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Towards Digital Twins for Multi-Sensor Land and Plant Monitoring

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Abstract

Small and medium-sized farms struggle with increased needs for monitoring in different dimensions, even by having to respond to regulatory requirements, e.g., by the global push to reduce pesticides and to improve soil health. Moreover, with the rising needs for food production there has been an effort to shift agriculture into a new era, in which the sector needs to be modernized by using new digital technologies. The goal of our research work is to provide farmers with a reliable ”digital twin”, i.e., a monitoring ecosystem that allows them to visualize multi-sensor data collected from their fields, but also to ”plug in” predictive models, e.g., for plant disease prediction. The paper presents an extensible solution, designed in co-creation with stakeholders, that can use a wide range of ”sensors”, ranging from free satellite images, low-cost off-the-shelf sensors, to even novel technologies, such as odour sensors. The TWINSOR concept is introduced, but also a first prototype applied to the vineyard is described as a first result.

Keywords: digital agriculture; IoT; multi-sensor monitoring; digital twin; vineyard; mobile application; HCI.

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1. Introduction

With the rising needs for food production there has been an effort to shift Agriculture into a new era, requiring a sector modernization by using new digital technologies and through the development of new agricultural concepts, such as, Precision Agriculture, Smart Farming and Digital Agriculture. This revolution has been a catalyst for the

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development of many tools that aim to help farmers to accomplish some of the most common tasks. Despite this, Agriculture seems to have fallen behind other industries since there is a limited investment in the use of new sustainable smart farming technologies (SFT). There are different reasons for this, such as, the high prices of these systems when farmers tend to operate on very strict budgets, the inability to effectively use the tools as many of the farmers belong to an older age group tending to have low tech education, and even a large discrepancy between the daily work requirements and the ability of new technologies and their users to meet these requirements [12].

There are applications that are capable of managing irrigation systems, some that help farmers choose the right fertilizers for crops, others that measure fruit and vegetable yield, or that educate farmers on how to identify diseases in their plants. However, many of these applications are created without regard for the user. They do not take into consideration how difficult their integration into the normal work day of a farmer can be. They are also usually tailored to a much more general audience instead of being adapted to address the needs of specific types of users, mainly for small and medium-sized farms. These farms really need innovative solutions as they struggle with increased needs for monitoring from various angles, including regulatory requirements driven, e.g., by the global push to reduce pesticides and to improve soil health.

This paper presents research work on Digital Agriculture towards digital twins for multi-sensor land and plant monitoring under the frame of the TWINSOR project. The aim of TWINSOR is providing farmers with a ”digital twin”, i.e., a monitoring ecosystem that allows them to visualize multi-sensor data collected from their fields, but also to ”plug in” predictive models, e.g., for frost or plant disease prediction. The system should allow the use of a wide range of ”sensors” ranging from free satellite images, low-cost off-the-shelf sensors, such as, weather stations, to even sophisticated and novel technologies, such as hyperspectral cameras, noise and odour sensors. TWINSOR is being developed as a citizen social science research project in co-creation, which may contribute strongly for its success as it is being designed with the participation of different stakeholders that are aware of real needs of the farms.

The paper is organized as follows. Section 2 presents related work, while section 3 describes TWINSOR with a strong focus on the concept and its architecture. Section 4 is focused on introducing a first prototype for the vineyard. Finally, conclusions and future work are summarized in Section 5.

2. Related Work

In the agricultural sector, digitalization is considered as a function of four components [8]: Smart Agriculture, Smart Technology, Smart Design and Smart Business. As a holistic approach, Digital Agriculture uses the knowledge of information science, environmental science, computer and software engineering, system science, GIS (Geographical Information System), GPS (Global Position System), remote sensing technology, and virtual satellite imaging for better integration of soil, climate and environment information with agriculture [17]. However, it is interesting to notice that in a survey conducted by Kernecker et al., in which participants were asked about the use of SFT, such as recording and mapping technologies, GPS based steering tools, apps and farm management information system (FMIS), and autonomous machines, they indicated apps and FMIS as being the most useful for their farms [12]. Users of SFT are frequently confronted with the challenge to interpret data and to assure device connectivity and data preciseness. Many times, small and medium winegrowers report obstacles to the use of sensors since they consider it is not necessary to measure so much data, or that the usefulness of this information is not clear [11]. Farmers tend to give a positive assessment to SFT in general, but looking at SFT’s impacts on economic profitability and on environmental performance, the level of conviction is clearly moderate [12].

Regarding the use of mobile applications with a focus on the data visualization dimension, since it is a major concern in our prototype design, the DataBio project is an example of the appropriate use of different visualization techniques [5]. This project had as its major objective the demonstration of the benefits of using Big Data technologies in the production of raw materials in agriculture, forestry, food and biomaterials in a sustainable and responsible way. This system uses Big Data and a precision agriculture scheme to provide farmers with prescriptive, descriptive and predictive information. PMapp [20] is another mobile-based tool that is used to record the incidence and severity of powdery mildew in a vineyard by estimating infection levels. It does so by allowing farmers to compare a representation generated by a computer to the bunches on their plants, estimating how much area is affected, which is something quite hard to do with no assistance. It also maintains records of that data for later analysis. This app also educates farmers by making them more capable of recognizing patterns and severity of mildew.

On the other side, BioLeaf is a solution that allows the user to upload photos of leaves through the mobile application to automatically identify the regions of the leaves that have been damaged by insects [13]. It is also capable of estimating the percentage of defoliation in relation to the total leave area. It is necessary to place a white surface behind the leafs so that the app can make a correct analysis of it. This application was tested initially on soybeans leafs but later experiments have shown that it is also effective of different plants like vine leaves. Regarding VitiCanopy [6], this tool intends to allow grapevine growers to use pictures of the crops taken by users to assess size and density of the canopy, leaf area of the vines and many other parameters. Product quality attributes can be achieved by using these parameters to monitor porosity and growth in order to assess the vigor of the plant, fruit zone light transmission, or water requirements.

OneSoil Scouting is a mobile application that gives users the ability to monitor their crops using European satellite images [15]. By selecting the location of the crop on the interface, the application uses an AI algorithm to automatically determine its limits, then the application calculates the NDVI (Normalized Difference Vegetation Index) using satellite images, presents a report of the health of the plants that is updated every three to five days, and a notification is shown to the user when it does so. Finally, FieldScout is an app that provides maps of biomass, soil zones and nitrogen levels in the leaves [3]. This can help farmers to determine if it is necessary to take precautionary or remedial actions, such as fertilizing or watering. Growth maps and charts are also used to show deviations in average growth to give further support to the farmer.

Recently, several studies have found a solution in the use of social networking principles and technologies. The guiding motivation is that a social-oriented approach is intended to aid in the discovery, collection, and composition of resources and knowledge offered by distributed objects and networks [7].

3. TWINSOR - A Digital Agriculture Ecosystem

TWINSOR is being designed as an extensible ecosystem for land and plant monitoring and decision support, for agriculture in particular, that will benefit primarily small and medium-sized farms, providing farmers with easily deployable tools that allow them to have continuous insights about their crops in order to manage them in more effective and sustainable ways. TWINSOR also intends to break new ground with the use of the digital twin concept and mixed reality applied to the farming field. The digital twin allows observing and, ultimately, simulating of various internal and external factors with a focus on pest and disease detection. A digital twin is a dynamic representation of a real-life object that mirrors its states and behaviours across its lifecycle so it can be used to monitor, analyze and simulate current and future states of, and interventions on, these objects, using data integration, artificial intelligence and machine learning [19].

3.1. Goals and Impact

The Farm to Fork Strategy (F2F) will enable the transition to a sustainable European Union food system that safeguards food security and ensures access to healthy diets sourced from a healthy planet [9]. The strategy has 27 concrete actions to transform the EU's food system by 2030, including: a reduction by 50% of the use and risk of pesticides; a reduction by at least 20% of the use of fertilizers – including animal manure; reaching 25% of agricultural land under organic farming, of which the current level is 8%.

Considering F2F strategy, TWINSOR is being designed in order to contribute with the following four outcomes:

Providing an innovative solution for the use of digital technologies tailored to the needs of small and medium-sized farms. The solution should be flexible, agile and extensible enough by using low-cost sensors, as much as possible, but also integrating available sensory services. These requirements will provide a generic solution that can be applied to each use case providing an instantiation towards the needs of each farm. In a long-term perspective, TWINSOR contributes to the F2F objectives as its ambition is to predict plant diseases and ensure optimal resource-utilization, which leads to less use of pesticides and fertilizers. This solution can facilitate organic farming, making small and medium-sized farms more competitive and viable by choosing this "organic option", while providing consumers with safe, healthy and sustainable food, minimising pressure on ecosystems and improving public health.

Providing increased uptake of innovative digital technologies by farmers. In order to have a higher impact, the project development will follow a co-creation methodology, such as Design Thinking [4], involving all stakeholders in the whole process, especially farmers as they will be the end users of the proposed solution. In this user-centred approach, it will be possible to involve all relevant stakeholders besides the farmers, including agricultural technicians, and the civil society in the co-creation process by applying open science practices as much as possible. It will be important to produce a co-created citizen social science [2] solution to really impact the lives of farmers and consumers, bringing the latter closer to small and medium-sized farms, thus increasing their sustainability, but also increasing their ability to show consumers how they can improve their eating habits. It is important to study how to design end user interfaces that provide user friendly data visualizations, but also agile controls to put them in control. The farmers may work as sensory providers based on their long practical and empirical knowledge. Additionally, citizen sensing will be used to study how to include people in the process. The project will provide a digital solution that puts consumers as a component of the sensory process as this will potentiate changemaking.

Contributing to avoiding an increased digital divide between small and large farms. An important goal is to reduce the ”death” of small farms since they struggle to be economically sustainable. EU has a strong interest in small and local farmers. There are contrasting opinions about the role and importance of small farms in the European Union (EU), and the legitimacy of public support provided to them. The project copes with the increase in the digital divide between small and large farms, empowering the smaller ones through the user-centred design that will motivate farmers to use the solutions towards more cost-effective scenarios.

Increasing the environmental and economic performance of small and medium-sized farms. TWINSOR is expected to help small-sized farms, as the system is multi-scale so it can be adapted to their needs and financial resources. For instance, the impact of the usage of TWINSOR may allow to deal with pests in early stage, which leads to less pesticides and fungicides, which leads to clean and healthy food, leading to economic gains.

3.2. Overview of the TWINSOR Ecosystem

The TWINSOR ecosystem provides an integrated platform for various digital solutions, from sensor data collection and visualisation through data analysis with machine learning and artificial intelligence techniques to multi-variable simulations. The digital twin is not important just in terms of data display, but also to provide several levels of analysis according to farmers' needs. Figure 1 shows a high-level representation of the proposed Digital Agriculture ecosystem. It includes the following key solutions, based on preliminary concepts [14], which should be easily replaceable and extendable due to the modular nature of the proposed ecosystem: wide range of sensors and other input data; and different analytical tools and visualization outputs.

A data collection service will be built and pre-processed data will be stored in a farm monitoring database. As represented in the TWINSOR conceptual architecture, external data providers and apps (e.g. farm management systems), and open access satellite (e.g., Sentinel-2 [1]) data are to be added to broaden the range of data used by the system. In order to provide other researchers with access to measurement data obtained by TWINSOR, they are intended to be provisioned with an open data interface. The approach of the Narrowband-IoT sensor system (stationary sensor system), developed at University of Applied Sciences, is intended to derive measurements directly from the field [10]. Further research on LoRa/LoRaWAN technology may be applied. Another way to get measurements from the field is to use a mobile sensor system (e.g., drone), as well as a user's (e.g., farmer) smartphone with a mobile app.

A machine-learning-based data analysis service is being developed to analyze the pre-processed data, to prepare immediate intervention proposals and to provide the simulation service and digital twin with input data. The application of a multi-sensor system offers the advantage of utilizing complementary information from different sources, which can enhance the capability of predictive models. However, combining information from different sensor technologies into a single model comes with a set of challenges that have to be addressed. For instance, sensor information can have different dimensionality (e.g., 1D signals, 2D images) or varying sampling rates at which data is obtained. It is also not guaranteed that information from all sensors will be available at all times, which means that a predictive model would have to be robust to cope with missing input modalities. Therefore, deep learning based multimodal fusion techniques will be used to enable the accurate prediction of target attributes for different applications with varying sensor compositions.

TWINSOR system is expected to have a number of levels at which the user may interact, thus receiving feedback at different degrees of detail:

Smartphone mode: A mobile app is used by the end user to receive certain notifications and management recommendations from the data analysis service, but also from the agricultural technicians;

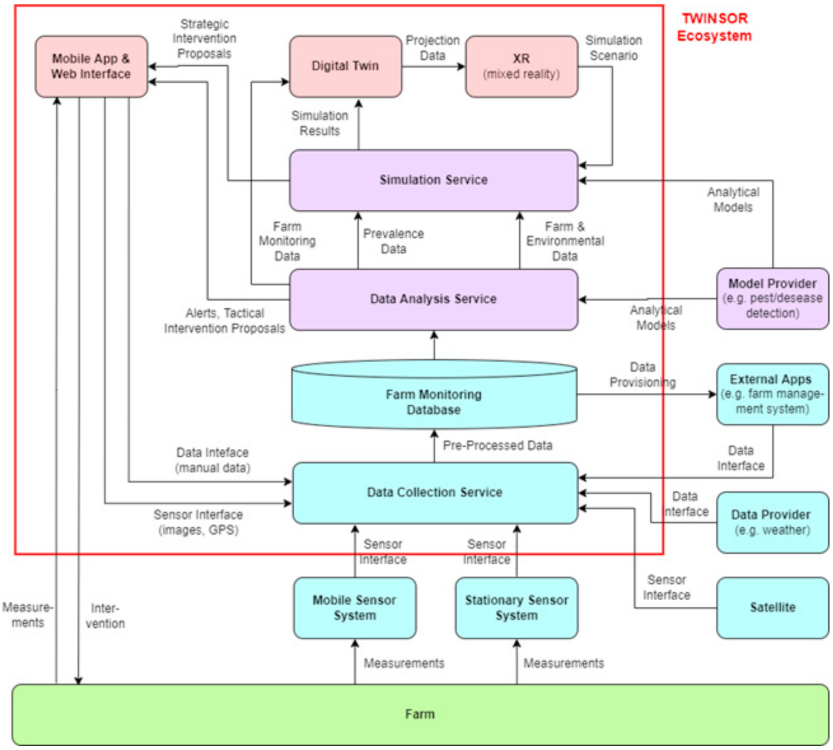

Fig. 1: TWINSOR conceptual architecture

Stationary sensor mode: An app, external data and IoT sensor measurements from the field are used. It allows TWINSOR to run the data analysis service, thus providing the user with more detailed intervention proposals.

Virtual twin mode: An app, external data, IoT sensor measurements and mobile sensor system are used. Mobile sensor system provide possibility to generate a digital twin, thus the user can interact with the simulation service, test different management scenarios and consider strategic intervention proposals.

4. Agri-Dash Prototype

Methods made available to farmers should predict as far in advance as possible, must be as simple as possible, and work with as little data as possible, preferably with data that farmers can access quickly, easy, and cheaply and, if possible, without the need for intensive training. Agri-Dash is a mobile application prototype that is being developed as part of TWINSOR, responding to the first use case considered under the project. Agri-Dash is being designed with the participation of Association of Wine Growers of the Municipality of Palmela (AVIPE)[1], in Portugal, aiming to assist small to medium farmers in their daily activities by providing them with useful information and recommendations, which may be manually provided by associations and/or technicians that support the farmers. Moreover, they can also be (semi-)automatically generated by the TWINSOR system based on the current status of the digital twin and any associated predictive models. While we expect that there may be some particularities related to this specific field and its needs, we are designing Agri-Dash to be as general as possible to cover other types of cultures and farming.

In Figure 2a, we present the ”Main Menu” of our application prototype that gives access to the ”Create Marker” interface (see Figure 2b), to the ”Map” (seen in Figure 2c), the ”Notification History” (in Figure 4b) and the ”List of Markers” (seen in Figure 3a). The ”Main Menu” is kept as simple as possible to keep it as easy to use as possible. In fact, since our application is supposed to be used on the field at any time, under less than ideal lighting conditions,

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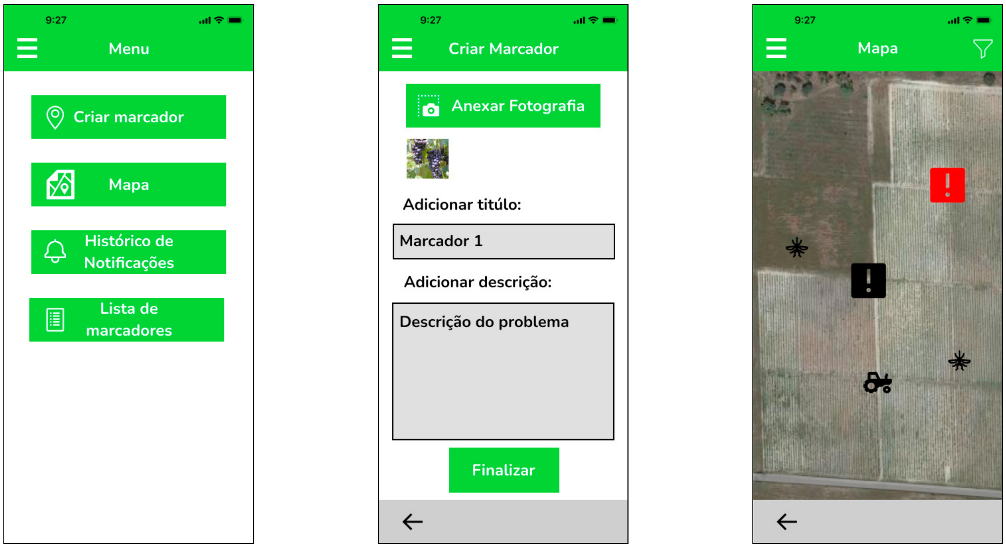
[1] Associação de Viticultores do Concelho de Palmela (AVIPE): `https://www.avipe.pt/`



Adicionar titúlo:
Marcador 1
Adicionar descrição:
Descrição do problema

(a) Main Menu (b) Creating a marker (c) Marker on the map

Fig. 2: Agri-Dash Prototype – Main Menu and Marker Creation

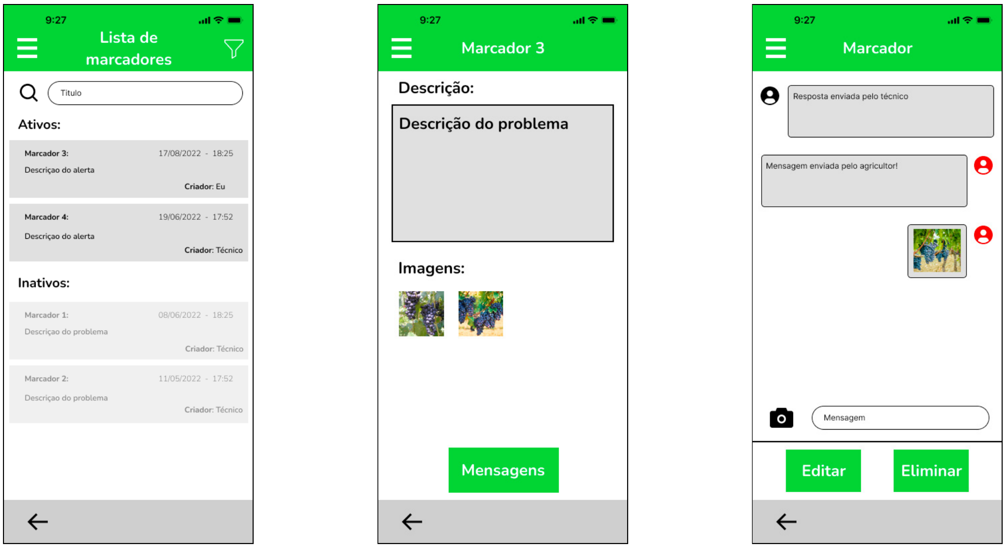
and by a demographic that is not very tech-savvy, the interface of the application should have relatively large elements that are easily discernible and easy to interact with under these harsh conditions.

Regarding Figure 2b, it presents the ”Create Marker” screen which is used to create a new marker that is placed and associated with the current position of the user. Each marker has a title and description about the issue that was found on the field, with users having the option of attaching photos taken with their smartphone to better illustrate it. Once created, the marker gets added to the ”Map”, as seen in Figure 2c. Moreover, this interface can also show other points of interest besides the user created markers, such as tractors, combines, planters, sprayers and other types of agricultural machinery. We intend for this information to be overlaid on top of Sentinel-2 satellite images of the area in true color, which currently get updated at least every 5 days [1]. There is also the possibility of providing additional layers of information that are useful to analyze the state of the crops, such as NDVI [18, 16] and NDMI (Normalized Difference Moisture Index) [21].

The complete list of markers associated with a given user can be accessed through the ”List of Markers” interface (Figure 3a). It allows users to view markers without having to use the map and enables them to filter the markers to be displayed according to different criteria. Moreover, inactive markers are also displayed at the bottom, which indicates these issues have been already dealt with. This can be especially useful when comparing a new situation that arises with past markers and their solutions. For instance, by selecting one of the markers on the list, or on the map, the user can view the previously details associated with the marker, i.e., its title, description and any attached images. Each marker also has a chat associated to it, which can be accessed by the button on the bottom of the screen that leads to the interface seen in Figure 3c. This chat can be used to exchange data and notes with a technician that supports the farmers. A core part of our vision is making the communication between them more accessible and valuable.

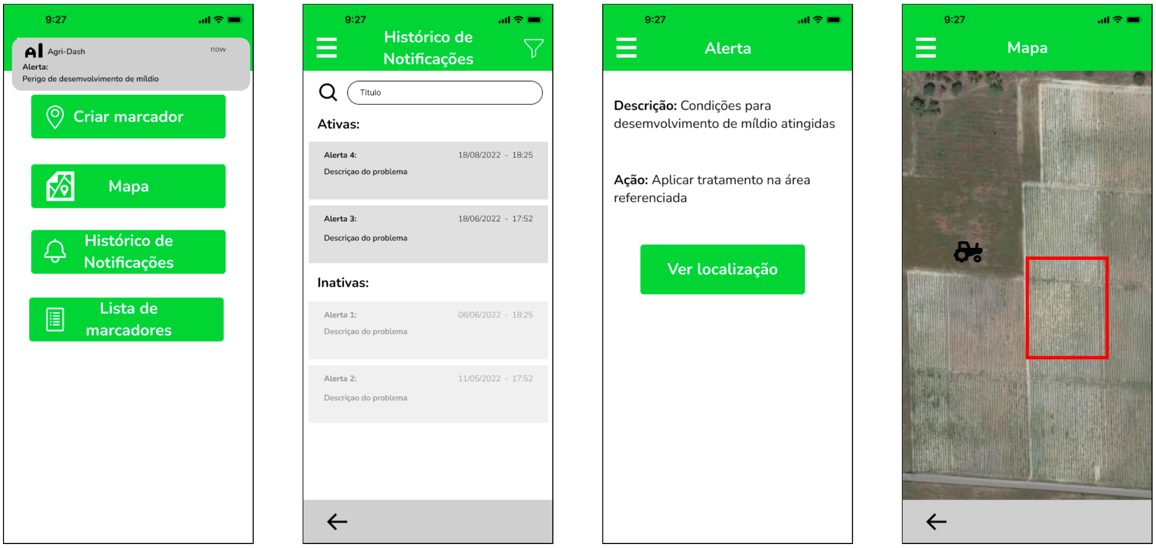
Finally, Figure 4 is focused on demonstrating the notification system, which can be triggered automatically based on inputs from the TWINSOR system, or manually by a technician when deemed necessary, to warn certain farmers about a relevant issue that they should take into consideration to keep their production under the best conditions possible. Therefore, as an example, Figure 4a shows a notification that can appear at any time on the screen of the smartphone (not only when our application is running).

Figure 4b shows the notification history, which can be accessed from the main screen of the application and that shows a list of received notifications. This screen is similar to the previous screen with the list of markers. It also separates notifications in active and inactive, which means that a notification has been received but it is still unread and/or relevant for the time being, or the notification has already been read and/or is no longer relevant given that too much time has passed. By selecting a notification, we can see the information associated with it, like the example



(a) List of markers (b) Marker details (c) Chat associated to the marker

Fig. 3: Agri-Dash Prototype – Marker List and Details



Descrição: Condições para desenvolvimento de míldio atingidas

Ação: Aplicar tratamento na área referenciada

(a) Notification (b) Notification history (c) Notification details (d) Location map of notification

Fig. 4: Agri-Dash Prototype – Notifications

that can be seen in Figure 4c. In certain cases, a ”View Location” button may be available if the notification alert is associated with a specific position or region. This button will lead the user to an interface with a map (similar to the one previously shown when dealing with markers) so that we can better show graphically the point of interest/area of interest that needs attention (see Figure 4d).

5. Conclusions

This paper presented research work towards digital twins for multi-sensor land and plant monitoring. The TWIN-SOR ecosystem is already a stable solution that is being developed after the research team has gathered valuable inputs from stakeholders and partners from the farming field. At the same time, Agri-Dash is under development with the collaboration of AVIPE and several farmers in a co-creation design setting. It is ready for the first testing phase ”in the wild” since this prototype is important to get feedback from winegrowers and study how they interact with these solutions while they are working. More further research are: to identify existing databases worldwide that collect information to be included in TWINSOR ecosystem; and to identify sensor capabilities to create a mobile sensor system for local information acquisition.

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