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IMPLEMENTING BLOCKCHAIN TECHNOLOGY IN IOT VINEYARD MONITORING SYSTEM

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Abstract. Data management is essential in the precision agriculture industry since it is a requirement for exposing a product's attributes and qualities to the customer while ensuring crop security, traceability, and all other values associated with product and organization sustainability. In this way, the aim of the article is to present a solution for securing information from the IoT vineyard monitoring system and to integrate advanced technologies into the crop monitoring process to increase productivity and quality. The background of the article is supported by the study of the DISAVIT project, which develops an intelligent decision support system for smart viticulture. Monitoring the health of the vineyard and their tendency to the occurrence of certain diseases characteristic of these crops requires the analysis of soil quality parameters and meteorological aspects. The data used in this study is collected from Wireless Sensor Networks (WSNs), then transmitted using 5G communication and stored in the Cloud for processing and interpretation. The HyperLedger framework, which is based on Blockchain technology, is also used to secure the data. Finally, starting from the system's operating architecture, data interpretation and visualization will be performed and the functionality of the data security system will be tested.

Keywords: Blockchain, IoT, WSN, vineyard, precision agriculture

1. INTRODUCTION

Using the technique of precision viticulture, growers can monitor and manage the microclimate of the vineyard as well as plant diseases and pests. The condition of the soil and the health of the plants are impacted by a variety of environmental elements and climatic events. The development of the vineyard, including its growth and maturation as well as its diseases, is influenced by temperature and relative humidity (RH). The incidence of diseases caused by fungi or apoplexy is influenced by rain. Wind and hail can seriously harm the fruit, the bark, and the leaves. The evolution of biological processes and the development of the roots are influenced by soil temperature, while soil moisture influences the crop's water requirements. Also,

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frost can be a major issue for vine growers since it can damage plant tissues, which will harm the evolution of the leaves and fruits (Navarro et al., 2020).

The long-term improvement in productivity can be achieved by emerging technologies such as Internet of Things (IoT), which has considerable potential for Precision Agriculture and Smart Farming. A novel vision on precision farming is provided by the Internet of Things concept, which makes it possible to manage cultivated fields in real time and according to local conditions. IoT-based smart farming involves the development of a system for crop monitoring with the goal of automating a number of essential farming processes, including the monitoring of crop evolution, irrigation management, fertilizer distribution and disease detection. In this scenario, IoT technologies can help with the collection of real-time data from the agricultural areas. Important actions about the management of the crops can be supported by prompt processing and utilization of this information.

Precision Agriculture (PA) and remote sensing have advanced due to the development of UAV-based remote sensing systems. In contrast to traditional methods, the use of UAVs to monitor crops provides considerable opportunities to collect environmental data in a simple, efficient, and cost-effective method. The potential of remote sensing in Precision Agriculture is considered as being focused on UAV-based IoT technology. The capacity of UAVs to fly at a low altitude produces images of the crops with extremely high spatial resolution. This considerably enhances the effectiveness of the monitoring systems (Tsouros et al., 2019).

Even though soil and water supplies are no longer considered as limitless or abundant resources, there have been significant worries about their long-term effects. With the aim of reducing losses and waste, it has been discovered that Precision Agriculture (PA) can frequently assist in maximizing these and other resources. Additionally, PA can lower input costs, maximize potential output, and decrease input variability. The concept PA refers to a group of information technologies (IT) that are focused on minimizing negative environmental effects while generating quick advantages (Cisternas et al., 2020).

The article's purpose is to provide a method for securing data from an IoT vineyard monitoring system and to include cutting-edge technology into the crop monitoring process to improve crop quality and productivity. Measuring soil quality indicators and climatic parameters is necessary for monitoring the health of the vineyard and their predisposition to generate diseases specific to these crops. For processing and analysis, the information regarding relevant parameters was gathered through Wireless Sensor Networks and stored in the Cloud. The data is additionally secured using the HyperLedger framework, which is based on Blockchain technology.

Study of the DISAVIT project, which creates an intelligent decision support system for smart viticulture, provides evidence to support the background of this paper. The pilot site used in the DISAVIT project is located in Prahova County, in Valea Călugărească village, also representing the base of the experiments carried out in this article. Within the project DISAVIT, it has developed a software application that uses an AI algorithm to identify diseases present on vine leaves from the analysis of drone images. Also, another project that influenced the work of this paper is U-GARDEN, which promotes the implementation of urban gardens and agroforestry experiences as key components of the strategic framework for sustainable urban development in European cities.

The rest of this article is structured as follows. The most significant and commercial systems for applying Blockchain technology to monitor vineyards are reviewed in Section 2. Section 3 details the implementation of the system including the functional architecture and the Blockchain component. The experimental approach and the results of the various tests are described in Section 4. Finally, the conclusions are addressed in Section 5.

2. RELATED WORK

The value of applying new technologies in precision agriculture is increasingly acknowledged in the literature. Precision agriculture is a new technique that makes use of satellite technology, Geographic Information Systems (GIS), remote sensing, and Information Technology (IT) to improve all agricultural activities and services. Nowadays, smart sensors, Artificial Intelligence (AI), Cloud Computing, the Internet of Things (IoT), drones and Blockchain are all used in precision agriculture. Based on these technologies, it is currently possible to process and gain access to real-time data regarding soil, crop, and weather conditions as well as other important services such as the supply chain for crops and fruits, animal grazing and food safety.

Blockchain rapidly gained recognition as a key technology for many precision agriculture applications. Developing Blockchain-based IoT systems for precision agriculture is being considered as a solution to the requirement to create intelligent P2P systems that are capable of monitoring, securing, and analyzing agricultural data. Blockchain is essential in replacing traditional forms of storing, organizing, and distributing agricultural data in favor of a system that is more dependable, transparent, immutable, and decentralized. The Internet of Things and Blockchain working together in precision farming will increase intelligence and autonomy in handling precision agriculture in even more effective and optimum ways (Torky et al., 2020).

Blockchain technology is being used in a variety of supply chains in the Business-to-Business (B2B) and Business-to-Consumer (B2C) networks. The use of Blockchain technology in supply-chain management is continuously being researched and developed, both conceptually and as solutions that have been carried out and instances of such solutions. When integrating blockchains in supply-chain management, there are various options for platforms and permissions. The Hyperledger Fabric, Ethereum platform, and Stellar are employed in the most common permissioned network scenarios. Platform-independent solutions do exist, though. This is the Ethereum platform for networks that need permissions. Ethereum is preferred by hybrid solutions, yet cases of Unspecified platform do exist. Because

Ethereum and its derivatives offer smart contracts, they constitute the foundation for the majority of Blockchain supply-chain solutions (Radeva et al., 2022).

The integration of IoT technologies is a significant component in the digitalization of viticulture. The structure of the Internet of Things is the collection of data from things, storage of that data through the internet, analysis of that data, and even the suggestion of the correct action to take. Irrigation, harvesting, fertilization, and other decision-making are all supported by IoT in viticulture. The latest technology enables quick responses to changing conditions and circumstances, as well as the best mapping of vineyards. Technologies in general, and the Internet of Things in particular, are growing in popularity and opening up new options for winegrowers (Kudryashova et al., 2021).

Regarding agriculture and viticulture, IoT devices have both advantages and disadvantages. The author Spachos (2020) presents an implementation of low-cost hardware for real-time data processing and collection in a vineyard. For the purpose of measuring soil temperature and humidity, wireless nodes composed of small, affordable IoT devices are utilized. If the monitoring data reach above a certain threshold, a drone flies over the region in the direction of the node that provided the data and captures images. The images are then sent to a control room for additional processing after the drone returns to the base station. The system framework and implementation that are being introduced are what make the authors work new. Wireless monitoring nodes were created using affordable, readily accessible IoT hardware.

For optimal seeding procedures, new techniques such as vision-based and wireless sensors are employed to identify crop parameters such as soil depth. FarmBot and Agribots are two examples of the robotic equipment being produced for smart farming to increase crop yield. If these technologies are used on a broad scale, agricultural procedures including seeding, weeding, fertilizing, and irrigation might all be improved. Agribots is a particular type of robot, and can locate the agricultural field by integrating digital processors with the vehicle's optical system. This kind of robot operates on any agricultural land where location maps are created using the Global Positioning System (GPS) (Khan et al., 2021).

Vite.net presents a comprehensive strategy for the sustainable management of vineyards. The real-time monitoring Decision Support System (DSS) and web-based tool analyze the data gathered using cutting-edge modeling techniques, providing the vineyard manager up-to-date information. This paper (Ara et al., 2021) is a great resource for learning how to establish a software monitoring system and it presents encouraging outcomes found in Italian vineyards. The information on the sensor nodes is removed, though, because the authors rely on third-party hardware.

NAV is a Wireless Sensor Network used for remote, real-time vineyard monitoring. A weather station and other wifi nodes are part of the system, and they are situated in the vineyard. The nodes' GSM modems are used to transmit data to a distant central server. NAV only gathers micro-meteorological data (Kumar et al., 2020).

Regarding business opportunities, several organizations already provide monitoring systems for vineyards. For instance, VintiOS is a type of precision agriculture software that helps winemakers and oenologists make decisions about the quantity and quality of grapes produced. The software enables the user to control all the data associated with the farm and displays the farm's location. Monet is a similar technology that keeps track of a vineyard's health, including the probability that it will develop specific diseases, weather data, and other important occurrences. SmartVineyard and Ranchsystems are other unique solutions for monitoring of the vineyards (Ghiglieno et al., 2019).

3. SYSTEM IMPLEMENTATION

3.1 System Architecture

The system architecture used in the DISAVIT project is illustrated in Fig. 1 and includes a smart viticulture platform based on IoT technologies, designed to monitor, alert and provide notifications to improve the grapevine harvest.

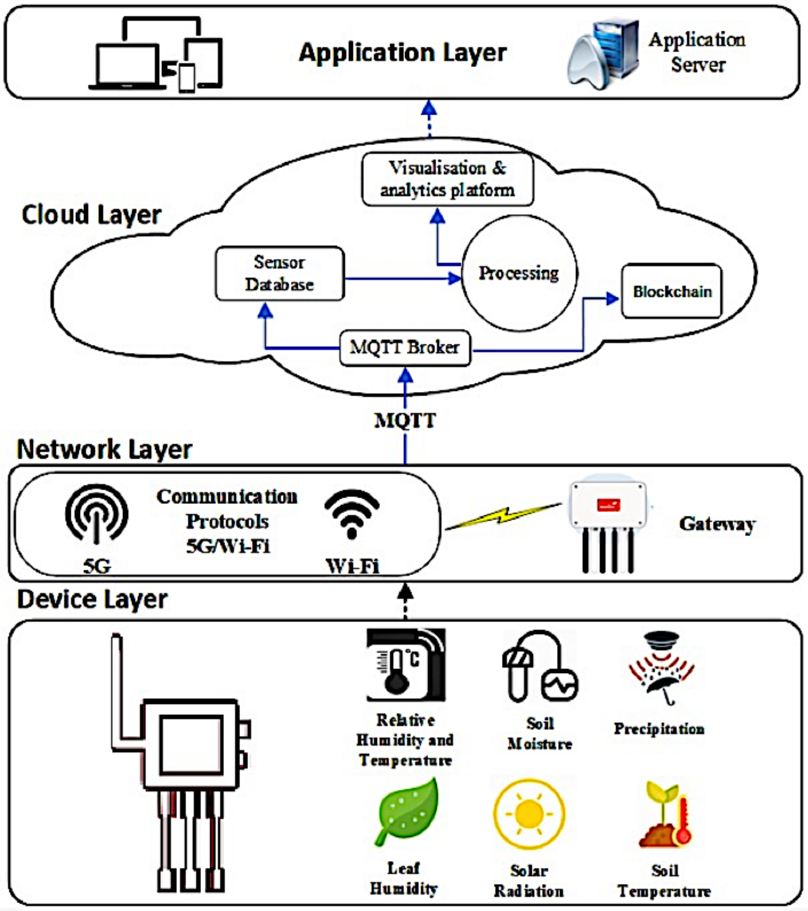


Fig. 1. *System architecture*

The system architecture is divided into several layers as follows: the first layer is named Device Layer and includes all the hardware monitoring devices that are placed in the vineyards for monitoring. They collect essential data for vineyard management, such as air temperature, air humidity, soil temperature, soil moisture, solar radiation, leaf humidity and rainfall.

The second layer, Network Layer, is composed of devices that ensure communication between the monitoring devices and the upper layers of the system regardless of distance. The technologies used are Wi-Fi and 3G/4G/5G. In order to ensure high frequency transmission, high energy consumption is required and for this reason software routines have been implemented to make data transmission more efficient, thus avoiding packet loss. The data from the sensors is received by a Meshlium Gateway which will send the data to the next layer (Cloud), so that the data can be stored in a database. The network protocol implemented to send the data to the next layer is MQTT (Message Queuing Telemetry Transport), a simple protocol designed to limit resource consumption within an IoT platform.

The third layer is named the Cloud Layer, which comprises the database where the time data series used in the Application Layer are stored. In addition to the database, this layer implements the processing of the data before it reaches the visualization platform and its forwarding to the HyperLedger framework to store it in the Blockchain network.

The last layer, Application Layer, consists of the final application that is available to users on both mobile devices and other devices (laptops, PCs). The web application provides data visualisation in the form of graphs or tables so that users can quickly analyse the data. In the same application, the alert part that each user can set according to their preferences, is also available.

3.2 Blockchain Implementation

The DISAIVT project uses Blockchain technology to store data in a distributed database. Blockchain is a chain of blocks containing secure data. The blocks are in series in a peer-to-peer network. The Blockchain architecture consists of three main elements:

1. Node - a user (or a PC/VM) that holds a full copy of the entire ledger
2. Block - a data structure used for storing some data (transactions most often, sensor data in this case, or more data from text bases)
3. Transaction - the smallest building block of the ledger (in this case, a data entry).

Sensor data needs to be stored at different points so that cyber-attacks do not affect the data integrity. Data is sent from various telemetry stations (soil quality, air quality, weather) through MQTT and then saved in Hyperledger Fabric as blocks that are attached to the created Blockchain. The advantage of using Hyperledger

Fabric for this application is that it offers more attributes, compared to other Blockchain technologies that imply smart contracts, such as Ethereum.

The method proposed in the DISAVIT project aims to retrieve more data from the monitoring stations and packaged in a JSON format. The data is queried in Node-RED which subsequently sends the data to the Blockchain network. This facilitates the trading speed so that, for a set of measurements received, a single smart contract is generated. The process is illustrated in detail through a low-level architecture, presented in Fig. 2.

To implement a Blockchain network, the first step is to install Hyperledger Fabric on a server. Once this framework is installed, a personal chain and a smart contract are created using the GO programming language, so that the data received from the sensors follows a specific format. The format of the smart contract is illustrated in Fig. 3.

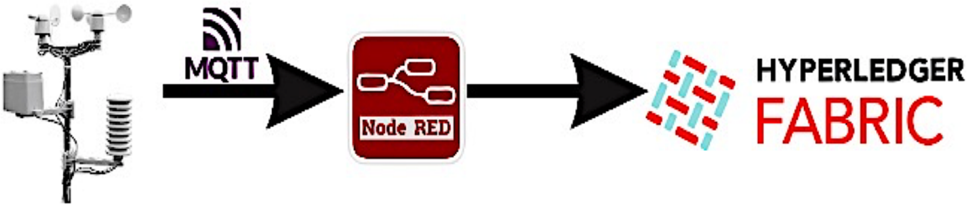
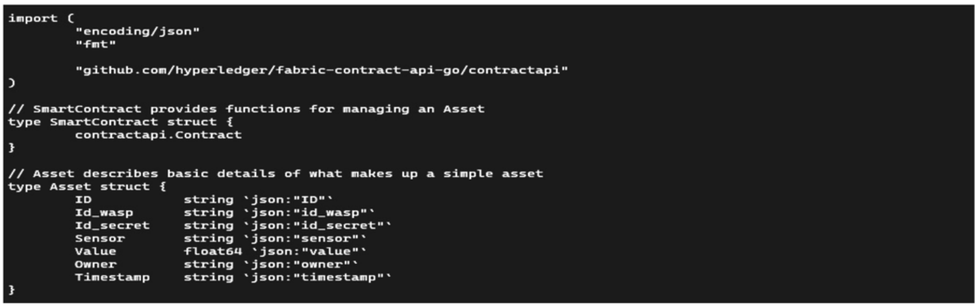


Fig. 2. ***Low-level architecture***

The Node-RED development tool is used to populate the previously created chain with the values measured by the monitoring stations. With this tool, the topic where the data is sent through MQTT to the Broker is subscribed and then automatically stored through a data push in the Blockchain network.



```
import (
        "encoding/json"
        "fmt"

        "github.com/hyperledger/fabric-contract-api-go/contractapi"
)

// SmartContract provides functions for managing an Asset
type SmartContract struct {
        contractapi.Contract
}

// Asset describes basic details of what makes up a simple asset
type Asset struct {
        ID             string `json:"ID"`
        Id_wasp        string `json:"id_wasp"`
        Id_secret      string `json:"id_secret"`
        Sensor         string `json:"sensor"`
        Value          float64 `json:"value"`
        Owner          string `json:"owner"`
        Timestamp      string `json:"timestamp"`
}
```

Fig. 3. ***Smart contract format***

The reason HyperLedger was chosen over other Blockchain systems, such as Ethereum, is that it offers a much higher degree of privacy and scalability. HyperLedger's modular architecture gives users more flexibility depending on their preferences. Another reason for choosing HyperLedger is because of the Blockchain security, as the user needs permission to access the existing network. In contrast, in Ethereum networks, any user can view and access previous transactions.

4. RESULTS

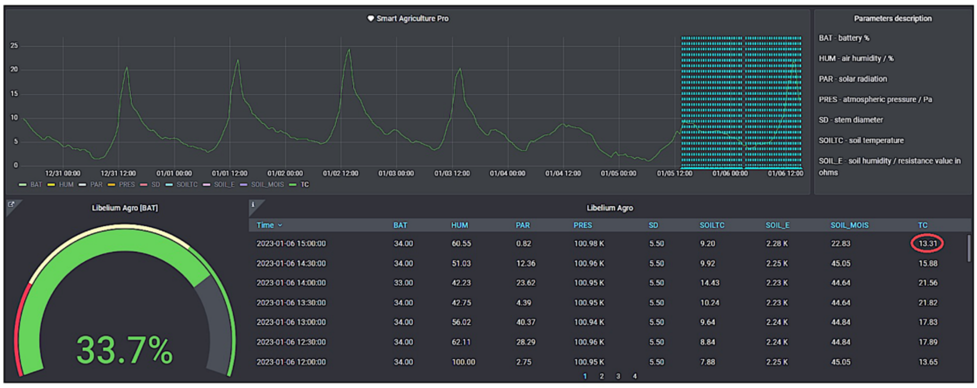
The pilot site is located in Prahova County, in the village of Valea Călugărească, in the grounds of the Research and Development Institute for Viticulture and Vinification (ICDVV). The Institute is located in the Valea Călugărească viticultural centre, belonging to the Dealu Mare vineyard, one of the largest and most famous vineyards in the country (approximately 15.000 ha), specialised in the production of high-quality wines.

Geographically, the vineyard centre has the following average coordinates: 26009' east longitude and 44058' north latitude, and territorially-administratively, it belongs to the villages of Valea Călugărească, Bucov, Albești Paleologu and the town of Urlați. Fig. 4 illustrates the vineyard in the pilot location Valea Călugărească.

Fig. 4. ***The pilot site – Valea Călugărească***

The health status of the vineyard can be influenced by certain parameters. In order to avoid the occurrence of certain diseases characteristic of vineyards, it is necessary to monitor and analyse soil quality and meteorological parameters: air temperature, air humidity, soil temperature, soil moisture, solar radiation, leaf humidity and rainfall. The values of the monitored parameters are analysed and then visualised through the Grafana platform. Grafana is an open source, cross-platform online application for interactive visualization and analytics. When connected to supported data sources, it offers charts, graphs, and alerts for the web.

Fig. 5 represents a dashboard created in Grafana, illustrating the values of temperature parameter monitored in real time by the IoT station located in Valea Călugărească. In addition, in this dashboard is presented a legend of the monitored parameters and a diagram indicating the battery level. The monitored values are displayed in graphical and tabular format.



Parameters description

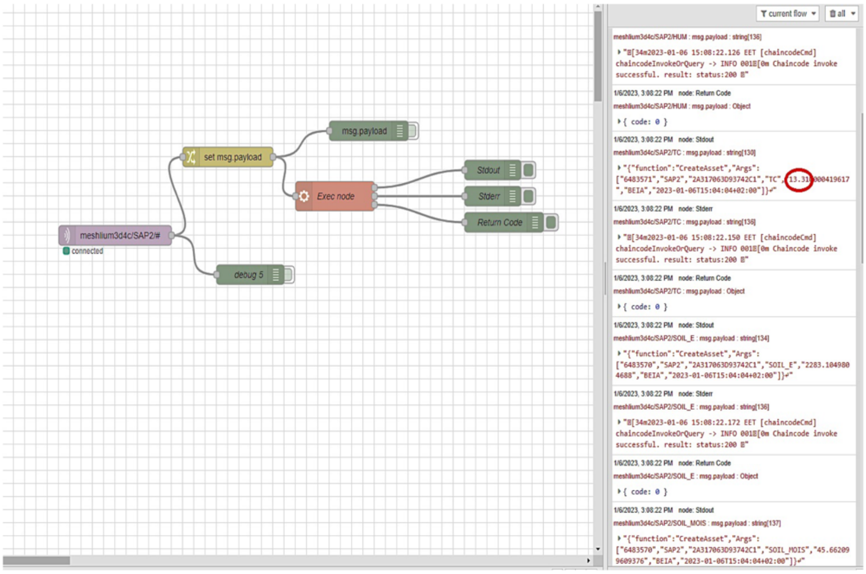
BAT - battery %
HUM - air humidity / %
PAR - solar radiation
PRES - atmospheric pressure / Pa
SD - stem diameter
SOILTC - soil temperature
SOIL_E - soil humidity / resistance value in ohms

Libelium Agro

Time	BAT	HUM	PAR	PRES	SD	SOILTC	SOIL_E	SOIL_MOIS	TC
2023-01-06 15:00:00	34.00	60.55	0.82	100.98 K	5.50	9.20	2.28 K	22.83	13.31
2023-01-06 14:30:00	34.00	51.03	12.36	100.96 K	5.50	9.92	2.25 K	45.05	15.88
2023-01-06 14:00:00	33.00	42.23	23.62	100.95 K	5.50	14.43	2.23 K	44.64	21.56
2023-01-06 13:30:00	34.00	42.75	4.39	100.95 K	5.50	10.24	2.23 K	44.64	21.82
2023-01-06 13:00:00	34.00	56.02	40.37	100.94 K	5.50	9.64	2.24 K	44.84	17.83
2023-01-06 12:30:00	34.00	62.11	28.29	100.96 K	5.50	8.84	2.24 K	44.84	17.89
2023-01-06 12:00:00	34.00	100.00	2.75	100.95 K	5.50	7.88	2.25 K	45.05	13.65

Fig. 5. ***Dashboard Data visualization graph***

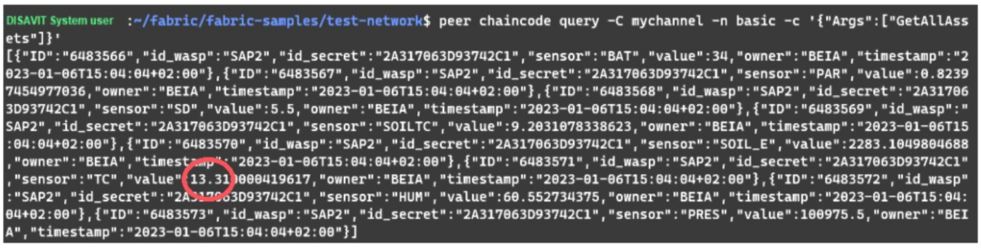
Following the tests, the functionality of the IoT system was demonstrated to monitor the vineyard and store the data in the HyperLedger Blockchain network. Fig. 6 illustrates the flow in Node-Red that subscribes to the MQTT Broker and the topic on which data is sent from the IoT station and with the help of an "exec node" function pushes the data to the Blockchain network. In addition, the "debug" window can be found, displaying the values read from the MQTT Broker topic.



```
meshlium3d4c/SAP2/HUM : msg.payload : string[136]
 "[34m2023-01-06 15:08:22.126 EET [chaincodeCmd]
chaincodeInvokeOrQuery -> INFO 001[0m Chaincode invoke
successful. result: status:200 "
1/6/2023, 3:08:22 PM  node: Return Code
meshlium3d4c/SAP2/HUM : msg.payload : Object
 { code: 0 }
1/6/2023, 3:08:22 PM  node: Stdout
meshlium3d4c/SAP2/TC : msg.payload : string[130]
 "{"function":"CreateAsset","Args":
["6483571","SAP2","2A317063D93742C1","TC","13.31[illegible]000419617
","BEIA","2023-01-06T15:04:04+02:00"]}↵"
1/6/2023, 3:08:22 PM  node: Stderr
meshlium3d4c/SAP2/TC : msg.payload : string[136]
 "[34m2023-01-06 15:08:22.150 EET [chaincodeCmd]
chaincodeInvokeOrQuery -> INFO 001[0m Chaincode invoke
successful. result: status:200 "
1/6/2023, 3:08:22 PM  node: Return Code
meshlium3d4c/SAP2/TC : msg.payload : Object
 { code: 0 }
1/6/2023, 3:08:22 PM  node: Stdout
meshlium3d4c/SAP2/SOIL_E : msg.payload : string[134]
 "{"function":"CreateAsset","Args":
["6483570","SAP2","2A317063D93742C1","SOIL_E","2283.104980
4688","BEIA","2023-01-06T15:04:04+02:00"]}↵"
1/6/2023, 3:08:22 PM  node: Stderr
meshlium3d4c/SAP2/SOIL_E : msg.payload : string[136]
 "[34m2023-01-06 15:08:22.172 EET [chaincodeCmd]
chaincodeInvokeOrQuery -> INFO 001[0m Chaincode invoke
successful. result: status:200 "
1/6/2023, 3:08:22 PM  node: Return Code
meshlium3d4c/SAP2/SOIL_E : msg.payload : Object
 { code: 0 }
1/6/2023, 3:08:22 PM  node: Stdout
meshlium3d4c/SAP2/SOIL_MOIS : msg.payload : string[137]
 "{"function":"CreateAsset","Args":
["6483570","SAP2","2A317063D93742C1","SOIL_MOIS","45.66209
9609376","BEIA","2023-01-06T15:04:04+02:00"]}↵"
```

Fig. 6. ***Node-Red flow of reading data and sending it to the Blockchain network***

Fig. 7 represents a capture in which the value chain stored in the Blockchain network is analyzed. It can be observed that the values are identical to those which are illustrated in the other two previous figures. For the validation of the implemented system, a particular case of air temperature monitored with the Libelium station, located in the Valea Călugărească pilot area, is analysed.



```
DISAVIT System user  :~/fabric/fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args":["GetAllAss
ets"]}'
[{"ID":"6483566","id_wasp":"SAP2","id_secret":"2A317063D93742C1","sensor":"BAT","value":34,"owner":"BEIA","timestamp":"2
023-01-06T15:04:04+02:00"},{"ID":"6483567","id_wasp":"SAP2","id_secret":"2A317063D93742C1","sensor":"PAR","value":0.8239
7454977036,"owner":"BEIA","timestamp":"2023-01-06T15:04:04+02:00"},{"ID":"6483568","id_wasp":"SAP2","id_secret":"2A31706
3D93742C1","sensor":"SD","value":5.5,"owner":"BEIA","timestamp":"2023-01-06T15:04:04+02:00"},{"ID":"6483569","id_wasp":"
SAP2","id_secret":"2A317063D93742C1","sensor":"SOILTC","value":9.2031078338623,"owner":"BEIA","timestamp":"2023-01-06T15
:04:04+02:00"},{"ID":"6483570","id_wasp":"SAP2","id_secret":"2A317063D93742C1","sensor":"SOIL_E","value":2283.1049804688
,"owner":"BEIA","timestamp":"2023-01-06T15:04:04+02:00"},{"ID":"6483571","id_wasp":"SAP2","id_secret":"2A317063D93742C1"
,"sensor":"TC","value":13.31000419617,"owner":"BEIA","timestamp":"2023-01-06T15:04:04+02:00"},{"ID":"6483572","id_wasp"
:"SAP2","id_secret":"2A317063D93742C1","sensor":"HUM","value":60.552734375,"owner":"BEIA","timestamp":"2023-01-06T15:04:
04+02:00"},{"ID":"6483573","id_wasp":"SAP2","id_secret":"2A317063D93742C1","sensor":"PRES","value":100975.5,"owner":"BEI
A","timestamp":"2023-01-06T15:04:04+02:00"}]
```

Fig. 7. ***Analyzing the chain for visualizing the values stored in the Blockchain network***

The air temperature value monitored around 03:00 p.m. on 6th of January 2023 is approximately 13.31 Celsius degrees, as it can be seen in the Fig. 5. This information can be found highlighted in the figures for easy identification.

5. CONCLUSIONS

The results obtained following the performed tests demonstrate that the system presented in this work has achieved its objective of monitoring in real-time the essential parameters of the vineyard, as well as storing the measured values in the Blockchain security network.

Due to IoT technologies, it was possible to develop a system using a software platform, Grafana, that informs the user through monitoring dashboards and alerts in case of an event that disrupts the nominal parameters of vine growth.

The performed tests proved that the data from the monitoring station is successfully stored in the decentralized HyperLedger Fabric database, which provides data authenticity validation along with all the advantages of Blockchain technology.

This work represents an important step in the digitalization of the viticulture and agricultural sector and can be adapted according to the needs of farmers.

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