvestability.

The proposed methodology is presented in **Figure 6**.

Figure 6 – Procedure developed to automate banana analysis

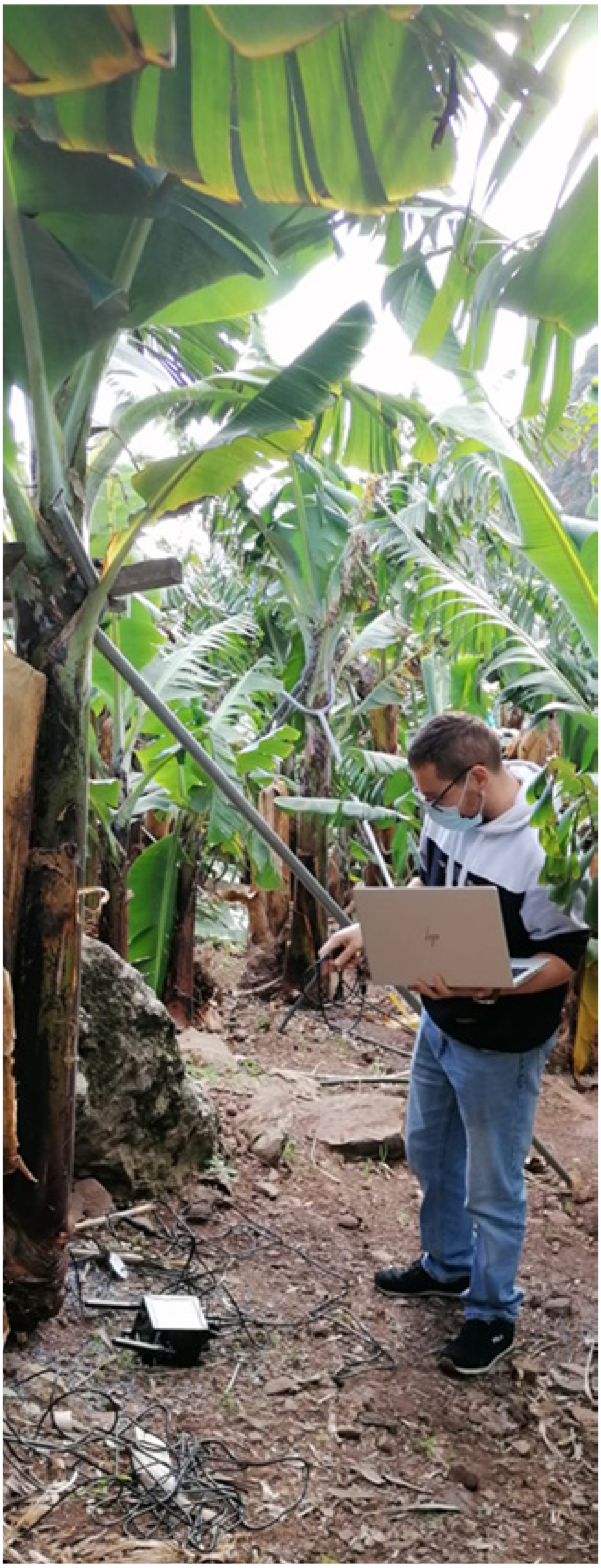
Preliminary conclusions and future perspectives

Food and agricultural companies are increasing investments to integrate IoT solutions in some of their processes to cut down costs, increase the quality and quantity of the harvest, and improve some of the routine activities of the farmers. IoT leverages farmers to get connected to their farms from anywhere and anytime.

By using IoT technology, the BASE project aimed to develop the application of precision agriculture technologies to control the banana production cycle, allowing the decision-maker to manage the harvesting time point with precision. The project oversees the existence of field agronomic essays and quality analysis to validate the information obtained through sensors, evaluation of crop water requirements, and data analysis. Although conventional laboratory methods may offer highly accurate analysis of soil chemistry, in situ-based soil nutrient sensors that provide real-time feedback are needed to indeed increase farming and environment management efficiency.

Altice Labs' cloud Live!Green application enables users to visualize and analyze data as a first demo of the future product, allowing them to identify critical issues and help them make decisions. It is, therefore, possible to obtain and manage knowledge about precision farming with remote sensing applications in banana crops. The deployment has also allowed us to identify and characterize two concrete plantain crop areas thanks to the wireless sensor network.

Users will save time in the field since they do not have to physically access the work field whenever they need to check something. Compared to conventional lab instruments for soil nutrient analysis, in situ-based sensors are more advantageous due to their low-cost and high-density measurement capability for large-area soil nutrient mapping.



For the morpho-agronomic data, preliminary results showed good phenological evolution of the banana plants in the vegetative growth stage (**Figure 7**). It is expected that this behavior will be maintained in the other stages.

Figure 7 – Morpho-agronomic evaluation of banana plants

The data of other phenological stages is required to highlight a draft of the first model of banana plant development. Additionally, the water and irrigation requirements of banana plants are also under study. The banana water balance was calculated through evapotranspiration by the Food and Agriculture Organization of the United Nations (FAO) Penman-Monteith equation [12] (**Figure 8**).

$$ET_0 = \frac{0.408\Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34u_2)}$$

Legend

ET_o - reference evapotranspiration (mm day^{-1})
R_n - net radiation at the crop surface (MJ m^{-2} day^{-1})
G - soil heat-flux density (MJ m^{-2} day^{-1})
T - mean daily air temperature (°C) at 2m height
u_2 - wind speed at 2m height (m s^{-1})
e_s - saturation vapor pressure (kPa)
e_a - actual vapor pressure (kPa), based on relative humidity measurements
$(e_s - e_a)$ - saturation vapor pressure deficit (VPD) (kPa)
Δ - slope of the vapor pressure curve (kPa $°C^{-1}$)
γ - psychrometric constant (kPa $°C^{-1}$)

Figure 8 – FAO Penman-Monteith equation

Preliminary meteorological data highlighted the need for an adequate irrigation supplement for the plantation to support the plant's growth and development and achieve an adequate management of water resources.

On the other hand, using artificial intelligence paves the way for farmers to optimize production and minimize resource utilization. The project gathers and compiles information on other variables that influence growth, production, and fruit maturation to elaborate the Madeira banana growth model, allowing the usage of machine learning algorithms and predictive analytics to foresee when banana fruit will reach maturity.

This approach of using machine learning based on image analysis for banana harvesting is brand new and allows the examination to be carried out in a non-destructive way. The machine learning model was based on transfer learning, using a pre-trained deep learning model developed using millions of images to optimize its capability of image-based feature extraction. Therefore, by using transfer learning, the problem associated with the need for extensive data volume is lessened, allowing the development of the model with fewer images.

Hence, this automation proposal aims to improve and standardize laborers' work, saving this domain knowledge to real industry experts and preserving the knowledge by making machine learning models and a continuously growing dataset.

Potential future challenges and development directions have to do with improving data reliability, given that the banana production cycle is around 12 to 14 months and the project lasts 18 months.

Thus, it is essential to consider at least two banana growth cycles to collect as much data as possible to ensure that machine learning algorithms are fed with a large number of datasets.

Another improvement for the project is correlating ferti-irrigation data with other data in the Live!Data platform to have better knowledge of the nutrients necessary for improving banana plants' productivity.

Moreover, it could be helpful to use sap flow sensors in this study, as sap flow measurements may be a sensitive and accurate method to determine the whole-plant water and nutrient needs during banana plants' development. The correlation of this data with the agroecological conditions of the banana location fields in Madeira would add great value to improve plant productivity on the whole Island.

References

[1] M. Blakeney, "Agricultural Innovation and Sustainable Development," Sustainability, vol. 14, p. 2698, 2022

[2] C. G. Sousa, "Comercialização de banana aumentou 18,4% na Madeira," Jornal Económico, 25 May 2022. [Online]. Available: https://jornaleconomico.pt/noticias/comercializacao-de-banana-aumentou-184-na-madeira-897533

[3] GESBA, "Banana da Madeira - um setor em crescimento," 3 July 2013. [Online]. Available: https://dica.madeira.gov.pt/index.php/agricultura-geral/238-banana-da-madeira-um-setor-em-crescimento

[4] GESBA, "GESBA – Empresa de Gestão do Sector da Banana, Lda. – uma aposta no crescimento sustentável e continuado da Banana da Madeira," 16 July 2014. [Online]. Available: https://dica.madeira.gov.pt/index.php/outros-temas/diversos/685-gesba-empresa-de-gestao-do-sector-da-banana-lda-uma-aposta-no-crescimento-sustentavel-e-continuado-da-banana-da-madeira

[5] K. Jayachandran, B. Lamar and S. Bhansali, "Review - The "Real-Time" Revolution for In situ Soil Nutrient Sensing," Journal of The Electrochemical Society, vol. 167, no. 3, p. 37569, 2020

[6] Altice Labs, "Live! Data Management," Altice Labs, 2022. [Online]. Available: https://www.alticelabs.com/products/data-management/

[7] LARSyS, "Interactive Technologies Institute - Laboratory of Robotics and Systems in Engineering and Science," 2022. [Online]. Available: https://iti.larsys.pt/

[8] ISOPlexis, "ISOPlexis - Centro de Agricultura Sustentável e Tecnologia Alimentar," ISOPlexis - Universidade da Madeira, 2022. [Online]. Available: https://isoplexis.uma.pt/

[9] Libelium Comunicaciones Distribuidas S.L., "Libelium's new Smart Agriculture Xtreme Sensor Node Provides Maximum Accuracy for Crop Monitoring," Libelium, 5 June 2018. [Online]. Available: https://www.libelium.com/libeliumworld/libeliums-new-smart-agriculture-xtreme-sensor-node-provides-maximum-accuracy-for-crop-monitoring/

[10] libelium.com, "Sensors probes," 2021. [Online]. Available: https://development.libelium.com/smart-agriculture-xtreme-sensor-guide/sensors-probes

[11] JXCT, "Soil NPK Meter RS485 Precision Soil Fertility Nutrient Sensor for Agriculture," JXCTIoT, 2022. [Online]. Available: http://www.jxct-iot.com/product/showproduct.php?id=190

[12] R. G. Allen, L. S. Pereira, D. Raes and M. Smith, Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper, vol. 56, FAO, 1998

Acronyms

4G	Fourth generation mobile networks
API	Application Programming Interface
ARDITI	Regional Agency for the Development of Research, Technology and Innovation
CSV	Comma-Separated Values
EAFRD	European Agricultural Fund for Rural Development
FAO	Food and Agriculture Organization of the United Nations
GESBA	The Banana Sector Management Company of Madeira Island (GESBA-Empresa de Gestão do Sector da Banana, Lda)
IoT	Internet of Things
JSON	JavaScript Object Notation
REST	Representational State Transfer, an architectural style for developing web services
SIM	Subscriber Identity Module
UMa	University of Madeira

Acknowledgements

The authors would like to thank the invaluable collaboration of:

- Gonçalo Machado, Iúri Viveiros, Pedro Carvalho, and Fausto Carvalho, from Altice Labs.
- Helena Garcês, Francisco Silva, Rúben Sousa, Rui Gouveia, Jorge Dias, and Artur Lima, from GESBA-Empresa de Gestão do Sector da Banana, Lda.
- João Neto, Pedro Sousa, Gregório Freitas, Carla Gouveia, from ISOPlexis Centre Sustainable Agriculture and Food Technology – Madeira University.
- Fábio Mendonça, Sheikh Mostafa, Ahatsham Hayat, Preety Baglat, from Interactive Technologies Institute / Larsys and Universidade da Madeira.
- Carlos Gomes , from ARDITI - Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Inovação.
- Pedro Abreu, Filipe Freitas, and Jorge Sequeira, from Altice Portugal.

Fundings

- LARSyS (Project- UIDB/50009/2020), and M1420-01-0247-FEDER-000033.
- Project BASE: BAnana SEnsing (PRODERAM20-16.2.2-FEADER-1810).
- ARDITI – Agência Regional para o Desenvolvimento da Investigação, Tecnologia e Inovação under the scope of the project M1420-09-5369- FSE-000002 – Post-Doctoral Fellowship, co-financed by the Madeira 14-20 Program - European Social Fund.

Authors

Nuno Silva

Product Manager

Altice Labs, Portugal

nunos@alticelabs.com

www.linkedin.com/in/nuno-silva-9a62851

Diana Côrte

Director of Quality and Management Systems

GESBA - Empresa de Gestão do Sector da Banana, Lda, Portugal

diana.corte@gesba.pt

www.linkedin.com/in/côrte-diana-b9530391

Miguel Ângelo Carvalho

Associate Professor

ISOPlexis Centre Sustainable Agriculture and Food Technology – Madeira University, Portugal

miguel.carvalho@staff.uma.pt

https://www.linkedin.com/in/miguel-carvalho-b12165112

Morgado Dias

Associate Professor

Interactive Technologies Institute / LarSys and Universidade da Madeira, Portugal

morgado@staff.uma.pt

https://www.linkedin.com/in/morgado-dias-b631883

Contacts

Address
Rua Eng. José Ferreira Pinto Basto
3810 - 106 Aveiro (PORTUGAL)

Phone
+351 234 403 200

Media
contact@alticelabs.com
www.alticelabs.com