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Big Wine Optimization Use Case: An IoT European Large Scale Pilot in Viticulture

Mario DIAZ NAVA [a1] Barna KERESZTES [b], Olivier SOMMIER [c], Léa CIMETIERE [c], Jean-Pierre DA COSTA [b], Christian GERMAIN [b], Jean-Jacques DUBOURDIEU [d]
[a] *STMicroelectronics (Grenoble 2) SAS, F-38019 Grenoble, France*
[b] *Université de Bordeaux, CNRS, IMS, UMR 5218, F-33405 Talence, France.*
[c] *Ertus Group, F-33100 Bordeaux France*
[d] *Denis Dubourdieu Domaines, Château Doisy Daëne, F-33720 Barsac, France*

Abstract. As part of the Internet of Food & Farm project for the adoption of IoT in the agri-food sector, this paper presents the design, implementation, and evaluation of an end-to-end and open IoT system architecture. This use case aims to further improve the entire viticulture value chain in a renowned estate of 135 ha in the Bordeaux area (France). Based on the first generation of end-devices (~74) and gateways, the team designed the system's architecture and relied on a LoRa network to collect and analyze the environmental data that would ultimately allow them to optimize resource consumption, improve vine yield and wine quality.

Keywords. Sensors, IoT, End-devices, Gateway, LoRaWAN, network, data analysis, middleware, AI/ML, Edge computing, Local Network, precision viticulture and Decision Support System

1. Introduction

Big Wine Optimization (BWO) was part of IoF2020 (Internet of Food and Farm 2020) [1] project, a H2020/Large Scale Pilot funded by the European Union to accelerate the adoption and deployment of IoT technologies in the agri-food sector. Electronic components and systems plays a key role in precision agriculture and viticulture [2], bringing efficient and cost-effective solutions [3] to provide decision making data to the winegrowers [4].

BWO aims to: 1) **Improve the vine yield and wine production** by defining and implementing an IoT system able to gather the data, coming from different vineyards and wineries, to perform data analysis, system and risk management, and decision making. 2) **Provide** to winegrowers and producers **new tools to optimize resources** (manpower, fertilizers, materials, electricity, water, etc.) and preserve the environment by reducing the use of pesticides, carbon footprint, etc. 3) **Deploy a cost-effective precision viticulture** management and a global vineyard control system **to increase competitiveness**. 4) **Optimize** the use of inputs in winemaking by controlling **environmental factors affecting the process** (temperature, humidity, oxygen, etc.).

[1] Corresponding Author, Mario DIAZ NAVA, STMicroelectronics (Grenoble 2) SAS, 12, Rue Jules Horowitz, 38019 Grenoble | France; E-mail: mario.diaznava@st.com

BWO addresses the following main challenges: 1) Real time weather conditions monitoring at parcel and vineyard level. 2) Managing a high number of vineyards with data driven applications. 3) Optimize water resources during wine production. 3) Optimize the wine production and preserve its quality. 4) Reduce the costs related to the production by increasing inputs efficiency. 5) Preserve the environment (reduction of carbon footprint, better control of water and electricity use, recycle vine and wine waste). 6) Compliance with ISO 14001 and HVE 3 certifications.

The rest of this paper is organized as follows: Section 2 provides a complete description of the IoT system deployed. Section 3 presents the results obtained. Section 4 concludes this paper and discusses the evolution of the IoT system considering the arrival of intelligent end-devices and the benefits to move from a Cloud to an Edge computing solution.

2. Material and Methods

This project started in 2017, when the IoT solutions were based on GSM communication using SIM-card [5]. At that time, new communication solutions arrived on the market as SigFox [6] and LoRa [7]. From the beginning of the project, the choice was to implement a Local Area network based on LoRaWAN. The rationale behind this choice was for technological and economic reasons. LoRaWAN supports the upstream and downstream communication, necessary to deploy a local area network supporting sensors and actuators. SigFox was mainly designed to support the upstream communication. GSM and 3G/4G solutions were not the right choice due to the business model (payment based on the number of sensors and among of data transmitted) and low autonomy, the devices were not optimized low-power consumption From another side, LoRaWAN was subscription free (cost saving in communication for the farmer) and allowed to build an ad hoc network according to the farm needs. The range of LoRa gateways allowed covering the large experimental area using only a few gateways [8].

2.1. Description of the experimental site

Figure 1. Denis Dubourdieu Domaines located in Barsac, Graves and Cadillac areas.

The IoT System was deployed in the 5 vineyards belonging to *Denis Dubourdieu Domaines* (DDD) [9]: *Doisy-Daëne*, *Floridène, Reynon*, *Cantegril* and *Haura*. The estate is in Barsac, 30 km south-east of Bordeaux, France (Figure 1). Each vineyard has its own winery. The vineyards total surface is 135 hectares and the distances between two vineyards goes from 1 km up to almost 10km for the two farthest. The terrain is hilly and the various sites are not visible in a direct line from each other.

The goal of this deployment is to validate in large scale that an IoT system architecture can be scale up and correctly working end-to-end system with more than 74 end-devices (around 150 sensors) to monitor the vineyards and wineries of the 5 vineyards constituting DDD. The data gathered from the end-devices distributed in the estate are analyzed for decision-making to improve the vine yield and wine quality. The first sensors were deployed in 2018 in *Doisy-Daëne* and *Floridène* domains and were extended in 2019 to *Reynon*, *Cantegril* and *Haura*.

2.2. Global Architecture of the end-to-end IoT System

Figure 2 depicts IoT System Architecture implemented in DDD composed of 3 domains:

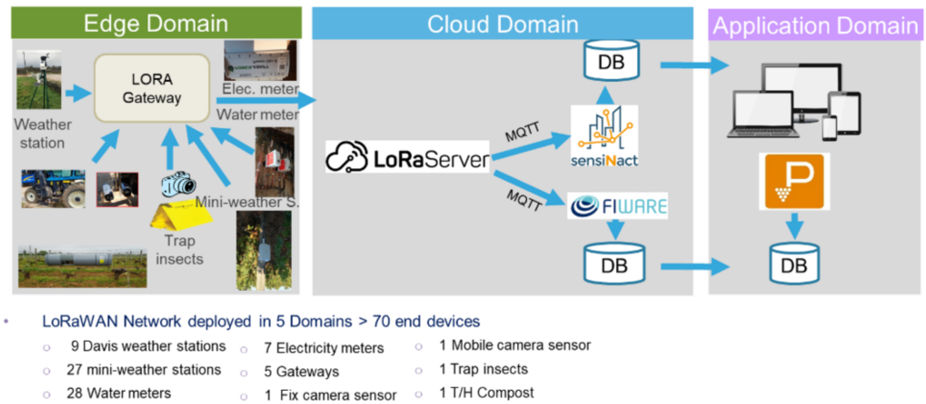

Figure 2: IoT System Architecture

Edge domain: it contains the end-devices interacting with the environment to measure the weather conditions and the vine phenological stages of vineyards as well as the environmental conditions in the wineries.

Cloud domain: A secured LoRaWAN server is used to subscribe and monitor the sensor-nodes deployed, to recover the data coming from the LoRaWAN gateways and in conjunction with the SensiNact and FiWire middleware, they decapsulate the data and store it in a database for its analysis. The LoRa server is based on a secured MQTT protocol supporting by the two middleware [10].

Application domain: processes the results obtained from data analytics according to the application requirements to help the end-user for decision-making. A dashboard is provided to facilitate the exploitation of the whole results by the end-user. This is done through the user interface of the Process2Wine management software.

2.3. LoRaWAN Network

Five LoRaWAN Gateways were deployed to gather the data coming from end-devices distributed in the vineyards and wineries in DDD. In each *Doisy-Daëne* and *Cantegril* domains was installed a LoRa Lorrier LR2 gateway. Three Kerlink gateways were deployed in *Reynon, Floridène and Haura* premises.

The end-devices encode the raw data in Cayenne LPP [11] and send them, through the LoRa protocol, to the gateways where they are encapsulated in the IP protocol. These new frames are sent by the ADSL modem, available in each winery, through Internet to local cloud. To ensure a good communication, the local connection between the gateway and the ADSL modem is done via Ethernet rather than WiFi.

2.4. End devices to measure weather conditions

Figure 3 shows the weather-monitoring end-devices [12] developed and connected to the LoRa Network:

- The commercial Davis weather station "Vantage Pro2" was adapted and connected LoRaWAN network to measure temperature, humidity, barometric pressure, rain fall, wind direction and speed, and solar radiation. 9 stations were deployed to monitor the weather conditions in the five vineyards. Figure 3a shows a Davis weather station, with its LoRa adapter and solar panel.
- A mini-weather station was specifically developed by HopU company and connected to the LoRa network to measure only temperature and humidity. The goal is to measure weather conditions with higher precision and identify micro-climes. To reach this goal; these stations were deployed every 2.5 ha. 8 mini-weather stations were deployed 5 in *Doisy-Daëne* and 3 in *Floridène*.

Figure 3: (a) Davis Weather station. **(b)** Mini-weather station

2.5. End-devices to monitor the health and growing stages of the vine.

Three types of end-devices, using optical sensors, were developed to monitor the evolution of the health and growth of the vine.

Figure 4: (a) Image from MobiCam for berry detection and counting; **(b) (c)** MobiCam on a tractor.

The *MobiCam* prototype camera sensor, developed by IMS, is attached to a tractor and acquires an image of each vine plant during cultivation operations. The imaging system is composed of a 5 Mpixels industrial Basler Ace global shutter RGB camera with a 55° horizontal field of view lens, a high-power 58GN xenon flash. An on-board industrial computer (4-core ARM chip) controls camera and the flash, and stores the acquired image data. The images, stored in a memory card, are externally processed to estimate the vine vigor (foliage surface in summer, volume of shoots in winter), abnormal coloring of the foliage or number and color of berries [13]. Figure 4a shows an image taken by the MobiCam to monitor the yield expectation. The flash is used to reduce the shade and to be independent of the weather conditions. The MobiCam is shown in Figure 4 bc.

The *FixCam* prototype camera sensor was developed by IMS. It is mainly composed of a Raspberry Pi model A, a Raspberry Pi camera v2 without infrared filter and a white lighting and a near infra-red lighting. The sensor is placed in a plot to monitor the vine. The images are taken every night to ensure homogenous artificial light condition. They are processed internally and the resulting data, indicating the evolution of the vine vigor (surface, porosity of the foliage), are sent to the system through the LoRa network. Figure 5a shows the vine on each image taken by the prototype sensor depicted in Figure 5b.

Figure 5: **(a)** Photo taken to berry vine growth monitoring. **(b)** FixCamsensor

The *CapTrap* camera sensor (developed by Cap2020 company and adapted to LoRa) detects the presence of insects and send their number on the LoRa network every day. Figure 6 shows the insects captured by CapTrap, and the device itself.

Figure 6: **(a)** Insects detected and counted on the trap. **(b)** CapTrap insect camera sensor

2.6. End-devices monitoring the environment conditions and natural resources uses in the winery.

Nine end-devices/mini-weather stations were deployed: 7 in Doisy Daëne and 2 in Floridène wineries to measure the environment conditions temperature and humidity to monitor the wine aging conditions. Furthermore, 10 commercial end-devices (UC11-T1 from Ursalink) named as “micro-weather stations” were also deployed in the 5 wineries.

These devices are smaller with a lower power consumption than the "mini-weather stations" which is a key parameter for the end-devices.

28 Water meters were deployed in the 5 wineries for the different water source (potable, well water) to measure the water consumption used in the wineries for wine processing. Various type of Hydrao water meters, with different sensors technologies (Ultrasound and micro-turbine) and water pipes diameters were installed. The micro-turbine generates energy stored in a battery to ensure full water meter autonomy.

For security and conformity reasons, 7 Power-Elec 6, commercial electricity meters from Power-ADAPT, were deployed in each electrical cabinet of the 5 wineries.

2.7. Software

The software designed performs the processing at each system domain and ensure end-to-end system communication from data gathering by the sensors to the display of its values in the Process2Wine interface. Process2Wine [14] is a commercial vineyard and winery management software from Ertus Group and extended to support IoT. The software used is the following.

Camera embedded software: CapTrap sensor uses deep learning techniques to detect and count the insects in the field of the camera. The FixCam sensor uses NDVI computation and thresholding to estimate the vegetation surface on each image. For both cameras, the software in charge of these tasks is embedded in the end-device. The MobiCam uses both classical images tools (Hough Transform, Classification…) and Deep Learning techniques to detect vegetation and count the visible berries. The embedded computer performances of the MobiCam being insufficient for real time processing, the images stored in a memory card are processed later on a desktop computer. A new MobiCam is under development to process the images online and send the results (metadata) through the LoRA network.

LoRa Server: TTN was used at first as LoRa server, to test and validate the end-to-end LoRaWAN communication. However, this solution did not match the project goals: to have a secure solution, to avoid dependency from third suppliers, to avoid unnecessary communication overhead. i.e., the goal was to have a local area network and mastering all the software components to easily commercialize the project results. For this reason, the LoRa server software was customized for our system solution.

Middleware: sensiNact [15] and FiWare [16] were integrated and debugged in the developed IoT System. Thanks to the adoption of Cayenne LPP, few additional developments were required to easily adapt the data sent by the new end-devices such as the water and electricity meters. This showed the architecture openness.

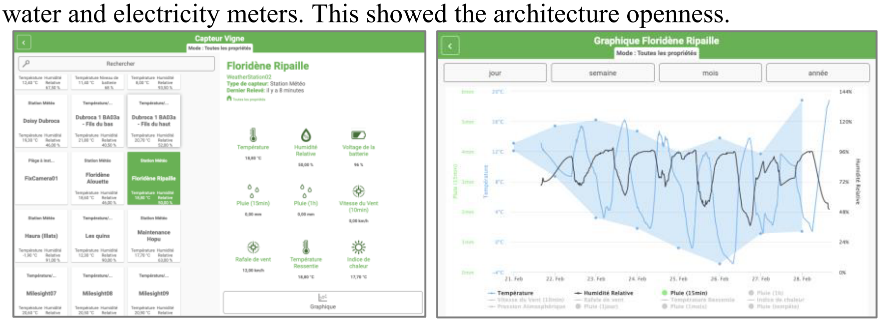

Figure 7 (a) Last value received from the Mini-weather station 08;
(b) 7 days Graph of Temperature and Humidity gathered from the Mini-weather station 08

User Interfaces: These interfaces (for desk and mobile), based on Process2Wine, were extended with an IoT Module to manage the information coming from each sensor deployed in the vineyards and wineries of DDD. The desktop interface allows to configure the sensors and to manage the access rights for the data display according to the users' rights. The mobile interface is a simplified interface that also allows viewing the data, coming from the sensors, generally filter by winery and vineyard. For instance, selecting by Vineyard in the interface, the user can see the last values received from the sensor selected. Figure 7a shows the last value (temperature and humidity) received from the Mini-weather station (deployed in the Doisy-Daëne vineyard), and Figure 7b shows the graph of these two parameters.

3. Results and discussion

3.1. Results

IoT end devices and Network Quality: Figure 2 summarizes the total number of devices (end-devices and gateways) deployed in DDD Estate. Table 1 gives the evaluation done, by domain, on the communication quality of the overall LoRaWAN network. It was noted that the quality is related to the distance between end-device and the gateway. For short distance the quality is good but for the long distance > 10 km can go from medium to low depending on the antenna gain.

Table 1. IoT system Evaluation in DDD Estate (Evaluation note +++ Good, ++ Medium, + Low)

Domain	Devices	Status	Eval.	Remarks
Reynon	10	Running	+++	
Cantegrill	10	Running	++	Intermittent data loss due transmission quality, distance between end-device and gateway >10 km
Haura	4	Running	++	Idem
Doisy-Daëne	35	Running	+++	
Floridène	15	Running	+++	

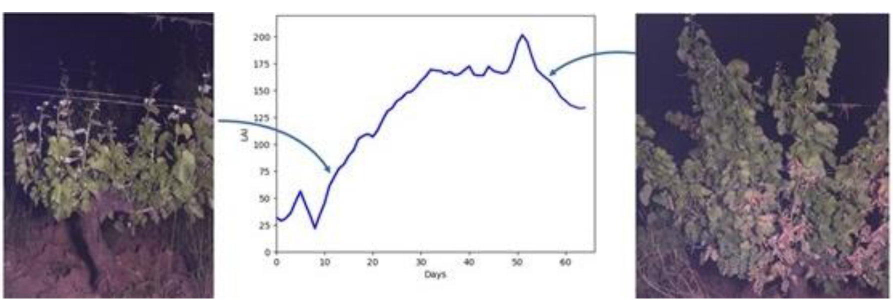

Figure 8: FixCam. Leaf Area Index (LAI) curve and the corresponding images.

Optical sensors: CapTrap sensor is operational and has provided insect counts all over the season; During the last season, the FixCam prototype has provided each night an estimation of the Leaf Area growth. The computation of this indicator is embedded in the sensor node, and only the indicator is communicated on the LoRaWAN network. Figure 8 provides an example of temporal curve for this Leaf Area estimation. The MobiCam prototype was used during two seasons in summer, on 5 plots in Floridène and Doisy Daëne. Figure 9 shows the resulting map of the number of berries detected.

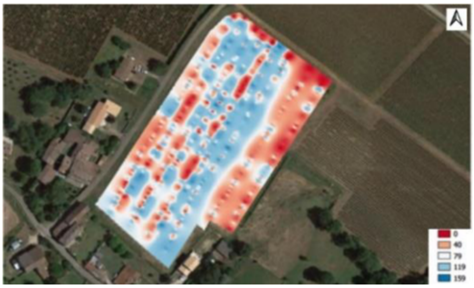

Figure 9: *MobiCam*. Map of the number of visible berries per vines, on a vine plot near *Floridène*.

Applications: From the data collected by the sensors, several models were created to meet the requirements of the wine growers. The models use the data collected by the sensors as a starting point but can also use other sources such as weather forecasts. For example, the frost model will anticipate the decrease in temperature observed on frosty nights. The frost model predicts the minimum temperature reached by the sensor located in the plot at the height of the vine buds. Under spring frost conditions, the temperature decreases regularly, reflecting a negative radiation balance at the level of the bud. In the observed conditions, this decrease can be expressed by equation (1) where *MTP* is the minimum temperature prediction, *TS* is the temperature at sunset, *ND* is the night duration and constants A = -5.79, B = 0.119 and C = 0.257:

$$MTP = A + B.TS + C.ND \qquad (1)$$

These factors are established for a given location since the soil play an important role in cooling depending on whether it is tilled or grassed. The meteorological station placed outside the plot, generally on a grassy surface, imperfectly reproduce this phenomenon.

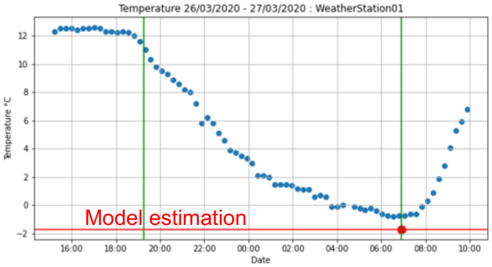

Figure 10. Spring frost model

Figure 10 shows the result of the model with data from the night of March 26-27 2020. The curve shows the rapid temperature decrease at the beginning of the night, then lower afterwards as recorded by the mini weather station. At the night end, a cloud must have developed covering the plot and limiting the cooling. Our model calculated a minimum at -1.8°C (red line) when the station only recorded -0.8°C at the minimum. The slowing down of the cooling in the last part of the night was due to the activation of the anti-freeze devices at 4 AM.

Thanks to the low-cost mini-weather stations, the winegrower can deploy several sensors in different points of the vineyard and to have a real-time picture of the temperatures within monitored plots. Then, he can regulate the intensity of the control means (candles, etc.) according to the observed temperatures and trigger them only in the places where it is necessary, which allows to make savings and to limit pollution. In conclusion, the models associated with each sensor predict locally the minimal temperature and allow a better anticipation.

3.2. Discussion

The main lessons learned, and actions taken between the beginning of the project and the IoT system large scale deployment in the DDD estate were the following.

LoRaWAN deployment: 1) To protect electricity and telecom networks against lighting: antenna with lighting protection was installed for each gateway. 2) To avoid the impact of the Voltage variation (which often happens in the farm premises), on the electronic devices (e.g., gateway) an inverter per gateway was installed to protect them. 3) To ensure the network coverage of the 135 ha of DDD, the distance between the end-nodes and gateways should be considered as well as the antennas gain. 4) To allow network interoperability for end-devices coming from different suppliers, the adoption of Cayenne Low Power Payload (LPP) allowed, with very few modifications in sensiNact, ensuring the right data decapsulation. 5) To adopt an Edge computing/ Private Network approach: This approach (having in the same server the SW related to the LoRa Server, the middleware, the data analysis close to the data source, and the DSS) provides higher system autonomy, higher security and privacy, higher reliability, near real time performances, less communication bandwidth use then energy saving. 6) To ensure system availability and higher reliability, a system monitoring was put in place to identify any anomaly to quickly fix it avoiding data lost. 7) To reduce energy consumption and increase end-devices autonomy, several actions were put in place such as reduce the frequency of transmitted data, use low power components, use solar panels, apply data coding technique to reduce the number of octets transmitted, etc.

More precise information: In the vineyard, a finer and more rigorous knowledge of local weather conditions are possible and through automated data processing to feed decision support systems (DSS) to implement precision viticulture based on plots characteristics especially for pests' management.

Education and experience: Put in use an IoT system is not an easy task and more difficult when it is a new technology to be deployed and interdisciplinary competences are required such: electronics, computer science, communication, agronomy, viticulture experts, CAD tools designers, data scientist, etc. This problem was experienced and the learning curb took time, introducing important delay.

Local support and maintenance: In top of education, one of the main issues in farming is to have well educated/trained people close to the farmers (locally) to provide support and maintenance in a short reaction time at cost effective. This is fundamental to introduce and accept by the farmer the adoption of this new technology.

4. Conclusion and perspectives

End-to-end operation of the IoT System, based on the LoRaWAN network was validated in the 5 DDD Estate. In general, the system is working well but the reliability is not yet so good as expected. Improvements are ongoing for instance the mini-weather stations replacement by other ones smaller and with higher autonomy. A gateway should be added to improve the LoRaWAN coverage, mainly for the end-devices located at more than 10 km from the closest waterway.

The algorithms used by the FixCam and the MobiCam must be completed to extend the possibilities of theses sensors use (growth stage monitoring, disease detection). Besides the FixCam, housing must be made more robust. The MobiCam image processing software must be embedded to obtain a viable "edge architecture".

The validation of the data analysis models is going to get insight information from the raw data and help the winegrower to take the right decisions.

Finally, the new generation of end-devices putting more intelligence and processing capabilities will help minimize data transfer and therefore overall energy consumption. Local processing (decision and action) will reduce the bandwidth and overall system latency as well as protecting local data integrity and confidentiality. Moving intelligence based on AI/ML to the Edge will be met through Ultra-Low power technologies in conjunction with innovative architectures and HW accelerators boosting the processing capabilities of microcontroller and sensors [17]. This technology evolution is in line with the Big Wine optimization project goal to have an Edge solution instead of in the Cloud.

Acknowledgements

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