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1st PHASE PROJECT REPORT ON

INTERNET OF THINGS TITLED

"GREENHOUSE MONITORING USING WSN"

Submitted in partial fulfillment for the award of

Bachelor of Engineering in Computer Science and Engineering

By

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CERTIFICATE

This is to certify that the 1st Phase project work entitled **"GREENHOUSE MONITORING USING WSN"** is a bonafied work carried out by **SUDEEP G N (1CK19CS081), VARUN G (1CK19CS089), VARUN S (1CK19CS091)** and **VEERESH B (1CK19CS092)** in partial fulfillment for the award of Bachelor of Engineering in Computer Science & Engineering of the Visvesvaraya Technological University, Belagavi during the year 2022-23. It is certified that all corrections/suggestions indicated for the internal assessment have been incorporated in the report. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the VII Semester Bachelor of Engineering Degree.

Signature of the Guide	Signature of the HOD	Signature of the Principal
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ABSTRACT

The greenhouse is one of the sustainable forms of smart agricultural farming. It is considered as an alternate method to overcome the food crisis which is generated due to high population growth, climate change, and environmental pollution. Although this method supports off-the-season crops within the enclosed area even in severe climatic zones. It has required to efficiently control and manage the crop parameters at a greenhouse in a more precise and secure way. The advancement of the Internet of Things (IoT) has introduced smart solutions to automate the greenhouse farming parameters such as plant monitoring, internal atmosphere control, and irrigation control. A rigorous discussion on greenhouse farming techniques, IoT-based greenhouse categories, network technologies (cloud/edge computing, IoT protocols, data analytics, sensors) has been presented.

DECLARATION

We **SUDEEP G N, VARUN G, VARUN S** and **VEERESH B** bearing USN **1CK19CS081, 1CK19CS089, 1CK19CS091** and **1CK19CS092** respectively, Student of 7th semester B.E., Computer Science and Engineering of VTU, declare that this project report entitled **"GREENHOUSE MONITORING USING WSN"**, embodies report of project work carried out under the guidance of **NARAYANASWAMY H** Assoc. Professor **Dept. Of CSE, CBIT** as partial fulfillment of the requirement of the award of the degree in Bachelor of Engineering, Computer Science and Engineering, affiliated to **VISVESVAERAYA TECHNOLOGICAL UNIVERSITY, BELAGAVI** during academic year **2022-2023**. Further the content embodies in the project has not been submitted previously by anybody for the award of any other degree.

Place: Kolar

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ACKNOWLEDGEMENT

The completion of any work is a showcase of constant dedication and co-operation of many people who lent their hands which went seen or unseen.

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CHAPTER 1

1 INTRODUCTION

The continuous growth of world population, environmental change, industrialization, the arable land over the globe is decreasing every year. Therefore, the demand and requirement for hygienic food and crop yield have been growing continuously.

A survey conducted by the United Nations of Food and Agriculture Organization (FAO) estimated that the population of the world is expected to reach 9.73 billion in 2050. It is expected that more cropland and water will need to meet the future food demands globally. Furthermore, other challenges such as abrupt changes in climate, lack of labor, and water scarcity spiral the pressure on agriculturists and farmers. The challenges faced by traditional agriculture and greenhouse farming need a fundamental change to develop sustainable and ecological food. Greenhouse farming is one of the best alternatives to overcome the food crisis as well as to ensure the sustainability of socio-ecological.

1.1 BASIC TOPICS OF PROJECT

The greenhouse is a structure like a house that is covered with a plastic material or glass mainly designed to cultivate multiple crops in any season. In order to increase the quantity and quality of food, a greenhouse can regulate the growing patterns of plants accordingly. Traditional greenhouses are specifically designed with dry lands and ignore the multiple environmental variables such as temperature, humidity, among others. Usually, a smart and productive greenhouse requires environmental monitoring and control devices, to manage various weather parameters.

The IoT-enabled greenhouse farming trends. The deployment of a wireless sensor network (WSN) enables climatic data to be gathered and distributed for understanding and monitoring the internal system of the greenhouse, but there is a need to handle several other features which can cause significant destruction to the grown plants, such as, less or high-water supply, bad weather conditions, and light intensity. The eradication of these issues can be done through a precise system that helps to automate the monitoring and control methods for a smart greenhouse.

1.2 PROBLEM STATEMENT

More cropland and water will need to meet the future food demands globally. Furthermore, other challenges such as abrupt changes in climate, lack of labor, and water scarcity spiral the pressure on agriculturists and farmers. The challenges faced by traditional agriculture and greenhouse farming need a fundamental change to develop sustainable and ecological food. Greenhouse Monitoring Using WSN farming is one of the best alternatives to overcome the food crisis as well as to ensure the sustainability of socio-ecological.

1.3 SCOPE OF THE PROJECT

The scope of this project are as follows:

- The IoT offers an automated greenhouse environment that enables a significant association among tangible things and people.
- A user is allowed to gather real-time data processing, analysis, and meditation.
- The IoT enabled greenhouse farming to enhance productivity and decrease labor costs.
- A farmer can grow multiple crops in the appropriate season with less human effort.
- The efficient use of water and proper soil monitoring results in high crop production.
- The deployed system collects and transfers the sensed information via the IoT cloud for easy access from anywhere and at any time.

1.4 MOTIVATION

- The purpose of a green house is to shield crops from excess clod and heat and unwanted pests. A Greenhouse makes it possible to grow certain types of crops year round.
- Within the framework of sustainable development the energy supply system is a crucial topic. Spurred on by the Kyoto Protocol the attention for the definition of energy saving programs
- Promotion of environment-friendly technologies as renewable energy is increasing.

- Context the combination of a further decrease of emissions (CO2, NOX) with a faze-out.
- At the international level hydrogen as an energy carrier is one of the major topics in the discussion on pathways towards a future sustainable energy society.
- It is expected to contribute both to the reduction of air pollution, CO2-reduction and energy supply stability. The reason for this is that hydrogen offers a long term potential for energy systems with almost zero-emission level; it can be based on local and renewable energy sources.
- In the USA a 'Roadmap to hydrogen' has been developed already and on the European level recently the policy paper 'Hydrogen Energy and Fuel Cells, a vision of our future' has been presented.
- Within the Belgian energy policy the knowledge on hydrogen is rather limited and this project intends to be the first step in a scientific assessment of hydrogen in the Belgian context.

1.5 OBJECTIVE

A greenhouse is an important part of the agriculture and horticulture sectors in our country.

- It is used for growing plants faster at any season whether the climate is according to plant or not.
- Automatic monitoring and controlling of the climatic parameters will directly or indirectly govern the plant growth and hence their production.
- Green houses are used where climatic conditions are not as expected. At those places Green houses are used as an artificial environment to create required environmental conditions.

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1.6 ORGANIZATION OF THE REPORT

The report is organized into chapters as follows:

Chapter 1 - Introduction: This chapter presents a brief description about Greenhouse Monitoring Using WSN.

Chapter 2 - Review of literature: In this section, the works carried out by various researchers are as follow.

Chapter 3 - System requirement specification: The chapter 2 presents the specific requirement, software and hardware requirements interfaces used. It also presents a brief summary about the chapter.

CHAPTER 2

2 LITERATURE SURVEY

A Literature review is an objective, critical summary of reported research works relevant to a topic under consideration for research. Its purpose is to create familiarity with current thinking and research on particular topic and may justify future research into previously overlooked or understudied area.

2.1 RELATED WORK

[1] An Intelligent IoT-Based System Design for Controlling and Monitoring Greenhouse Temperature. Ahmad F Subahi1 , Kheir Eddine Bouazza1.

Improving agricultural production can only be achieved using innovative environmentally suitable solutions and modern agricultural technologies. Using Internet of Things (IoT) technologies in greenhouse farming allows reduction of the immediate impact of external climatic conditions. In this paper, a highly scalable intelligent system controlling, and monitoring greenhouse temperature using IoT technologies is introduced. The first objective of this system is to monitor the greenhouse environment and control the internal temperature to reduce consumed energy while maintaining good conditions that improve productivity.

[2] IoT and machine learning based approach for fully automated greenhouse. H. Jaiswal, K. P. Radha, R. Singuluri, and S. A. Sampson.

With the rapid evolution of technology, automation has taken over almost all fields of operation. The change in human-computer interaction has accelerated over the years. Greenhouses have come a long way in terms of technological advances. For 100% yields, it is essential to constantly monitor the optimal parameters for plant growth. Here in this work, different parameters that impact the yield of crops like humidity, CO_2 levels, light intensity, soil moisture, temperature are being monitored, controlled and coordinated using Raspberry Pi and Arduino. Internet of Things has enabled real-time data collection from the Smart Greenhouse and visualization on ThingSpeak platform. This paper proposes a fully automated greenhouse embedded with hydroponics and vertical farming and with excellent security provisions and surveillance to become a highly advanced and diverse version of currently prevailing models.

[3] Security and Privacy for Green IoT-Based Agriculture: Review, Blockchain Solutions, and Challenges. M. A. Ferrag, L. Shu, X. Yang, A. Derhab, and L. Maglaras

This paper presents research challenges on security and privacy issues in the field of green IoT-based agriculture. We start by describing a four-tier green IoT-based agriculture architecture and summarizing the existing surveys that deal with smart agriculture. Then, we provide a classification of threat models against green IoT-based agriculture into five categories, including, attacks against privacy, authentication, confidentiality, availability, and integrity properties. Moreover, we provide a taxonomy and a side-by-side comparison of the state-of-the-art methods toward secure and privacy-preserving technologies for IoT applications and how they will be adapted for green IoT-based agriculture.

[4] Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk. M. Ayaz, M. Ammad-Uddin, Z. Sharif, A. Mansour, and E. M. Aggoune

The rapid emergence of the Internet-of-Things (IoT) based technologies redesigned almost every industry including ‘‘smart agriculture’’ which moved the industry from statistical to quantitative approaches. Such revolutionary changes are shaking the existing agriculture methods and creating new opportunities along a range of challenges. This article highlights the potential of wireless sensors and IoT in agriculture, as well as the challenges expected to be faced when integrating this technology with the traditional farming practices. IoT devices and communication techniques associated with wireless sensors encountered in agriculture applications are analyzed in detail.

[5] A New IoT-based Platform for Greenhouse Crop Production M. Munoz, J.L. Guzman, J.A. Sanchez, F. Rodriguez, M. Torres and M. Berenguel

This work proposes a cloud solution to build an Internet of Things (IoT) platform applied in a greenhouse crop production context. Real-time and historical data, as well as prediction models, can be accessed by means of RESTful (Representational State Transfer) web services developed for such a purpose. Forecasting is also provided following a Greenhouse Models as a Service (GMaaS) approach. Traditionally, such models are hardcoded in applications or are embedded in software tools to be used as Decision Support Systems (DSS). In addition, the proposed platform allows users to register new IoT devices and their greenhouse data in the FIWARE platform, providing a cloud scale solution for the case study. RESTful services of the proposed platform are also used by a web application allowing users to interact easily with the system.

[6] Development of an Intelligent LED Lighting Control Testbed for IoT-based Smart Greenhouses. J. Jiang and M. Moallem.

The aim of our study is to develop an intelligent control system for mixing color ratios using LED lights in a greenhouse environment. To this end, different components of an experimental testbed is presented for achieving the desired light requirements for plant growth in a greenhouse environment. The proposed testbed provides a easy-to-use plant growth system with IoT-enabled control and monitoring features. To testify the features mentioned above, a feedback lighting control method to achieve a desired photosynthetic photon flux desnity (PPFD) set point is implemented. A two-week experiment was conducted on microgreen kale which was planted in the testbed and harvested at the end of the experiment. The experimental results has shown that the tested microgreen kale grew with a healthy condition in the proposed testbed and lighting environment.

[7] Design of a Novel Remote Monitoring System for Smart Greenhouses Using the Internet of Things and Deep Convolutional Neural Networks. Adel Mellit, Mohamed Benghanem, Omar Herrak and Abdelaziz Messalaoui

To support farmers and improve the quality of crops production, designing of smart greenhouses is becoming indispensable. In this paper, a novel prototype for remote monitoring of a greenhouse is designed. The prototype allows creating an adequate artificial environment inside the greenhouse (e.g., water irrigation, ventilation, light intensity, and CO2 concentration). An Android mobile application was also developed using an A6 GSM module for notifying farmers (e.g., sending a warning message in case of any anomaly) regarding the state of the plants. A low-cost camera was used to collect and send images of the plants via the webpage for possible diseases identification and classification. In this context, a deep learning convolutional neural network was developed and implemented into a Raspberry Pi 4. To supply the prototype, a small-scale photovoltaic system was built.

[8] Keeping data at the edge of smart irrigation networks: A case study in strawberry greenhouses Constantinos Marios Angelopoulos, Gabriel Filios, Sotiris Nikoletseas, Theofanis P. Raptis

Cloud-based approaches for smart irrigation have been widely used in the recent years. However, the network traffic, security and regulatory challenges, which come hand in hand with sharing the crop data with third parties outside the edge of the network, lead strawberry farmers and data owners to rely on global clouds and potentially lose control over their data, which are usually transferred to third party data centers. In this paper, we follow a three-step methodological approach in order to design, implement and validate a solution for smart strawberry irrigation in greenhouses.

[9] IoT-based adaptive network mechanism for reliable smart farm system Muhammad Rusyadi Ramlia , Philip Tobianto Daelyb , Dong-Seong Kima , Jae Min Leea

This paper presents an adaptive network mechanism for a smart farm system by using LoRaWAN and IEEE 802.11ac protocols. Generally, the internet of things (IoT) system for agriculture application is used in an environment where significant interferences can occur. These interferences can disrupt the network performance of the system. In this paper, an adaptive network mechanism is designed to improve the network performance of the system, in order to achieve a more reliable smart farm system. Specifically, the proposed adaptive network mechanism is implemented in the application layer. The system has the ability to adjust a protocol based on the network condition. For instance, the IEEE 802.11ac is suitable for transmitting data which require high data rate such as image or video.

[10] Environment Monitoring of Rose Crops Greenhouse Based on Autonomous Vehicles with a WSN and Data Analysis Paul D. Rosero-Montalvo, Vanessa C. Erazo-Chamorro, Vivian F. López-Batista, María N. Moreno-García and Diego H. Peluffo-Ordóñez

The main objective is to improve the quality of the crops while regulating the production time. To this end, a system consisting of autonomous quadruped vehicles connected with a wireless sensor network (WSN) is developed, which supports the decision-making on type of action to be carried out in a greenhouse to maintain the appropriate environmental conditions for rose cultivation. A data analysis process was carried out, aimed at designing an in-situ intelligent system able to make proper decisions regarding the cultivation process. The proposed system produces a significant reduction of data in the training set obtained by the WSN while reaching a high classification performance in real conditions—amounting to 90% and 97.5%, respectively.

CHAPTER 3

3 SYSTEM REQUIREMENT SPECIFICATION

3.1 INTRODUCTION

System requirement specifications gathered by extracting the appropriate information to implement the system. It is the elaborative conditions which the system need to attain. Moreover, the SRS delivers a complete knowledge of the system to understand what this project is going to achieve without any constraints on how to achieve this goal. This SRS not providing the information to outside characters but it hides the plan and gives little implementation details.

3.2 Hardware Requirements

- Arduino module
- Sensors like ph, water level, moisture etc.
- DC Fan
- Zigbee Module
- WIFI Module
- Light Dependent Resistor

3.3 Software Requirements

- Programming Platform: Arduino IDE
- Programming Language: Embedded C, C++ etc.
- Storage Type: Clouds

3.4 Summary

The chapter 3 considers all the system requirements which we require to develop this proposed system. Section 3.1 grants specific requirements like programming languages, frameworks are being used and under which platform this project has been done in detail. The hardware requirements and software requirements for this project have been explained in section 3.2 and 3.3

3.5 Conceptual Design & Network Architecture

3.5.1 Conceptual Design

Figure 3-5.1 Conceptual design of Greenhouse farming.

Figure 3-5.1 shows the conceptual design of a smart greenhouse. Several devices, for instance, actuators, sensors, and controlling tools are installed inside the vertical farm to observe and control the services. Sensors are linked directly to the climate parameters, through which collected data is transmitted to the server by IoT protocol. Moreover, the link of actuators to the parameters is indirect. Actuators regulate the control devices such as a heater, humidifier, air-conditioner, sliding window, and lights. The variation outcomes of environmental conditions force the actuation process to reset the required standard condition by regulating the devices.

3.5.2 Network Architecture

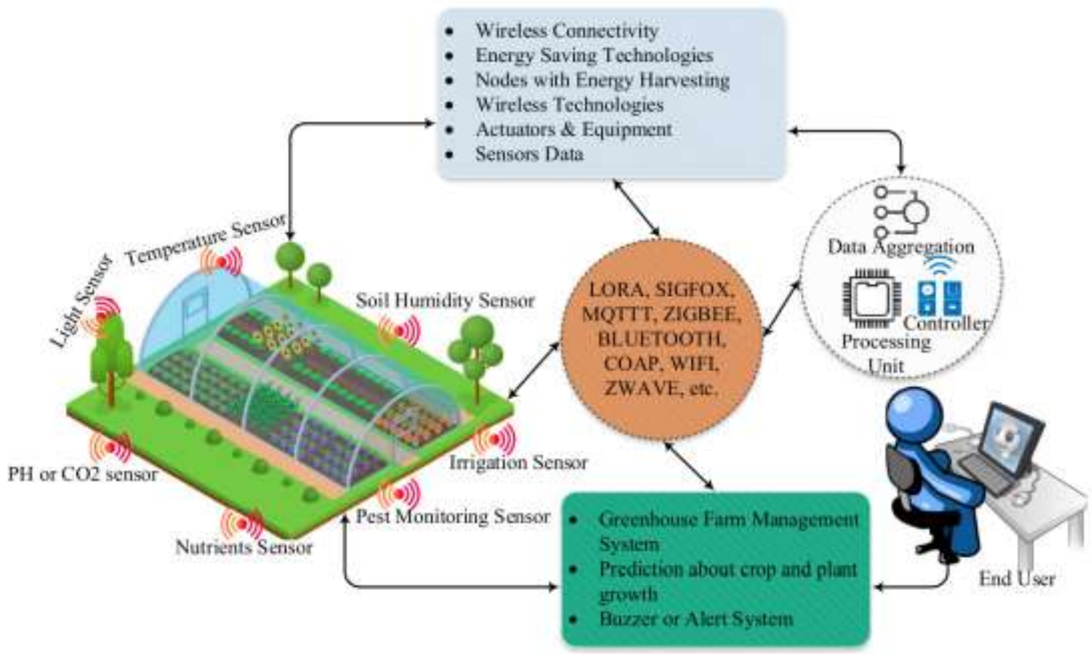

Figure 3-5.2 IoT-based greenhouse network architecture.

Figure 3-5.2 which is using four different layers named Cloud Storage, Fog/edge Computing, Gateway, and hardware segment. The cloud storage component delivers the resources on request by centralizing the greenhouse environmental information. Gateways are used to play a significant role in data distribution for those devices which have no design capability to share information directly by using the internet. Fog/edge computing is helpful to integrate all the resources for the distributed components. The resource's scalability is surged by decreasing the computational burden at the cloud. Lastly, the hardware segment contains multiple sensors, actuators, microcontrollers (Arduino or Raspberry PI), and a central processing unit (CPU) which are used to measure several greenhouse farming variables. Fast communication can be achieved in a smart greenhouse by using IoT communication protocols such as MQQT, COAP as Representational State Transfer (REST), and MQTT.

3.6 Functional Requirements :

- Device should be able to read all the sensors values accordingly.
- Device should do minimal computation.
- Device should perform functions automatically.
- Device should send the collected data to remote monitoring /cloud.

3.7 Non Functional Requirements :

- Software's should be support for all the sensor values and installation can be changed.
- Requirement data will be stored in the cloud database for further operations.
- Software can handle data operations from end users.

CHAPTER 4

4 SYSTEM ANALYSIS

4.1 EXISTING SYSTEM

- Greenhouse monitoring is not automatic.
- It requires labor works.
- Mobile communication was used.
- Only some humidity levels were determined.
- The data were transmitted using Bluetooth communication protocol.

4.2 PROPOSED SYSTEM

- Uses the WSN technology.
- More greenhouse monitoring parameters.
- An application was created to monitoring the greenhouse.

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APPENDIX A - ACRONYMS

WSN – Wireless Sensor Network

FAO – Food and Agricultural Organization

DSS – Decision Support System

SRS – System Requirements Specifications

GSM – Global System for Mobile communication

PPFD – Photosynthetic Photon Flux Density

REST – Representational State Transfer

MQTT – Message Queuing Telemetry Transport

COAP – Constrained Application Protocol

CPU – Central Processing Unit

IOT – Internet Of Things

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An Intelligent IoT-Based System Design for Controlling and Monitoring Greenhouse Temperature

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ABSTRACT The Kingdom of Saudi Arabia is known for its extreme climate where temperatures can exceed 50 °C, especially in summer. Improving agricultural production can only be achieved using innovative environmentally suitable solutions and modern agricultural technologies. Using Internet of Things (IoT) technologies in greenhouse farming allows reduction of the immediate impact of external climatic conditions. In this paper, a highly scalable intelligent system controlling, and monitoring greenhouse temperature using IoT technologies is introduced. The first objective of this system is to monitor the greenhouse environment and control the internal temperature to reduce consumed energy while maintaining good conditions that improve productivity. A Petri Nets (PN) model is used to achieve both monitoring of the greenhouse environment and generating the suitable reference temperature which is sent later to a temperature regulation block. The second objective is to provide an Energy-Efficient (EE) scalable system design that handles massive amounts of IoT big data captured from sensors using a dynamic graph data model to be used for future analysis and prediction of production, crop growth rate, energy consumption and other related issues. The design tries to organize various possible unstructured formats of raw data, collected from different kinds of IoT devices, unified and technology-independent fashion using the benefit of model transformations and model-driven architecture to transform data in structured form.

INDEX TERMS Intelligent Greenhouse Agriculture, Temperature Control System, Internet of Things (IoT), Petri Nets (PNs), Graph database, Model Transformations, Model-Driven Architecture (MDA).

I. INTRODUCTION

Agriculture in the Kingdom of Saudi Arabia (KSA) faces several constraints, including extreme temperatures, water scarcity, sea water desalination costs, and non-fertile soil. To overcome this hostile environment and ensure agricultural self-sufficiency, multiple government agricultural programs were launched to ensure food security [1]. Indeed, agricultural self-sufficiency is a sign of a country's stability and strength [2]. Agricultural self-sufficiency can only be achieved by introducing innovative environmentally suitable solutions and modern agricultural technologies necessary for improving productivity and decreasing production costs. Greenhouse farming is interesting in the sense that it succeeds in isolating the yield of nature, and allowing the protection of plants against the immediate impact of external climatic conditions [3].

In the desert climate where the summer lasts over half of the year, as in Saudi Arabia. The average temperature in July is around 43 °C, and the average one in January is about 14 °C. It is impossible to enhance the production of vegetables and fruits like tomatoes, Cucumbers, Sweet peppers and strawberries, as the optimum temperature for their growth falls in the range between 11°C to 28°C.

From that, it can be realized that there is a necessity of providing an appropriate controlled microclimate, for various kinds of crops, that requires caring of four main environmental parameters, namely, temperature, humidity, CO_2 level and light intensity. This makes greenhouses is an appropriate economical solution for farming because climate variables can be manipulated and controlled to achieve optimal growth rate of crops. Greenhouse allows producing crops, especially fruits and vegetables production that requires cold weather to grow fast in a quality manner, all year round and meet consumer demand for out-of-season fruit and vegetables [4].

The Internet of Things (IoT) concept allows the system, using electronic circuits, sensors and programming, to detect and control other devices remotely, creating a good interaction between the physical and computer world in order to improve efficiency and accuracy while achieving financial benefits [5]. The use of IoT in the development of smart homes has received increasing interest. The studies presented focus mainly on energy management through the control of electrical units [6-10]. The results are very interesting, and are being used more and more in everyday life.

The use of IoT in greenhouse agriculture contributes to its development [11]. Thus, the information collected from the sensors, inside and outside of the greenhouse, can be analyzed and stored on a central cloud data storage for archiving long term analysis and data mining tasks, as well as stored on cloud edge points for faster processing. End-users can access these data from any active internet device and gain benefits of the generated knowledge regarding their greenhouse crops production, energy consumption, and other related issues associated to this business [12-14]. The use of IoT in greenhouses is receiving increasing attention and many interesting results have been achieved [15-17].

In this paper, based on the IoT new advances in using sensors equipment, we propose to build an intelligent Energy-Efficient (EE) system which monitors and controls internal greenhouse temperature. The proposed system will allow increased and improved productivity. The main study objective is not only to build a consistent growing environment, but also to automate the whole system and make it smart to save energy and production costs. The proposed approach focuses on monitoring and controlling greenhouse internal temperature, but it can be extended to other kinds of properties, e.g. Carbon dioxide (CO_2) and humidity.

The proposed system is considered as smart because it is able, autonomously, to monitor the outside temperature and the energy consumption rush hours, in order to accurately generate the suitable reference temperature, and ensure that the greenhouse temperature reaches this reference temperature. In addition, this system can identify the angle of the Sun rays in order to control the opening and closing of the awnings, which results in reducing the effects of high-temperatures.

All these captured parameters related to temperature and energy are recorded for future analysis and prediction in a dynamic graph data model used in designing the backend storage of the system. The proposed system design supports handling IoT data in a unified and technology-independent fashion, using a suitable strategy of model transformations, a principle of model-driven engineering methodology of software system development. The designed graph-based schema accepts multiple formats of IoT data and parameters that come from various sensor brands.

The rest of this paper is organized as follows. Section II represents a brief highlight about the related technologies to the proposed work, including the concepts of big data, graph data model, principles of model transformations and model-driven architecture (MDA). Section III, discusses in depth the overall architectural design of the proposed greenhouse system, including its core components: temperature control & monitoring subsystem with simulation results, data conversion subsystem, and greenhouse management information system. Section IV, presents the contribution summary of the proposed greenhouse system. Finally, in the conclusion (section V), we summarize the ideas and innovations presented in this paper and outline some future perspectives and applications.

II. RELATED TECHNOLOGIES

A. IoT SENSORS

A broad variety of sensors that provides a mature sensing technology for greenhouse monitoring applications is available in markets These sensors can be utilized for collecting, automatically, important information including microclimate data in the greenhouse, control actions, crops growth rate and characteristics of the crops and more related data. The availability of these various kinds of advanced sensing technologies in the markets makes the implementation of the proposed IoT-based system is achievable.

Temperature sensors, for instance, can be used to measure, periodically the temperature inside the greenhouse. There are some common models utilized for this purpose, such as LP PYRA 02 [4], E+E Elektronik EE160 [18], DHT11 [19, 20], and LM35 model [21]. On the other hand, Humidity sensors can be utilized for sensing the amount of vapours in the air, such as LP PYRA 02 [4], E+E Elektronik EE160 [18], DHT11 [19, 20], and HSM20G [21]. Additionally, there is another important sensing technology need to be utilized inside the greenhouse for measuring the level of CO_2. It is available in markets with different models such as Vaisala GMP220 [4]. Sensors for sensing the density of Sun rays is also another kind of critical and sensitive technology required in the greenhouse visible, such as LP PYRA 02 [4], and Apogee Instruments Inc. SP110 [18].

A. ENERGY EFFICIENCY (EE)

Energy efficiency (EE) has always been a research hotspot in the field of Internet of Things [22, 23]. According to [22], for instance, an integrated structure is introduced for both wireless and wired parts to optimize the energy efficiency (EE) performance of the fifth generation (5G) Internet of Things systems. A cellular partition zooming (CPZ) mechanism and a precaching mechanism were utilized for the wireless part and the wired one respectively. The integration of both mechanism, in the proposed comprehensive solution (structure), provided better deployment of the select-and-sleep mechanism in the introduced component of the unified control center. In order to cover wider outdoor area, the single antenna RRHs was replaced by massive MIMO array instead. As a

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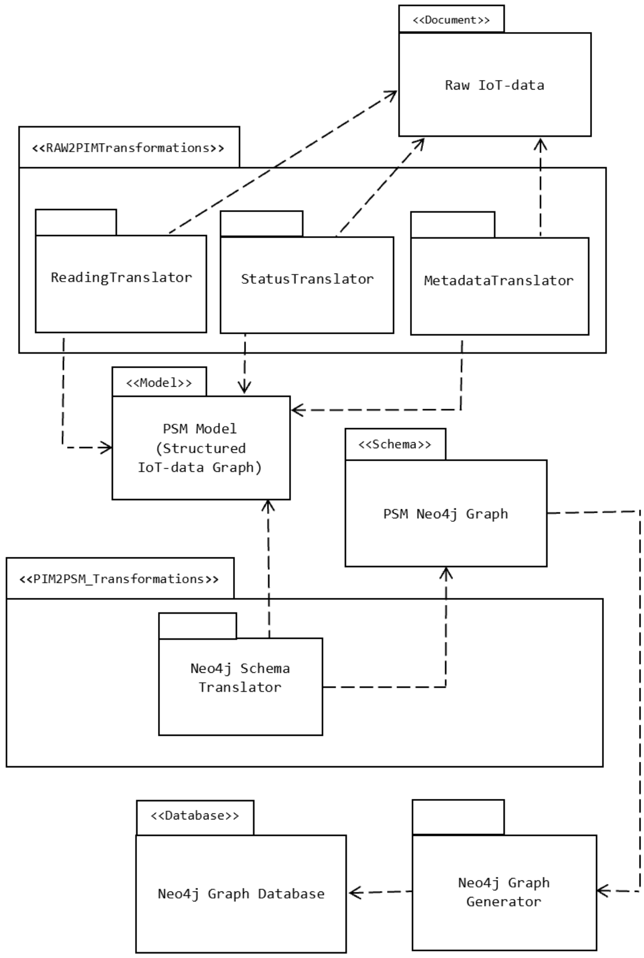

FIGURE 12. **A transformations chain of unstructured IoT data into Neo4j Cypher**

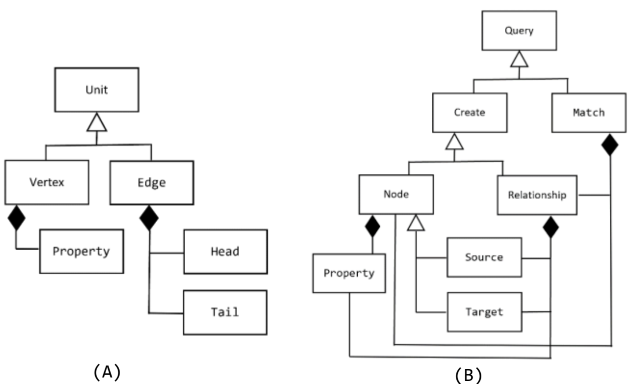

FIGURE 9. **Concepts of PIM & PSM graphs at the metamodel level**

$$
\begin{aligned}
& tr: PIM \rightarrow PSM \\
& \quad r1: Vertex \rightarrow Node \\
& \quad\quad \forall v: Vertex, \forall a: Attribute \cdot ((v \in PIM \land a \in PIM) \\
& \quad\quad\quad\quad\quad \land AttributeOf(a, v)) \\
& \quad\quad \rightarrow \\
& \quad\quad \exists!\, n: Node, \exists!\, p: Property \cdot ((n \in PSM \land p \in PSM) \land \\
& \quad\quad\quad (CreateNode(n, v) \land CreateProperty(p, a) \\
& \quad\quad\quad\quad\quad \land PropertyOf(p, n)))
\end{aligned}
$$

$$
\begin{aligned}
& r2: Edge \rightarrow Relationship \\
& \quad \forall v1, v2: Vertex \cdot ((v1 \in PIM \land v2 \in PIM) \land \\
& \quad\quad \forall e: Edge, \forall a: Attribute \cdot ((e \in PIM \land a \in PIM) \\
& \quad\quad\quad\quad\quad \land AttributeOf(a, e)) \\
& \quad\quad \rightarrow \\
& \quad\quad \exists!\, n1, n2: Node \cdot ((n1 \in PSM \land n2 \in PSM) \land (ReferTo(n1, v1) \\
& \quad\quad\quad\quad\quad \land ReferTo(n2, v2)) \\
& \quad\quad \exists!\, r: Relationship, \exists!\, p: Property \cdot ((r \in PSM \land p \in PSM) \\
& \quad\quad\quad\quad \land \big(CreateRelationship(r, e) \land CreateProperty(p, a) \\
& \quad\quad\quad\quad\quad\quad \land PropertyOf(p, r)\big) \land RelateTo(n1, n2))
\end{aligned}
$$

LISTING 1. **Transformation rules from the PIM graph into PSM graph**

```
<Vertex type=”ActuatorOrder“ id=”ao8833”>
    <Attribute name=”actionType“ value=”CLOSE“ />
    <Attribute name=”priority“ value=”1“ />
    <Attribute name=”reqTimestamp“ value=”13:53:28PM“ />
</Vertex>
<Vertex type=” Actuator“ id=” ac1002”>
    <Attribute name=”job“ value=”partialOpen“ />
    <Attribute name=”voltageReq“  value=”73.89V” />
    <Attribute name=”job“ value=”partialOpen“ />
    <Attribute name=”size“  value=”1.2k” />
</Vertex >
<Edge id=”r1” label=”ACTIVATES“>
    <Head ref=”ao8833“ />
    <Tail ref=”ac1002“ />
</Edge >
```

LISTING 2. **Underlying representation of the intermediate PIM graph**

```
<Query action=”create”>
    <Node name=”node1” type=”ActuatorOrder“ aoId=”ao8833”>
        <Property name=”actionType“ value=”CLOSE“ />
        <Property name=”priority“ value=”1“ />
        <Property name=”reqTimestamp“ value=”13:53:28PM“ />
    </Node>
    <Return ref=”aoId” />
</Query>
<Query action=”create”>
    <Node name=”node2” type=”Actuator“ aid=”ac1002”>
        <Property name=”job“ value=”partialOpen“ />
        <Property name=”voltageReq“  value=”73.89V” />
        <Property name=”job“ value=”partialOpen“ />
        <Property name=”size“  value=”1.2k” />
    </Node>
    <Return ref=”aId” />
</Query>
<Query action=”create”>
    <Relationship id=”r1” label=”ACTIVATES“>
        <Source ref=”ao8833“ />
        <Target ref=”ac1002“ />
    </Relationship >
    <Return ref=”id” />
</Query>
```

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CONCLUSION

monitors the greenhouse environment, generates the reference temperature, and regulates the internal temperature was developed. The use of a PN model allows us to monitor the greenhouse environment, to generate suitable reference temperatures, and to supervise the whole system.

A controlled awning that reduces the effects of the Sun rays was also introduced.

The proposed system is autonomously able to: monitor the outside temperature, monitor the energy consumption rush hours, monitor the angles of the Sun rays, generate the suitable temperature, send this temperature as a reference signal for temperature regulation, guarantee that the ambient greenhouse temperature reaches this reference temperature, and finally, goes into standby state in the absence of tasks to accomplish.

The main innovative point of this work is to build a smart system through associating different techniques; greenhouse monitoring and supervising through PN, temperature regulation using a closed loop system and awnings control to obtain a smart framework that reduces energy consumption and ensuring an appropriate greenhouse growing environment. This is considered very beneficial while achieving energy savings and reducing production costs, it keeps an appropriate environment for plants to grow. The effectiveness of the proposed approach is demonstrated via a number of simulations that are performed using a greenhouse temperature transfer function.

Additionally, all captured information that is related to energy consumption, internal greenhouse temperature and other agricultural attributes are structured using a proper strategy of model transformations, then stored and archived in the dynamic Neo4j graph-based database system. This is introduced and discussed as a scalable design of a supporting management information system in the second part of this work.

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IoT and Machine Learning based approach for Fully Automated Greenhouse

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***Abstract*—With the rapid evolution of technology, automation has taken over almost all fields of operation. The change in human-computer interaction has accelerated over the years. Greenhouses have come a long way in terms of technological advances. For 100% yields, it is essential to constantly monitor the optimal parameters for plant growth. Here in this work, different parameters that impact the yield of crops like humidity, CO_2 levels, light intensity, soil moisture, temperature are being monitored, controlled and coordinated using Raspberry Pi and Arduino. Internet of Things has enabled real-time data collection from the Smart Greenhouse and visualization on ThingSpeak platform. This paper proposes a fully automated greenhouse embedded with hydroponics and vertical farming and with excellent security provisions and surveillance to become a highly advanced and diverse version of currently prevailing models.**

Keywords— Greenhouse, Automation, Internet of Things, Humidity. Temperature, Soil Moisture, Carbon Dioxide, Light Intensity, Hydroponics, Vertical Farming, Facial Recognition, ThingSpeak, Raspberry Pi, Arduino

I. INTRODUCTION

In recent decades, technology has been incorporated in almost all agricultural applications, leading to highly digitized systems which give accurate results. Agricultural demands are changing, and so are consumer preferences from conventional needs. These demands need to be met by this industry which is facing a rise in labour expenses due to shortage of manual workers. Modern agriculture has encouraged farmers to turn to technology to make the farms more efficient, automated and cost effective [1]. A greenhouse incorporates all these agricultural advancements under one roof, providing controlled growth conditions according to crop requirements to ensure abundant yield.

Rapid climate change over the years, and unpredictable weather conditions has led to crop failure frequently. With the help of a greenhouse, all kinds of produce, especially seasonal crops can be grown throughout the year to give multiple yields. Pesticides and insecticides can be utilized judiciously to prevent diseases and to get rid of pests. Modern farming techniques like hydroponics and aeroponics are possible to implement in a greenhouse cultivation environment[2].

In the last decade, plenty of research has been conducted in this domain by various researchers. Thangavel Bhuvaneswari et. al. in 2014 have proposed a design to control temperature by enabling ventilation and open/close roof based on rain drop sensor detection [3]. Ahmad Halim et. al. in 2016 designed an automated scheduling based on plant growth for greenhouse management. The main objective of their research was to monitor and to control temperature, humidity, soil moisture and carbon dioxide stated in a real-time and to ensure that it will continue to maintain their optimum conditions based on the plant growth phases in order to fulfil the photosynthesis process [4].

Pallavi S et. al. in 2017 proposed a plan to control CO2, soil moisture, temperature, and light. Based on the soil moisture the controlling action is accomplished for the greenhouse windows/doors based on crops once a quarter complete round the year[5]. In 2017, Muhammad Faizan Siddiqui et. al. developed an automatic greenhouse system that monitors and controls temperature, light, and soil moisture using fan, light bulb, and water sprayer respectively [6].

P. Deedeepya et. al. in 2018 have proposed a system that can monitor the changes in factors like temperature, humidity, soil moisture by integrating the sensor elements to Raspberry Pi and sends alerts to the user through a mobile application [7]. In 2018, Thirukkuralkani et. al. in their paper have measured real-time parameter and serially communicated to the host system by means of ZigBee technology with LabVIEW and microcontroller, for the proper maintenances of climatic conditions according to the plant growth [8]. Ozlem Alpay et. al. in 2018 predicted the amount of energy and water consumed for controlling the climate parameters such as temperature, relative humidity, and soil moisture by using node packets placed in the greenhouse. They used star topology to place the node packs in a wireless sensor network and applied fuzzy logic method to receive input data from the sensors [9]. A sustainable IoT enabled greenhouse that maintains optimum temperature, humidity, light and soil moisture levels with little or no input from the user was proposed by Susan Nnadi et.al in 2018 [10].

J. Warrington et. al. in their research on the influence of blue and red biased light spectra on plant growth proved enhanced concentration of amino acids (aspartic and glutamic acid) and proteins in the presence of blue light and increased concentrations of soluble sugars and starch in leaf tissue in the presence of red light. This shows that blue light and red light help enhance plant growth resulting in better yield [11]. In 1997, G.D. Goins et. al. in their study on effect of red light with and without blue light on plant growth proved that the combination of red light along with blue resulted in enhanced foliage and yield production. Blue light has a great influence in formation of chlorophyll, enabling the plant to absorb more sunlight. Exposure to this light increases plant growth and maturity rates. Red light in combination with blue light has been observed to contribute to the optimal development of a plant and give better yield [12].

In the present work, a scaled down greenhouse prototype has been designed after understanding how various parameters affect plant growth and coming up with the most ideal arrangement to ensure optimum yield. It consists of various sensors which measure and control the important

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parameters like humidity, temperature, light intensity, air quality and soil moisture which are responsible for the growth of the crops. An algorithm is designed for each parameter. As the parameter levels fall below or rise above the threshold range, an action is taken to maintain the value in the optimum range. A fertilizer testing system has also been designed to measure the levels of macronutrients present in the soil to help analyse and improve the soil quality. This prototype supports hydroponics and vertical farming along with traditional land farming. A fingerprint-controlled and face-controlled security gate is a plus, along with camera surveillance to monitor the footage from anywhere in the world.

This fully automated greenhouse monitors and controls the parameters without any kind of human interaction. Using Internet of Things, the data collected from all the sensors is observed and analysed using visualization tools available on ThingSpeak cloud. Implementation of this model on a large scale will help reduce the dependence on manual labour and reduce crop failure.

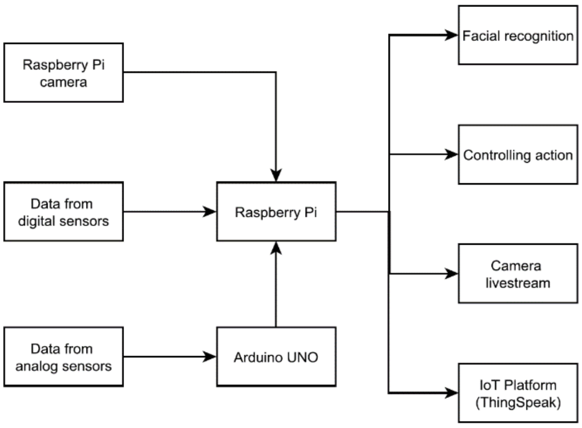

Fig.1. Block diagram depicting the general work flow of the prototype.

II. SYSTEM DESIGN

This automated greenhouse has been equipped to measure and control various parameters namely – Temperature, Humidity, Air Quality, Soil Moisture, Light Intensity and Height of Crop by integrating various sensors using Raspberry Pi. A security and surveillance system has also been designed for safety of the enclosure.

A. *Temperature*

Temperature plays the most crucial role in growth and development of plants. Maintaining a constant temperature during the day as well as night can support production of seasonal crops throughout the year. During the day the temperature can rise too high than the desired range, in such a situation a cooling fan is used while at night a heat source is used to avoid freezing temperatures. DS18B20 Waterproof Digital Temperature Sensor is utilized to give accurate temperature results. It ranges from -50□ to +125□.

B. *Humidity*

To achieve optimal plant growth, humidity control is vital. High relative humidity can lead to fungal growth and eventually cause plant diseases. Whereas dry environments can drastically reduce plant growth and ultimately lead to wilting and death. When humidity is below desired range, a mist fan is switched on until it reaches the default range. To combat high humidity, exhaust fan is used. DHT11 has been interfaced to monitor humidity levels inside the greenhouse.

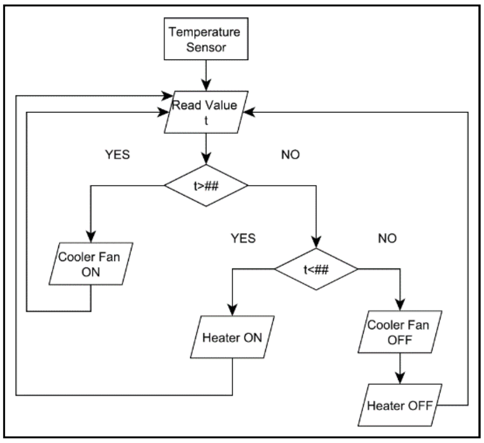

Fig.2. Temperature automation algorithm.

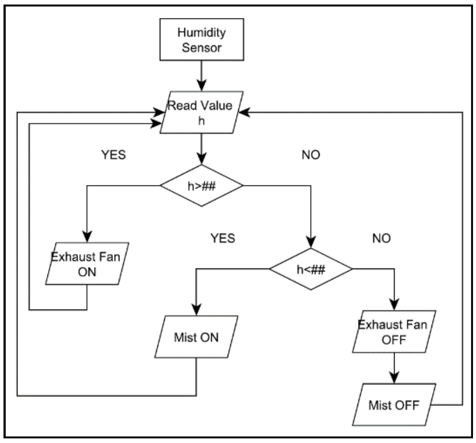

Fig.3. Humidity automation algorithm.

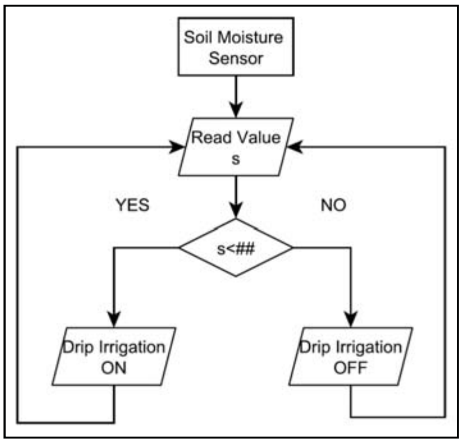

Fig. 4. Soil moisture automation algorithm.

C. *Soil Moisture*

Another important factor in plant growth is the soil moisture content. Soil Moisture Sensor helps to monitor the volumetric content of the soil to control the irrigation in the greenhouse [5]. When the moisture level falls below the required range, it could lead to yield loss and plant death. Drip irrigation has been implemented to maintain a constant level of moisture according to the plant requirement.

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D. Light Intensity

Sunlight plays an important role in photosynthesis. An LDR Sensor Module has been used to measure the light intensity. When natural light intensity reduces, artificial light is switched on to optimize plant growth. To provide an artificial light source after sunset, a combination of red and blue light has been used. Research states that this combination yields more leaves and crops, depending on the type of plant [11-12].

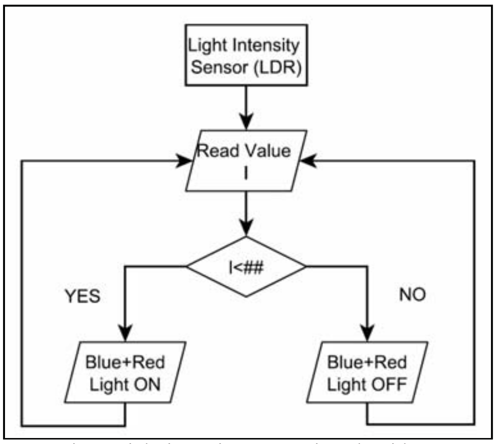

Fig.5. Light intensity automation algorithm.

E. Air Quality

The carbon dioxide levels highly influence the plant growth rate and hence it becomes necessary to monitor and control the concentration to achieve optimal growth. A closed greenhouse system generally contains low levels of CO2 during the day to utilize the available light and hence air circulation becomes a necessity [5]. An exhaust fan has been installed to enrich the greenhouse with CO2 and ultimately accelerate plant growth in the presence of enough light.

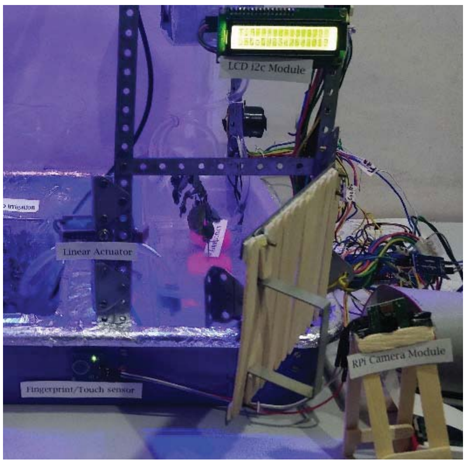

Fig.6. Security entrance of the greenhouse

F. Height of Crop

It is important to identify when the crop has fully grown. An Ultrasonic Sensor has been installed to measure the height of crop. Height can be remotely monitored by the user and helps to keep a check on the growth progress of the plant.

G. Security System

Protection of the enclosure from strangers and animals is an important necessity. A fail-safe security system is designed with both facial and fingerprint recognition. At the entrance of the greenhouse, a gate has been installed which is controlled by a linear solenoid actuator. Once an authorized face ID or fingerprint is identified, the door opens. Camera surveillance is enabled which can be viewed from anywhere in the world.

Fig.7. Active Hydroponic System embedded in water tank.

H. ThingSpeak-Internet of Things

ThingSpeak is an open source IoT application and API, to store and retrieve data from sensors and actuators. It handles real-time data collection, visualizes the collected data in the charts form, has ability to create plugins and apps for collaborating with web services, social network sites and other APIs [7]. This cloud has been used to analyze and visualize temperature, humidity, soil moisture, carbon dioxide levels, height of crops and light intensity. This data can be viewed remotely by the owner with access to internet.

Fig.8. Climate-controlled Vertical Farming.

I. Active Hydroponic System

The concept of hydroponics or soil less gardening has been around for thousands of years now. Hydroponics has several advantages over soil grown plants. It stimulates root growth with the extra oxygen accessible to them and tends to absorb nutrients faster. The nutrients are added to the water directly several times a day according to plant requirement. Hydroponic plants require very little energy to find food since its readily available in the water. This saved energy can be utilized to produce more fruit and speed up growth. We have implemented an active hydroponic system embedded inside analyzed between 2-3 sensors, in a way that one is a derivative of the other/s, the number of sensors being utilized can be reduced, ultimately improving the cost efficiency and reducing complexity of hardware. Apart from surveillance, the camera can also be utilized to help in identifying fruit growth and plant diseases.

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Security and Privacy for Green IoT-Based Agriculture: Review, Blockchain Solutions, and Challenges

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ABSTRACT This paper presents research challenges on security and privacy issues in the field of green IoT-based agriculture. We start by describing a four-tier green IoT-based agriculture architecture and summarizing the existing surveys that deal with smart agriculture. Then, we provide a classification of threat models against green IoT-based agriculture into five categories, including, attacks against privacy, authentication, confidentiality, availability, and integrity properties. Moreover, we provide a taxonomy and a side-by-side comparison of the state-of-the-art methods toward secure and privacy-preserving technologies for IoT applications and how they will be adapted for green IoT-based agriculture. In addition, we analyze the privacy-oriented blockchain-based solutions as well as consensus algorithms for IoT applications and how they will be adapted for green IoT-based agriculture. Based on the current survey, we highlight open research challenges and discuss possible future research directions in the security and privacy of green IoT-based agriculture.

INDEX TERMS Security, privacy, authentication, blockchain, smart agriculture, greenhouse.

I. INTRODUCTION

The Internet of Things (IoT) has been applied in many areas, such as smart farming [1], smart home [2], wearables [3], smart city [4], connected health [5], connected car [6], connected drones [7], among other areas. The IoT allows physical objects to communicate together, share information and coordinate decisions. The IoT transforms traditional objects into intelligent objects by exploiting its enabling technologies such as communication technologies, Internet protocols, application, and sensor networks [8], [9].

The global smart agriculture market is expected to reach \$15.3 billion by the end of 2025 compared to \$5 billion in the year 2016 [10]. Smart agriculture will become an important IoT application area in agri-products exporting countries. Recently, the IoT application has been deployed for smart agriculture using wireless sensor networks (WSNs) such as irrigation sensor network [11], prediction of frost events [12], precision soil farming [13], blind entity identification [14], smart farming [15], and precision agriculture [16].

To develop a green IoT-based agriculture solution, there are six main challenges, including, hardware, data analytics, maintenance, mobility, infrastructure, data security, and privacy [17]. The hardware challenges concern the choice of sensors and meters for IoT devices. Therefore, there are various kinds of sensors types that can be used in IoT application (e.g., temperature sensor, proximity sensor, pressure sensor, water quality sensor, chemical sensor, gas sensor, humidity sensor...etc.). The data analytics challenge concern the application of predictive algorithms and machine learning (e.g., deep learning approaches) in IoT data to obtain a nutritive solution for smart agriculture. The maintenance challenge concerns regular sensors checks of all IoT devices since they can be easily damaged in the agriculture field. The mobility

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TABLE 1. Related surveys on green IoT-based agriculture.

Year	Author	Main focus/contributions
2017	Brewster et al. [20]	A review on developing IoT-based large-scale pilots in agriculture
2017	Ray [21]	A systematic survey that covers the IoT deployment for improved farming
2017	Tzounis et al. [38]	Review of embedded platforms and technologies in agriculture along with the main agriculture applications
2018	Elijah et al. [9]	An overview and detailed investigation of IoT and data analytics in agriculture
2019	Khanna and Kaur [22]	Fundamental structures of IoT and its impact in the field of precision agriculture
2019	Ruan et al. [23]	A brief survey on the applications of green IoT-based agriculture

challenge concerns the type of wireless communication (e.g., 4G, 5G, WiFi, 6LowPan, LoRa) that can connect sensors distributed over a large area in the agriculture field. The infrastructure challenges concern the installation and development of IoT networking architecture using new technologies such as fog computing, cloud computing, network virtualization...etc. The main problem in the development of green IoT-based agriculture is not located at the physical support but mainly in reassuring both security and privacy. With the adaption of green IoT-based agriculture, an adversary may find more ways to penetrate into the system (e.g., via a false data injection attack), raising new security and privacy issues and asking for more secure communications in the smart agriculture filed.

According to Cha *et al.* [18], privacy-enhancing technologies in IoT application can be classified into seven categories, including, enforcement, control over data, personal data protection, anonymization or pseudonymization, partial data disclosure, anonymous authorization, and holistic privacy preservation. Therefore, security requirements [19] in IoT application can be classified into authentication, confidentiality, non-repudiation, integrity, and access control. These security and privacy requirements should be achieved by the security protocols for green IoT-based agriculture.

There are related survey papers [9], [20]–[23] that focused on various aspects of IoT-based agriculture, as presented in Tab. 1. Brewster *et al.* [20] presented a review on developing IoT-based large-scale pilots in agriculture. Ray [21] presented a systematic survey that covers the IoT deployment for improved farming. Recently, the surveys [22], [23] discussed the fundamental structures of IoT and its impact in the field of green IoT-based agriculture. However, these surveys are very limited regarding research challenges on security and privacy.

In the literature, there are different related surveys that deal with IoT security. As shown in Table 2, we classify the IoT security surveys with respect to the following criteria:

- *Threat model:* It indicates whether the survey considered the threats against the IoT network.
- *Security & Privacy:* It indicates whether the survey focused considered the security and privacy countermeasures to protect the IoT network.
- *Blockchain:* It indicate whether the survey considered bloackanin-based solution for IoT security.
- *Target IoT application:* It indicates whether the survey focused on specific or general IoT applications.

Most of the IoT security surveys [24]–[31] describe the required security and privacy countermeasures and target without focusing on any particular application. Some of them restrict their covered countermeasures to IoT security taxonomy [26], IoT frameworks [27], [30], security communication protocols [24], [25], or trust-based solutions [31]. Some of the surveys describe the threat models that could comprise the security of IoT networks [26], [28], [29], [31]–[33]. Recently, blockchain-based solutions for IoT security have attracted more attention in [29], [34]–[36]. Kouicem *et al.* [35] present their security solutions and blockchain-based security solutions with respect to five IoT applications: Smart Grid, EHealth, Transportation, Smart city, and Manufacturing. Other surveys focused on industrial IoT [32], Smart Grid [37], or Smart Home [34]. To the best of our knowledge, our survey is the first that thoroughly covers threats models, secuirty and privacy countermeasures, blockchain-based solutions for IoT security, and focuses only on Green IoT-based agriculture applications.

Our contributions in this work are:

- We present a four-tier green IoT-based agriculture architecture.
- We present the threat models against green IoT-based agriculture and provide a classification into five categories, including, attacks against privacy, authentication, confidentiality, availability, and integrity properties.
- We review the security and privacy solutions for IoT applications and how they will be adapted for green IoT-based agriculture.
- We analyze the privacy-oriented blockchain-based solutions for IoT applications and how they will be adapted for green IoT-based agriculture.
- We provide the consensus algorithms for blockchain-based solutions and how they will be adapted for green IoT-based agriculture.
- We emphasize the security and privacy challenges solutions for green IoT-based agriculture.

The rest of this paper is organized as follows. Section II presents the four-tier green IoT-based agriculture architecture. In Section III, we present the threat models against green IoT-based agriculture and provide a classification into five categories. In Section IV, we provide the new trends of security and privacy solutions for green IoT-based agriculture. In Section V, we clearly highlight the pros and cons of the existing privacy-oriented blockchain-based solutions. Then, we discuss the security and privacy challenges solutions in Section VI. Lastly, Section VII presents conclusions.

sleeps for a fixed period of time. For more details about the PoET algorithm, we refer the reader to the Hyperledger Sawtooth project [112].

12) PROOF-OF-REPUTATION (PoR)

The PoR algorithm (used by GoChain [115]) is similar to PoA algorithm, which it is based on the reputations of the IoT nodes. An IoT node in the green IoT-based agriculture must have a reputation important enough to be voted as an authoritative node. Once an authoritative node is voted, he can sign and validate blocks in the blockchain network.

13) PRACTICAL BYZANTINE FAULT TOLERANCE (PBFT)

The PBFT (Practical Byzantine Fault Tolerance) algorithm is the first to be able to tolerate "Byzantine" faults, which is proposed by Miguel Castro and Barbara Liskov in 1999 [126]. This algorithm provides reliability and robustness properties in a synchronous environment and requires $N = 3f + 1$ replicas to tolerate simultaneous Byzantine faults. The PBFT algorithm can be effectively applied in almost all domains of IoT, including, Internet of Energy [118], Internet of Drones [120], Internet of Vehicles [127], ...etc. Therefore, the PBFT algorithm can be adapted by a Blockchain-based solution for green IoT-based agriculture, as presented in Fig. 6. Specifically, when a farmer buyer node wants to buy a product from agri-products sellers, they send its request to the fog node. This fog node creates a PRE-PREPARE message to propose to the other replicas the scheduling of the bloc. The correct replicas respond to the PRE-PREPARE with a PREPARE message, which is sent to all replicas (i.e., neighbor nodes). Once the neighbor nodes have received $2f$ PREPARE and the associated PRE-PREPARE, then they agree on the order of the farmer buyer node's request. At the end, the neighbor nodes send a VALIDATION message to all replicas. Once a replica has received $2f + 1$ VALIDATION, then it executes the request and responds to both farmer buyer node and agri-products seller. If the client does not receive a response after a specified time period, he forwards the request to all replicas. When a replica receives a request, it starts view-change. Note that there are more variations of PBFT algorithm such as Aardvark [128], Zyzzyva [129], HQ [130], Q/U [131], and Abstract [132].

14) DELEGATED BYZANTINE FAULT TOLERANCE (dBFT)

The dBFT algorithm is a consensus method (used by Neo [116]) where all users elect nodes, called bookkeepers, who are responsible for adding new blocks to the blockchain. This elected node group can be updated regularly. The vote is weighted by the amount of cryptocurrency owned. Each bookkeeper is randomly selected to propose a block. This node is called a speaker. The bookkeepers become speakers in turn by random drawing. The speaker checks the signatures and the validity of transactions and then collects them in a block. The speaker proposes his block to all the other bookkeepers. Afterward, the bookkeepers verify the block and then each one vote in favor or against the block. The consensus is reached when at least 66% of bookkeepers vote in favor of the block and it is then added to the blockchain. The dBFT algorithm can be adapted for green IoT-based agriculture by applying a voting system in agriculture sensors layer to choose delegates and speaker among IoT devices.

15) STELLAR CONSENSUS PROTOCOL (SCP)

The SCP protocol (used by Stellar Consensus [114]) is based on federated Byzantine agreement (FBA). The nodes exchange a series of votes to confirm and accept a value. For this purpose, the SCP protocol determines a minimum quorum. The "quorum" is a set of nodes that are sufficient to reach an agreement. Each node chooses one or more quorum slices and includes in each slice the nodes in which it has confidence. Each quorum slice will then produce interactions with each other. To reach an agreement, the SCP protocol uses the idea of quorum intersection. A federated Byzantine agreement system enjoys quorum intersection if any two of its quorums share a node. The SCP protocol can be adapted for green IoT-based agriculture by applying a voting system in agriculture sensors layer to choose quorum and quorum slice among IoT devices and then use quorum intersection to guarantee agreement.

16) OTHER CONSENSUS ALGORITHMS

There are other consensus algorithms that can be adapted by a Blockchain-based solution for green IoT-based agriculture. We cite the following nine consensus algorithms: Byteball consensus [133], Mokka consensus [134], SPECTRE consensus [135], Block-Lattice consensus [136], Hashgraph consensus [137], Tangle consensus [138], Directed Acyclic Graphs (used by Iota [139]), Proof of Believability (used by IOST [140]), and RAFT consensus [141].

VI. CHALLENGES

To complete our overview, we outline research challenges that could improve the security and privacy solutions for IoT-based agriculture, summarized in the following recommendations:

A. MACHINE LEARNING TECHNIQUES FOR INTRUSION DETECTION SYSTEMS

Intrusion detection systems (IDSs) are implemented along with other security systems such as authentication and access control techniques using encryption mechanisms to protect systems against cyber attacks. Using data mining and machine learning techniques (e.g., Deep learning, Random forests, Support Vector Machine, Naive Bayes, ...etc), IDSs can differentiate between normal and malicious actions. The implementation of IDSs for IoT-based agriculture as a software application will able to identify security incidents. Therefore, the question we ask here is : how to choose the right machine learning technique among different types (i.e., reinforcement learning, unsupervised learning, or supervised learning)? We believe that a comparative study of machine learning techniques for cyber security intrusion detection is needed for IoT-based agriculture.

B. DATASET FOR INTRUSION DETECTION IN IoT-BASED AGRICULTURE SCENARIOS

The datasets for cyber security are so important in intrusion detection, which are used for testing the performance of IDSs. Actually, most and recent IDSs are tested with KDD 1999 [142], NSL-KDD [143], CICIDS2017 [144], Bot-IoT [145], and CSE-CIC-IDS2018 [146]. These datasets are not simulated for IoT-based agriculture scenarios. A possible research direction in this topic could be related to developing a new dataset to build a network intrusion detector under IoT-based agriculture environment.

C. SCALABILITY ANALYSIS OF BLOCKCHAIN-BASED SOLUTIONS

To solve security and privacy problems (e.g., access control, reputation, trust, ...etc), we have seen that a blockchain-based solution brings advantages for IoT application. The application of a blockchain-based solution for IoT-based agriculture requires a study on the characteristics of the implementation. Therefore, there are many characteristics should be taken under consideration when a blockchain-based solution is proposed for IoT-based agriculture, such as scalability issues when the number of participating nodes at agriculture sensors layer is increased. Thus, one of the challenges that should receive more attention in the future is to provide a scalability analysis of blockchain-based solutions for IoT-based agriculture.

D. HOW TO PICK THE BEST CONSENSUS ALGORITHM

The performance of a blockchain-based solution for IoT-based agriculture is related to the effectiveness of the consensus algorithm. Therefore, since IoT devices at agriculture sensors layer are not always able to satisfy the high computational and energy requirements when addressing the validation of blocks and the storage of blockchain, consensus-efficient issues arise as follows:

- If the PoW algorithm is used, how to integrate a miner in each greenhouse for processing incoming and outgoing transactions?
- If the stellar consensus algorithm is used, how to design a voting system in agriculture sensors layer to choose quorum and quorum slice among IoT devices and then use quorum intersection to guarantee agreement?
- If the dBFT algorithm is used, how to design a voting system in agriculture sensors layer to choose bookkeepers and speaker among IoT devices?

E. DESIGN OF PRACTICAL AND COMPATIBLE CRYPTOGRAPHIC PROTOCOLS

In some cases of green IoT-based agriculture, it is not necessary to use blockchain to solve security and privacy problems (e.g., identity anonymity), which there are many other better solutions such as practical and compatible cryptographic solution. Therefore, a new cryptographic solution is proposed recently by Yang *et al.* [147] for the automatic dependent surveillance-broadcast, which they use the format-preserving encryption (FPE) and lightweight broadcast authentication protocol (TESLA) to achieve the identity anonymity. However, resource and power-constrained IoT devices at agriculture sensors layer are not always capable of meeting the substantial computational and power consumption in the processing of new cryptographic solution. Therefore, the design of practical and compatible cryptographic protocols is one of the significant research challenges in green IoT-based agriculture.

F. RESILIENCY AGAINST SPECIFIC ATTACKS IN THE CONTEXT OF LOW-RESOURCE IoT DEVICES

The threat models discussed in the environment of IoT-based agriculture and the key security problem is different in distinct smart agriculture applications. Sometimes, the specific problem does not exist in an IoT application, and it is meaningless to take combined attacks into consideration. The methods to solve attacks can be integrated together to solve problems in an application. To propose a scheme against a kind of attack in a smart agriculture application, the attack should be specific and defined at the beginning. The most important question that may arise is how to develop a new security strategy that can resist combined attacks while considering the practicability of deploying the solution, particularly in the context of low-resource IoT devices at agriculture sensors layer.

G. COUNTER MEASURES AGAINST 5G NETWORK SLICING THREATS

5G networks will be facilitators of IoT based agriculture applications, especially in the sensors layer (See Figure 1). 5G adopt network slicing as a means of partitioning the physical and network resources to optimally group the different traffic, isolate from other tenants and configure the network resources. The logical partitioning of network slicing divides and separates a single common physical network into various virtual, complete E2E networks and offers complete isolation for these virtual networks from each other in terms of access, transport, device and core network. The main advantage of Network Slicing is that now MNOs can configure and apply tailor-made customization of their network resources to accommodate different users and different traffic classes, and hence differentiated services.

Security of Network Slicing plays a significant role for the control and the coordination among different slices and for function of the related mechanisms that are responsible for the inter-network slices communication and the coordination between user and control plane. A security leakage that is related to the inter-slice communication functionality can lead to disruption of the inter-slice communication. Moreover, authentication for the identification of the privileged users in order to prevent impersonation attacks against slices seems to be critical for the proper control of the network resources. Furthermore, the provision of differentiated services is also related to the provision of different security level of services among the slices. However, this must not affect the security level of another slice. In addition, DoS attacks focus on the possible exhaustion of network resources to lead in unavailability of network provisioned services [148]. These attacks must be dealt with a multi layered security framework that includes traditional methods, e.g. IDS and field specific solutions, e.g. slice isolation.

H. DEPLOYING IoT IN AGRICULTURE

As we mentioned in Section II, IoT in agriculture can be envisioned in different layers and from different perspectives. In this subsection, we try to summarize and emphasize the different conditions that exist in an agricultural environment that make the deployment of IoT challenging.

When talking about the WSNs, the specific characteristics of the environment, in which the nodes will be deployed, should be taken into account. Crops, or other obstacles in farmlands whose positions may change over time, cause considerable interference in the communication between nodes. These moving obstacles affect the connection quality of links, changing the channel conditions over time, affecting the deployment, packet routing algorithms, failure diagnosis methods, and other aspects of WSNs. Environmental factors such as temperature, rainfall, humidity, high solar radiation along with changing shading by plant leaves, as well as noise produced by building structures, such as greenhouses, further increase Spatio-temporal climatic variation, greatly affecting the communication among nodes that are deployed in such harsh environment. This changing environment imposes requirements and calls for novel duty-cycle control, sampling and scheduling, data reconstructions, as well as data storage and query, intelligent control, and other solutions [38], [149].

Although in theory or in simulated environments all these challenges have been already studied and analyzed when it comes to the actual deployment of IoT in the agricultural sector this task is very demanding and challenging. The modules that are used in order to sense and report any situation need to be accurate enough, properly shielded against environmental factors which can either lead to false reporting or destruction of the sensors permanently [150]. In addition, the replacement of power source to distributed sensor nodes that are spread in wide areas can be a very difficult task, if not impossible and must be taken into consideration during the design of such systems.

In terms of communication among nodes, since many different technologies can be combined, from GSM to WPAN and P2P, interoperability is the main challenge when designing or deploying such systems, especially in agriculture where high temperature and high humidity affect it in a negative way. Also when different communication methods are used in the same area (e.g. Bluetooth, ZigBee, and WiFi) interference is a parameter that needs to be also considered [151].

Since the sensors devices are deployed in an open field, which cannot be monitored by people all the time, the system can easily be attacked physically. In addition, sensors devices are not densely deployed in agricultural applications and they are more complex in terms of hardware components. Finally the area where sensor devices are located is not monitored so well compared to the one deployed inside a city and it is easy to add malicious nodes (e.g., Malicious 4G stations) that can overhear the information that is exchanged or perform several attacks like DDoS or MITM.

VII. CONCLUSION

In this paper, we surveyed the state-of-the-art of existing security and privacy solutions for green IoT-based agriculture. We provided an overview of a four-tier green IoT-based agriculture architecture. Through extensive research and analysis that was conducted, we were able to classify the threat models against green IoT-based agriculture into five categories, including, attacks against privacy, authentication, confidentiality, availability, and integrity properties. In addition, we analyzed the privacy-oriented blockchain-based solutions as well as consensus algorithms for green IoT-based agriculture. There still exist several challenging research areas, such as machine learning techniques, datasets for intrusion detection, scalability analysis of blockchain-based solutions, how to pick the best consensus algorithm, and the design of practical and compatible cryptographic protocols, which should be further investigated in the near future.

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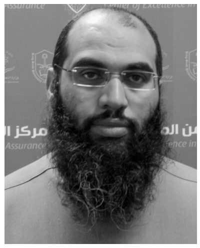

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Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk

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ABSTRACT Despite the perception people may have regarding the agricultural process, the reality is that today's agriculture industry is data-centered, precise, and smarter than ever. The rapid emergence of the Internet-of-Things (IoT) based technologies redesigned almost every industry including "smart agriculture" which moved the industry from statistical to quantitative approaches. Such revolutionary changes are shaking the existing agriculture methods and creating new opportunities along a range of challenges. This article highlights the potential of wireless sensors and IoT in agriculture, as well as the challenges expected to be faced when integrating this technology with the traditional farming practices. IoT devices and communication techniques associated with wireless sensors encountered in agriculture applications are analyzed in detail. What sensors are available for specific agriculture application, like soil preparation, crop status, irrigation, insect and pest detection are listed. How this technology helping the growers throughout the crop stages, from sowing until harvesting, packing and transportation is explained. Furthermore, the use of unmanned aerial vehicles for crop surveillance and other favorable applications such as optimizing crop yield is considered in this article. State-of-the-art IoT-based architectures and platforms used in agriculture are also highlighted wherever suitable. Finally, based on this thorough review, we identify current and future trends of IoT in agriculture and highlight potential research challenges.

INDEX TERMS Food quality and quantity, Internet-of-Things (IoTs), smart agriculture, advanced agriculture practices, urban farming, agriculture robots, automation, future food expectation.

I. INTRODUCTION

To improve the agricultural yield with fewer resources and labor efforts, substantial innovations have been made throughout human history. Nevertheless, the high population rate never let the demand and supply match during all these times. According to the forecasted figures, in 2050, the world population is expected to touch 9.8 billion, an increase of approximately 25% from the current figure [1]. Almost the entire mentioned rise of population is forecasted to occur among the developing countries [2]. On the other side, the trend of urbanization is forecasted to continue at an accelerated pace, with about 70% of the world's population predicted to be urban until 2050 (currently 49%) [3]. Furthermore, income levels will be multiples of what they are now, which will drive the food demand further, especially in developing countries. As a result, these nations will be more careful about their diet and food quality; hence, consumer preferences can move from wheat and grains to legumes and, later, to meat. In order to feed this larger, more urban, and richer population, food production should double by 2050 [4], [5]. Particularly, the current figure of 2.1 billion tons of annual cereal production should touch approximately 3 billion tons, and the annual meat production should increase by more than 200 million tons to fulfill the demand of 470 million tons [6], [7].

Not only for food, but crop production is becoming equally critical for industry; indeed crops like cotton, rubber, and gum

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are playing important roles in the economies of many nations. Furthermore, the food-crops-based bioenergy market started to increase recently. Even before a decade, only the production of ethanol utilized 110 million tons of coarse grains (approximately 10% of the world production) [7], [8]. Due to the rising utilization of food crops for bio-fuel production, bio-energy, and other industrial usages, food security is at stake. These demands are resulting in a further increase of the pressure on already scarce agricultural resources.

Unfortunately, only a limited portion of the earth's surface is suitable for agriculture uses due to various limitations, like temperature, climate, topography, and soil quality, and even most of the suitable areas are not homogenous. When zooming the versatilities of landscapes and plant types, many new differences start to emerge that can be difficult to quantify. Moreover, the available agricultural land is further shaped by political and economic factors, like land and climate patterns and population density, while rapid urbanization is constantly posing threats to the availability of arable land. Over the past decades, the total agriculture land utilized for food production has experienced a decline [9]. In 1991, the total arable area for food production was 19.5 million square miles (39.47% of the world's land area), which was reduced to approximately 18.6 million square miles (37.73% of the world's land area) in 2013 [10]. As such, the gap between demand and supply of food is becoming more significant and alarming with the passage of time.

Further examination showed that every crop field has different characteristics that can be measured separately in terms of both quality and quantity. Critical characteristics, like soil type, nutrient presence, flow of irrigation, pest resistance, etc., define its suitability and capability for a specific crop. In most of situations, the differentiations of characteristics can exist within a single crop field, even if the same crop is being cultivated in entire farm; hence, site-specific analyses are required for optimal yield production. Further, adding the dimension of time, specific crops in the same field rotate season-to-season and biologically reach different stages of their cycle within a year in areas where locational and temporal differences result in specific growth requirements to optimize the crop production. To respond to these demands with a range of issues, farmers need new technology-based methods to produce more from less land and with fewer hands.

Considering the standard farming procedures, farmers need to visit the agriculture sites frequently throughout the crop life to have a better idea about the crop conditions. For this, the need of smart agriculture arises, as 70% of farming time is spent monitoring and understanding the crop states instead of doing actual field work [11]. Considering the vastness of the agriculture industry, it incredibly demands for technological and precise solutions with the aim of sustainability while leaving minimum environmental impact. Recent sensing and communication technologies provide a true remote "eye in the field" ability in which farmers can observe happenings in the field without being in the field. Wireless sensors are facilitating the monitoring of crops constantly with higher accuracy and are able to, most importantly, detect early stages of unwanted state. This is the reason why modern agriculture involves the usage of smart tools and kits, from sowing to crop harvesting and even during storage and transportation. Timely reporting using a range of sensors makes the entire operation not only smart but also cost effective due to its precise monitoring capabilities. Variety of autonomous tractors, harvesters, robotic weeders, drones, and satellites currently complement agriculture equipment. Sensors can be installed and start collecting data in a short time, which is then available online for further analyses nearly immediately. Sensor technology offers crop and site-specific agriculture, as it supports precise data collection of every site.

Recently, the Internet-of-Things (IoT) is beginning to impact a wide array of sectors and industries, ranging from manufacturing, health, communications, and energy to the agriculture industry, in order to reduce inefficiencies and improve the performance across all markets [12]–[16]. If looking closely, one feels that the current applications are only scratching the surface and that the real impact of IoT and its uses are not yet witnessed. Still, considering this progress, especially in the near past, we can predict that IoT technologies are going to play a key role in various applications of the agriculture sector. This is because of the capabilities offered by IoT, including the basic communication infrastructure (used to connect the smart objects—from sensors, vehicles, to user mobile devices—using the Internet) and range of services, such as local or remote data acquisition, cloud-based intelligent information analysis and decision making, user interfacing, and agriculture operation automation. Such capabilities can revolutionize the agriculture industry which probably one of most inefficient sectors of our economic value chain today. To summarize this discussion, figure 1 provides the main drivers of technology, while figure 2 highlights

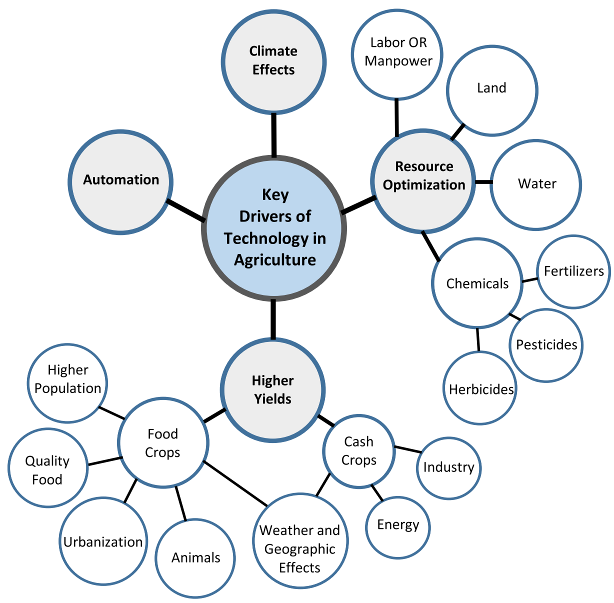

FIGURE 1. Key drivers of technology in agriculture industry.

FIGURE 2. Major hurdle's in technology implementation for smart agriculture.

the major hurdles of technology implementation in smart agriculture.

Researchers and engineers around the globe are proposing different methods and architectures and based on that suggesting a variety of equipment to monitor and fetch the information regarding crop status during different stages, considering numerous crop and field types. Focusing on the market demand, many leading manufactures are providing a range of sensors, unmanned aerial vehicles (UAVs), robots, communication devices, and other heavy machinery to deliver the sensed data. In addition, various commissions, food and agriculture organizations, and government bodies are developing polices and guidelines to observe and regulate the use of these technologies in order to maintain food and environment safety [17]–[20].

There are reasonable efforts that highlight the role of the IoT in the agriculture industry, but most of the published work focuses only on applications [10], [21], [22]. Most of the existing articles either provide no insight or show limited focus on the various IoT-based architectures, prototypes, advanced methods, the use of IoT for food quality, and other future issues considering the latest facts and figures. This manuscript examines the trends in IoT-based agriculture research and reveals numerous key issues that must be addressed in order to transform the agriculture industry by utilizing the recent IoT developments. The major contribution of this article is to provide real insight regarding:

- Expectations of the world from the agriculture industry
- Very recent developments in IoT, both scholarly and in industry are highlighted and how these developments are helping to provide solutions to the agriculture industry.
- Limitations, the agriculture industry is facing.
- Role of IoT to cope these limitations and other issues like resources shortage and their precise use, food spoilage, climate changes, environmental pollution, and urbanization.
- Strategies and policies that need to be considered when implementing IoT-based technologies
- Critical issues that are left to solve and possible solutions that are further required, while suggestions are provided considering these challenges.

This article is a compendium of knowledge that can help the researchers and agriculture engineers implementing the IoT-based technologies to achieve the desired smart agriculture. The rest of this document is organized as follows. Section II provides a deep overview of major applications of IoT in agriculture and what we can achieve by utilizing these technologies. Section III gives insight regarding the role of IoT in advanced agriculture practices, like vertical farming (VF), hydroponics, and phenotyping, to manage the issues of increased urban population. Section IV highlights various technologies and equipment, like sensors, robots, tractors, and communication devices, being used to implement IoT in this industry. Accepting the worth of UAVs in precision agriculture, Section V caters application achievements that are not possible even using other latest technologies. Food safety and transportation are other critical areas requiring focus to overcome the hunger issues which did not get the attention of researchers as it deserves. Section VI supplies the role of the IoT to ensure food quality for longer periods and to deliver to remote areas. Section VII identifies current and future trends of this technology in the crop industry by highlighting potential research challenges. Finally, Section VIII concludes this article.

II. MAJOR APPLICATIONS

By implementing the latest sensing and IoT technologies in agriculture practices, every aspect of traditional farming methods can be fundamentally changed. Currently, seamless integration of wireless sensors and the IoT in smart agriculture can raise agriculture to levels which were previously unimaginable. By following the practices of smart agriculture, IoT can help to improve the solutions of many traditional farming issues, like drought response, yield optimization, land suitability, irrigation, and pest control. Figure 3 lists a hierarchy of major applications, services and wireless sensors being used for smart agriculture applications. While, major instances in which the advanced technologies are helping at various stages to enhance overall efficiency are discussed below.

A. SOIL SAMPLING AND MAPPING

Soil is the "stomach" of plants, and its sampling is the first step of examination to obtain field-specific information, which is then further used to make various critical decisions at different stages. The main objective of soil analysis is to determine the nutrient status of a field so that measures can be taken accordingly when nutrient deficiencies are found. Comprehensive soil tests are recommended on an annual basis, ideally in Spring; however, based on soil conditions and

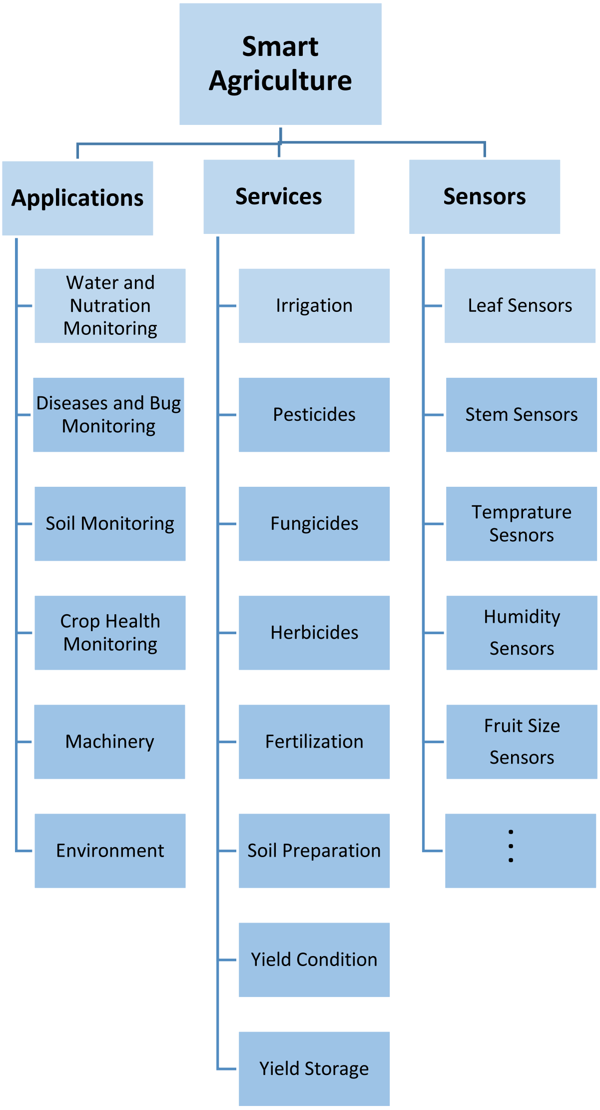

FIGURE 3. General hierarchy of possible applications, services and sensors for smart agriculture.

weather consents, it may be done in in Fall or Winter [23]. The factors that are critical to analyze the soil nutrient levels include soil type, cropping history, fertilizer application, irrigation level, topography, etc. These factors give insight regarding the chemical, physical, and biological statuses of a soil to identify the limiting factors such that the crops can be dealt accordingly. Soil mapping opens the door to sowing different crop varieties in a specific field to better match soil properties accordingly, like seed suitability, time to sow, and even the planting depth, as some are deep-rooted and others less. Furthermore, growing multiple crops together could also lead to smarter use of agriculture, simply making the best use of resources.

Currently, manufacturers are providing a wide range of toolkits and sensors that can assist farmers to track the soil quality and, based on this data, recommend remedies to avoid its degradation. These systems allow for the monitoring of soil properties, such as texture, water-holding capacity, and absorption rate, which ultimately help to minimize erosion, densification, salinization, acidification, and pollution (by avoiding excessive use of fertilizer). Lab-in-a-Box, a soil testing tool kit developed by AgroCares, is considered a complete laboratory in itself based on its offered services [24]. By using this, any farmer, without having any lab experience, can analyze up to 100 samples per day (overall, more than 22,000 nutrient samples a year) without visiting any lab.

Drought is a major concern which limits the productivity of crop yield. Most of the regions around the globe face this issue with various intensities. To deal with this issue, especially in very rural areas, remote sensing is being used to obtain frequent soil moisture data which helps to analyze the agricultural drought in far regions. For this purpose, the Soil Moisture and Ocean Salinity (SMOS) satellite was launched in 2009 which provides global soil moisture maps every, one to two days. Authors in [25] used SMOS L2 to calculate the Soil Water Deficit Index (SWDI) in Spain in 2014. In this effort, they followed different approaches to obtain the soil water parameters in order to compare with the SWDI acquired from in situ data. In [26], authors used the moderate resolution imaging spectroradiometer (MODIS) sensor to map various soil functional properties to estimate the land degradation risk for sub-Saharan Africa. The soil maps and field survey data, which covered all major climate zones on the continent, were used to develop the prediction models.

Sensors and vision based technologies are helpful to decide the distance and depth for sowing the seed efficiently. Like in [27], sensor and vision based autonomous robot called Agribot is developed for sowing seeds. The robot can perform on any agricultural lands on which the self-awareness of the robot's placement is ascertained through the global and local maps generated from Global Positioning System (GPS) while the on-board vision system is paired with a personal computer. Advancing further, various non-contact sensing methods are proposed to determine the seed flow rate as in [28] where the sensors are equipped with LEDs; consist of infrared, visible light and laser-LED as well as an element as a radiation receiver. The output voltage varies based on the movement of the seeds through the sensor and band of light rays, and falling of shades on the elements of receiver. The signal information, linked to the passing seeds, is used to measure the seed flow rate.

B. IRRIGATION

About 97% of Earth's water is salt-water held by oceans and seas, and only the remaining 3% is fresh water—more than two-third of which is frozen in the forms of glaciers and polar ice caps [29], [30]. Only 0.5% of the unfrozen fresh water is above the ground or in the air, as the rest lies underground [31]. In short, humanity relies on this 0.5% to fulfill all its requirements and to maintain the ecosystem, as enough fresh water must be kept in rivers, lakes, and other similar reservoirs to sustain it. It is worth mentioning that solely the agriculture industry uses approximately 70% of this accessible fresh water [32], [33]. In many countries, situation rises about Internet capabilities. Believing in its future success, it is expected that leading cellular operators with strong IoT ambitions can generate significant revenues by providing smart agriculture services when collaborating with LPWA technology providers. In order to achieve long term success of these short, mid and long range communication technologies, necessary steps for infrastructure construction are required towards attaining the technology-based agriculture.

C. UAVs AND OTHER ROBOTS

Drones are being widely used by farmers for crop growth monitoring and as a means to combat hunger and other harmful environmental impacts. Furthermore, they are being used to spray water and other pesticides efficiently, considering the tough terrains, especially when the crops possess different heights. Drones have proven their value, not only in terms of spraying speed but precision, as well, when compared with traditional machinery of same purpose. With recent advances in swarm technology and mission-based control, groups of drones equipped with heterogeneous sensors, including 3D cameras, can work together to provide farmers with comprehensive capabilities to manage their land. With the inclusion of UAVs in agriculture, farmers are able to put their eye in sky, but many challenges need to be addressed in order to enjoy the real advantages of this technology, especially the integration of other technologies and how to use them in poor weather conditions.

Beside drones, robotics within agriculture have improved productivity and resulted in higher and faster yields. Such robots, like spraying and weeding robots, are reducing agrochemical use. Robots equipped with laser and camera guidance are being used for identifying and removing weeds without human intervention. They navigate between rows of crops on their own, ultimately increasing the yield with reduced manpower. More recently, plant-transplanting and fruit-picking robots are emerging to add a new level of efficiency to traditional methods.

D. MACHINE LEARNING AND ANALYTICS

Machine learning and analytics are used to mine data for trends. In farming, machine learning is used, for example, to predict which genes are best suited for crop production. This has been giving growers all over the world the best seed varieties, those which are highly suitable to respective locations and climate conditions. Machine-learning algorithms, on the other hand, have indicated which products are of high demand and which products are currently unavailable in the market. Thus, for the farmer, this has given valuable clues for future farming. Recent advances in machine learning and analytics will make it possible for farmers to accurately classify their products and weed out less desirable crops before they arrive to customers.

E. POWER CONSUMPTION, RENEWABLE ENERGY, MICROGRIDS, AND SMART GRIDS

Despite its future opportunities, smart agriculture facing some limitations that are holding back the growth of IoT. One of them is power issue as due to its nature; smart farming requires wide use of energy. Among the main reasons of extensive power consumption some are including, long term sensor deployment, use of GPS repeatedly and transmission of sensed data via GPRS. Traditionally, farmers in remote areas have bought and utilized renewable energy sources randomly and at a hefty price, which has limited their ability to use them in farming to a great extent. However to solve the power issues in long term, deep analysis of power consumption sources like remote data transmission can help to tackle the problem at some extent. Further, smart grids and microgrids, however, lend themselves to seamless integration of distributed energy sources (DERs), thus, making them appealing for adoption by farmers. The emergence of smart power meters has further given the farmers the confidence to invest in DER, especially since they have the option to sell the excess power to the grid. Recent advances in energy storage devices, integrated electricity and heat systems will make DER even more attractive for farmers, as they will be able to store energy and use the heat generated by cooling and heating when needed. However, healthy investment requirements and public perceptions are two other barriers on the way to making these solutions successful.

F. HYDROPONICS AND VERTICAL FARMING (VF)

Other than employing the advanced technologies, new agricultural practices can be very crucial to overcome the geographic and resource limitation challenges. On one side, arable land is shrinking, and, at the same time, it is estimated that three million people around the globe are migrating to cities, resulting in more pressure on the existing limited urban resources [318]. Considering this rapid migration, it is estimated that by 2030, 60% of the world's population is going to depend on cities, and this number is further expected to rise to 68% until 2050 [319]. Considering both of these issues, it could be disaster for food production in the near future with current agriculture practices. VF is an answer of these issues, as it meets the challenges of land and water shortage and, at the same time, looks highly suitable to be adopted near the cities. VF is portrayed as the answer to the looming shortage of food and shrinking arable land, at least in some areas of the world. Further, hydroponics can play a key role, as this method lowers the requirements of water and space to a great extent. Rapid growths in computer power are propelling scientific discoveries in plant nutrition and growth that would make VF even more appealing to growers.

Along VF and hydroponics, new and advanced solutions are required to increase the arable land without disturbing the forests and other natural animal habitats. For this, we have to focus on the deserts as these cover one third of the Earth's land surface. The solutions are started already as Norwegian and Chinese firms/experts are doing efforts in Dubai, Qatar, Jordan and Chinese deserts [320]–[322].

Agriculture is not just an industry; in fact, it provides the basis of human society, as the goal is not just to grow crops, but the target is the perfection of human being. A vibrant and prosperous agriculture sector can provide the basis for a happy and healthy society, as recent decades witnessed this. The presence of advance technologies, especially the involvement of the IoT, matters a great deal in regard to reaching this goal. Environmental issues continue to cage the planet, which increases the need for safe and clean agriculture. This is the reason humanity is witnessing a second green revolution, largely based on the IoT. The use of these technologies makes the farming industry highly productive with reduced labor and other resource consumption; same time, minimizing the impact on the environment.

Our planet has the resources, but we have to learn how to utilize them wisely and precisely. Sensible use of technology can lead us where we can utilize these resources efficiently in order to ensure the food security of the current and coming generations. For this purpose, we need collective efforts to build such institutions that can shape long-term decisions and polices to eliminate hunger effectively. On this route, the experience, tools, and support from those nations that have succeeded in overcoming hunger should provide to those regions that are fighting to feed its local mouths. Although growth in every industry matters, growth in agriculture, particularly among small growers, can be highly effective to control the undernourishment issues, as more than 70% of the population of developing countries belongs to rural areas and somehow depends on agriculture sector.

VIII. CONCLUSION

The focus on smarter, better, and more efficient crop growing methodologies is required in order to meet the growing food demand of the increasing world population in the face of the ever-shrinking arable land. The development of new methods of improving crop yield and handling, one can readily see currently: technology-weaned, innovative younger people adopting farming as a profession, agriculture as a means for independence from fossil fuels, tracking the crop growth, safety and nutrition labeling, partnerships between growers, suppliers, and retailers and buyers. This paper considered all these aspects and highlighted the role of various technologies, especially IoT, in order to make the agriculture smarter and more efficient to meet future expectations. For this purpose, wireless sensors, UAVs, Cloud-computing, communication technologies are discussed thoroughly. Furthermore, a deeper insight on recent research efforts is provided. In addition, various IoT-based architectures and platforms are provided with respect to agriculture applications. A summary of current challenges facing the industry and future expectations are listed to provide guidance to researchers and engineers.

Based on all this, it can be concluded that every inch of farmland is vital to maximize crop production. However, to deal with every inch accordingly, the use of sustainable IoT-based sensors and communication technologies is not optional—it is necessary.

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A New IoT-based Platform for Greenhouse Crop Production

M. Muñoz, J.L. Guzmán, J.A. Sánchez, F. Rodríguez, M. Torres and M. Berenguel

***Abstract*—This work proposes a cloud solution to build an Internet of Things (IoT) platform applied in a greenhouse crop production context. Real-time and historical data, as well as prediction models, can be accessed by means of RESTful (Representational State Transfer) web services developed for such a purpose. Forecasting is also provided following a Greenhouse Models as a Service (GMaaS) approach. Currently, our GMaaS tool provides forecasting based on computational models developed for inside climate, crop production and irrigation processes. Traditionally, such models are hardcoded in applications or are embedded in software tools to be used as Decision Support Systems (DSS). However, using a GMaaS approach, models are available as RESTful services to be used as needed. In addition, the proposed platform allows users to register new IoT devices and their greenhouse data in the FIWARE platform, providing a cloud scale solution for the case study. RESTful services of the proposed platform are also used by a web application allowing users to interact easily with the system.**

***Index Terms*—Greenhouse Models, IoT, Cloud, DSS.**

I. INTRODUCTION

IN the last years, the European Union is boosting the digitalization process in different areas, introducing topics such as IoT, Big Data or Artificial Intelligence in many different contexts (e.g. agriculture, smart cities, smart agrifood, and so on). One example is the IoF2020 project, which introduces and enhances digitalization in several sectors, such as agriculture, livestock, and food in Europe with the aim of significantly improving productivity and sustainability of the system. Within this project, the User Case 4.2 deals with the digitalization of the protected agriculture based on the integration and the use of the data generated by physical and virtual sensors, control loops, networks, models and optimization techniques. FIWARE is another example of the firm commitment of the European Union in the digitalization process.

So, many works are being developed in this context. Smart Agriculture, also-called “thirdgreen revolution”, is presented as the inclusion of services and technologies such as IoT [1], [2], [3], data processing in Big Data [4], cloud computing [5], Farm Management Information Systems (FMIs), and artificial intelligence or Deep Learning [6]. In such a context, Everything as a Service (XaaS) has emerged as a trend, proposing delivering, using an Internet-based access, all the information generated by the integration of technologies, applications or products [7]. Moreover, in this digitalization process, embedded computer-assisted decision support systems are being used as an assistant for farm management. There are many examples of cloud-based decision support toolboxes. For instance, AgroDSS is a cloud-based DSS to combine existing FMIs. This cloud-based toolbox allows farmers to upload data and to use analysis tools and techniques to make future decisions on the system. [8]. Another example is presented in [9], where a cloud-based FMI has been developed and evaluated in a real greenhouse. Recently, solutions proposed by [10], [11] change the vision of these cloud-based technologies proposing an edge-computing and fog-computing platform for traceability and sustainability of the daily farms production to process the data generated at the network edge.

In our context, some challenges are present, such as processing and accessing sensor data, building a cloud solution that can scale up depending on the data requirements, providing an open system so that new and heterogeneous sensors and devices can be easily added, and the possibility to provide greenhouse models as a service.

The aim of this work is to contribute to this digitalization of the agricultural sector, where the implementation of a cloud-based solution for greenhouse crop production is presented. The proposed approach provides different services for economical and environmental benefits of the agricultural activity, and improving the system efficiency by providing suggestions for the use of water, pesticides, fertigation or energy. In this sense, historical and real-time data are available for each of the greenhouses registered in the platform. An open model to allow adding new devices spread over the world has been defined. Weather forecast options are also offered as a service for a 48 hours period. Also, a novel service called GMaaS is integrated into the platform, where greenhouse models are available to estimate indoor climate, crop production and irrigation values. Another advantage is that all these services are available as a REST API for different user needs. In fact, the proposed platform provides a graphical web-based application that is built over this REST API.

Notice that the greenhouse production agrosystem is a very complex process, where physical, chemical and biological processes take place at the same time with different patterns and time scales. For that reason, model-based tools are required as support to understand the dynamics of these systems. Greenhouse climate models, crop growth models and irrigation models have been widely studied in literature [12]. However, most of these models are implemented for research purposes or included as part of specific DSS systems. So, the use of the models by other users (researchers or farmers) is usually

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limited and complicated.

Thus, the GMaaS option presented in this work provides cloud-based models without any software/device dependence [13]. GMaaS services work through a REST API service implemented in the Matlab Production Server environment [14]. Implemented models can be used for different targets: as simulation tool where the model inputs can be obtained from historical data or from a weather forecast service; as real-time virtual sensor for control/feedback purposes where the model is invoked only one step ahead; and as graphical DSS service from a web-based application. The models implemented in the proposed platform are: inside climate models [15], [12], tomato crop models [16], and water and nitrogen balance model [17].

The remainder of this paper is organized as follows. Section 2 is devoted to describe the proposed IoT system architecture. The different system API services are described in section 3. Then, the different available greenhouse models are described in section 4. Afterwards, examples of the different services are presented in section 5, especially for those based on the GMaaS option. Finally, section 6 is devoted to give some conclusions.

II. IoT-BASED PLATFORM ARCHITECTURE

This section describes the architecture of the proposed IoT-based system which is based on FIWARE. FIWARE is an open source platform funded through a European PPP (Public Private Partnership) project, in which the public and private sectors collaborated to create the Internet of the future. This platform tries to promote the use of new technologies through a collective structure which will contribute to the growth and technological development in Europe. FIWARE is based on a modular architecture, which is supported by a set of GEs (Generic Enablers) that provide a series of functionalities and standards that facilitate the development of intelligent applications. Each of these components may be assembled with other components developed by third parties, thus allowing to accelerate the use of intelligent solutions. These GEs are a set of free and public APIs (Application Programming Interface) based on the formal OMA (Open Mobile Alliance) NGSI (Next Generation Services Interface) [18], [19] specifications with RESTful capabilities, accessible via HTTP. These GEs are separated by chapters depending on the functionality, named as context information management, language interpretation, data analysis, security layers and even web interfaces. FIWARE seeks to become the technological standard that the IoT needs. The core of FIWARE is the GE known as OCB (Orion Context Broker), which manages all the context information produced by the system. It is essential to know the term context because it is the basis of this FIWARE architecture. Context is the name given to all the information that surrounds an ecosystem, which can come from sensor networks, third party applications, public data sources, actuators, among other systems.

Figure 1 shows the cloud architecture of the proposed IoT platform, which is divided into layers: Context Producers, Backend and Frontend. This architecture allows working in a decoupled way. The main advantage of this approach is to allow changes in each layer without affecting the operation in other layers. The aim is to have independent services, even microservices, in each layer. This solution allows to continue developing integration solutions and new improvements to the system. The different layers are described in the following:

1) Layer 0, Context Producers: This is the first layer of the system. It generates all the context information. To generate this information, physical devices must be able to collect information from the environment. These devices consist of a set of microcontrollers and software for updating devices (sensors, actuators, and so on). Sensors only deal with collecting information. Actuators perform an action on their environment. Because of the similarity with the related term in FIWARE, layer names match with Context producer. Notice that Context producer in FIWARE is related to all the information available in the IoT ecosystem from third party systems, sensors, actuators, SCADA systems, and so on.

In our case study, eight greenhouses distributed among the different geographical locations in the province of Almería, Spain, dedicated to tomato crops are used. On the one hand, greenhouses are equipped with heterogeneous meteorological stations. Stations contain many sensors (e.g. CO_2, solar and global radiation, air and soil humidity, electric conductivity, water consumption, air and soil temperature, and etc.). The set of sensors provided by a station depends on its model and its manufacturer. On the other hand, greenhouses may also be equipped with other sensors and actuators connected to data acquisition systems. Figure 1 illustrates how systems and devices installed on greenhouses are connected to the Internet sending data to the next layer, the backend. Meterological stations, data acquisition systems, and SCADA computers provide their data through RESTful services. However, data provided are heterogeneous following no standards.

2) Layer 1, Backend: Located in the center of Figure 1, it deals with data extraction from Layer 0, data processing, databases and REST services. Frontend clients may be created over this layer. Below, the main components are described:

- *IoT Agent and Cron process*: This service deals with extracting context information, transforming and sending it to the IoT system. There are two services, named as IoT Agent and Cron process. IoT Agent transforms sensor values to the NGSI standard of FIWARE in order to solve the problem of interoperability between sensors. The service gets sensor data from different data sources (Layer 0), such as REST services, IoT stations, intelligent sensors and SCADA systems. The IoT Agent service is a developer-enabler for FIWARE which translates different communication protocols to the FIWARE standard. In the figure, it translates data from the meteorological stations to the NGSI standard in order to be sent to the Orion Context Broker (OCB). The another service is a Linux Cron process that periodically obtains data from REST services of the meteorological and SCADA systems, and transform and send them to OCB.
- Orion Context Broker (OCB): It manages context information generated by IoT stations [20]. The OCB data model is based on entities, attributes and metadata.

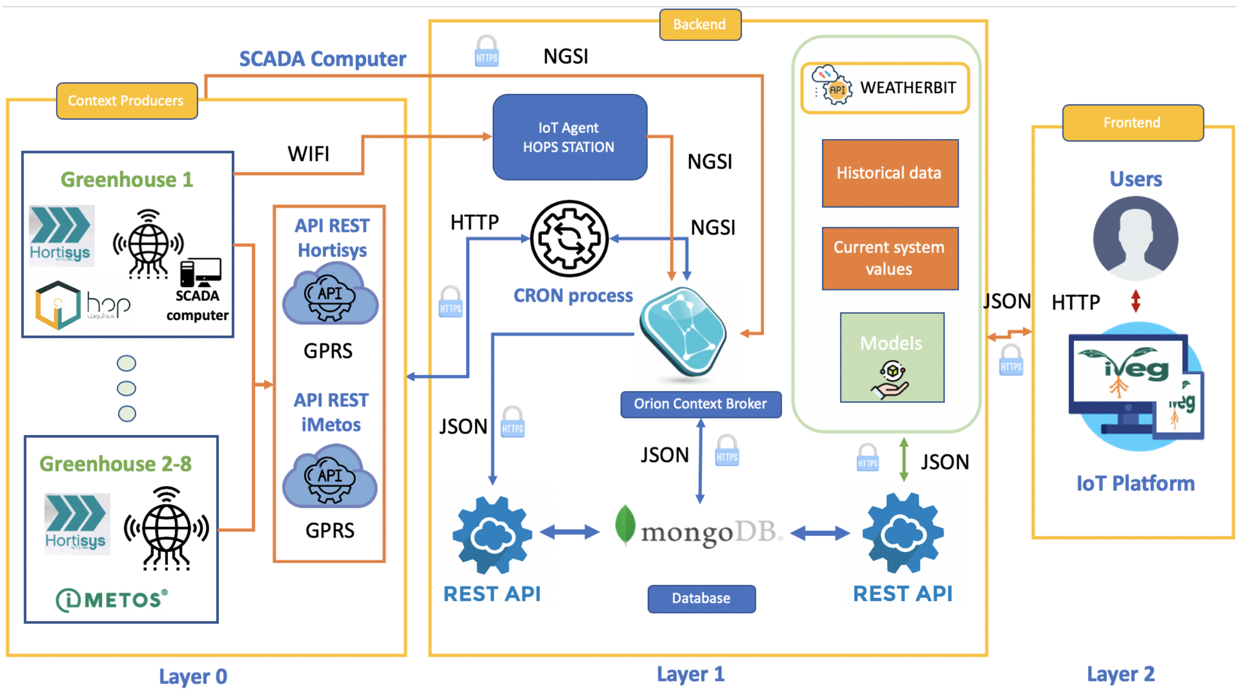

Fig. 1. IoT-based system architecture. The different system layers are depicted, with information about the data flow, communication protocols, data sources, and users.

our context, there is an entity type for each greenhouse station. FIWARE-Service and FIWARE-Service-Path headers are used to identify greenhouse and station names. Each entity is subscribed to the REST API service (see Figure 2), which stores the data in a database. So, whenever an attribute value changes, the new values are notified to the system, proceeding to store them in the database. Additional technical information about the data architecture can be found in [21].

- REST API: The backend layer is accessed using a REST API. Two REST APIs are available. The first one takes care of data persistence, collecting incoming notifications from OCB. The other one deals with the rest of requested operations by the client. Both APIs are based on Node.js. Node.js uses an event-driven, non-blocking I/O model that makes it lightweight and efficient, perfect for data-intensive real-time applications that run across the distributed device. Considering that the backend must the scalable, a horizontal scalable database is needed. Aggregation and sharding features are also needed. So, MongoDB was selected attending to those requirements. Backend requests are secured using JWT (JSON Web Token). JWT security is based on a token. When users try to sign in, they send login data to the server (Backend), which generates a JWT and sends it to the client. Every client request will need this JWT. Otherwise, requests are not attended. In addition, custom frontends may be developed over it, considering that Backend is based on a set of REST APIs.
- DSS: This component is responsible for performing system control operations. It is based on Matlab Production Server. It provides a REST API that gets parameters and methods needed to perform control operations. After processing requests, results are returned to the client in JSON format. This new approach of models as a service was proposed in [13].
- Database: The proposed architecture is supported by MongoDB. It is a non-relational document-oriented database. Documents are stored in BSON, a binary representation of JSON. Highlight features are related to performance, replicasets to provide high availability, and sharding to allow horizontal scaling.

3) Layer 2, Frontend: A Single Page Application (SPA), iVeg, has been developed. iVeg has been developed under the project IoF2020 on digitalization in agriculture [22], [21]. The original iVeg application integrated heterogeneous data sources from different service providers at different time scales from sensors and actuators. The current version has been connected to the proposed platform, using Backend and Context Producers provided by Layer 1 and Layer 0, respectively. End users use the application to make requests querying the services provided by Layer 1 in a transparent way. Section 5 shows an example illustrating this layer.

Thus, users/farmers may register their greenhouse devices in the proposed platform. Sensors and actuators data are stored in the database by means of a request to the REST API. Measures provided by the different devices are stored using a variable sampling time within 1-10 minutes, depending on the variable to be saved. Stored data are used to calibrate and to integrate specific models for inside climate, crop production, and irrigation into the platform, which are available as API services.

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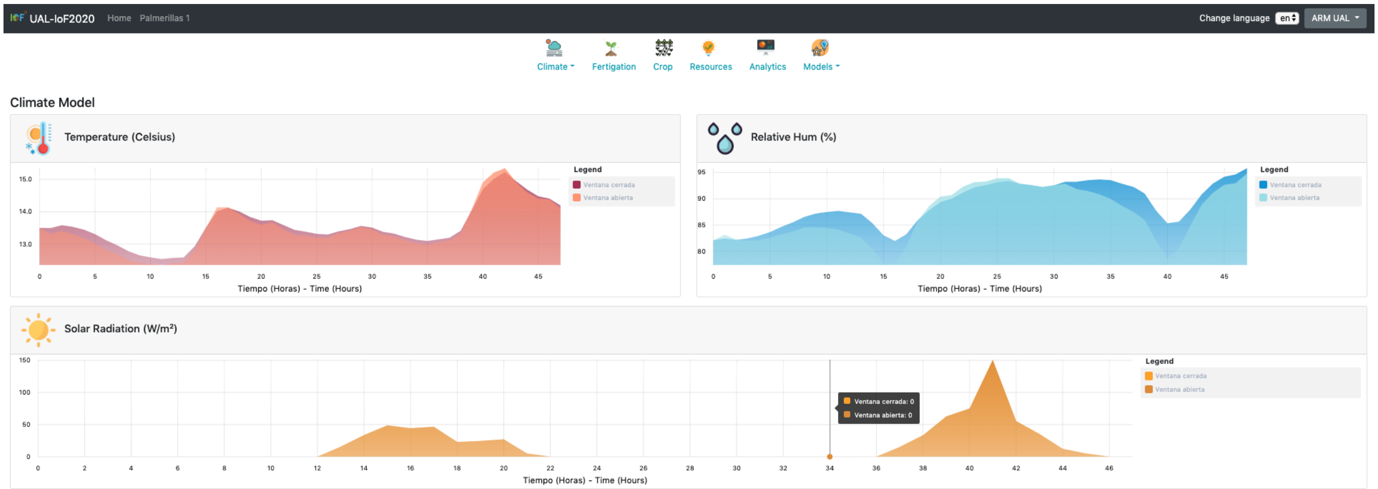

Fig. 4. Example of the climate service using the iVeg application.

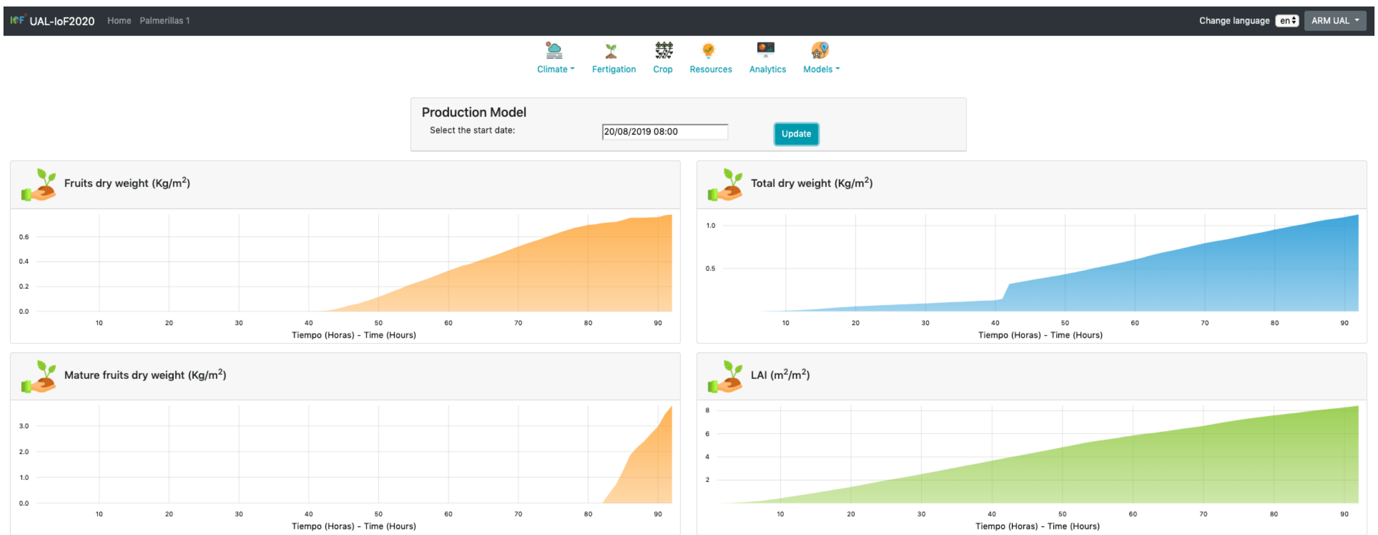

Fig. 5. Example of the production service using the iVeg application.

this information is shown.

VI. Conclusion

A cloud-based solution to provide services for the greenhouse crop production problem has been presented in this work. The services available in the proposed IoT-based system are: historical data, current values, weather forecasts, climate model, tomato production model, and irrigation model; which are available through the resulting REST API service. This API allows the versatility to access the services through two modalities: the iVeg web-based application developed under the framework of the IoF2020 project (use case 4.2 vegetables) or by directly using the REST API. Notice that this last option is really useful for research purposes, since any user can request data or models from any REST client. Therefore, the data and model-based services can be used for simulation/study purposes or for industrial purposes as a DSS by farmers/companies.

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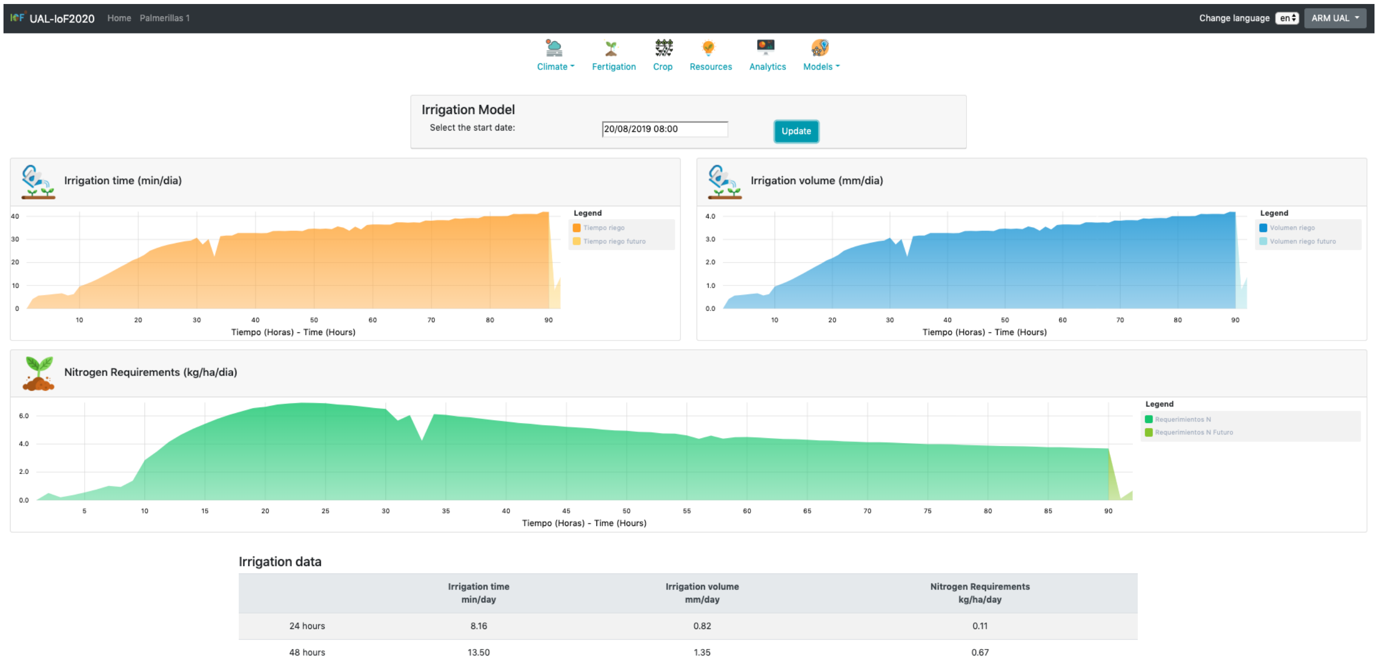

Fig. 6. Example of the irrigation service using the iVeg application.

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Development of an Intelligent LED Lighting Control Testbed for IoT-based Smart Greenhouses

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***Abstract*—The aim of our study is to develop an intelligent control system for mixing color ratios using LED lights in a greenhouse environment. To this end, different components of an experimental testbed is presented for achieving the desired light requirements for plant growth in a greenhouse environment. The proposed testbed provides a easy-to-use plant growth system with IoT-enabled control and monitoring features. To testify the features mentioned above, a feedback lighting control method to achieve a desired photosynthetic photon flux desnity (PPFD) set point is implemented. A two-week experiment was conducted on microgreen kale which was planted in the testbed and harvested at the end of the experiment. The experimental results has shown that the tested microgreen kale grew with a healthy condition in the proposed testbed and lighting environment.**

***Index Terms*—LED lighting, mixing color, PPFD, lighting control, greenhouse, plant growth, feedback control, raspberry pi, IoT.**

I. Introduction

In recent years, there has been a great deal of research on LED lighting due to their energy-efficient characteristics and cost reduction as a result of large scale manufacturing [1]- [4]. Control technologies that consider an optimal combination of energy saving and other factors such as human comfort, color temperature, and daylight harvesting have been investigated by several researchers (e.g., [5], [6]).

However, many lighting control strategies have been mostly limited in the residential and commercial office areas [7], [8], [9]. Meanwhile, the use of LED applications in horticulture has been increasingly spreading because of the advantages in the energy saving, controllability, and support for Internet of Things (IoT) technology based smart horticulture [10], [11], [12]. The combination of reaching a targeted photosynthetic photon flux density (PPFD) and mixing color ratio between blue, red, or UV light, which is mainly referred to as $light\ recipe$, has been widely investigated in the horticulture field. There has been many studies that have shown that $light\ recipe$ plays a key role on improving plant growth and increasing crop productivity [13]- [16].

In supplemental LED lighting for horticulture, one has to mix and control color to achieve a targeted amountof photosynthetic photon depending on the light requirement for plant growth. The past research for the control on the LED grow lights in horticulture have focused on the mixing color ratio control and achievement of the requirement of PPFD or daily light integral (DLI) for the plant growth [17], [18]. From the aspect of energy efficiency performance, researchers have proposed several methods [19], [20], [21]. In contrast to that, the research for achieving optimal light performance for plant growth and improving energy-efficiency while mixing appropriate color ratios of LED in a greenhouse environment has not been widely discussed. The concept of precision agriculture and unattended operation technology has been continuously developed with a fast pace. Greenhouse farmers have certain requirements for the LED control system in terms of light output quality and energy efficiency. Thus in this paper, we propose a testbed for plant growth using supplemental LED lighting which aims at providing an easy-to-use lighting system with adjustable PPFD output and mixing color ratios for creating customized $light\ recipes$. Also we have integrated the IoT technology with the testbed that offers the user a remote monitoring and control feature via a cellular network.

The rest of the paper is organized as follows. In section II, a requirements analysis is presented along with the development process of a proof of concept testbed. In section III, the features of the proposed system are specified and the implementation details are introduced. Experimental results and discussion are presented in sections IV and V, respectively.

II. Testbed design and development process

The testbed includes a compact plant ecosystem, a low cost embedded control system with affordable and easy-to-use hardware, a wireless network that supports remote access and a plug-and-play programmable LED lighting which is capable of mixing color and dimming control. Overall, it has the capability to conduct testing for a wide range of research activities including lighting control, IoT monitoring and management, mixing color ratios, and other sensor data such as humidity, temperature, CO_2, and images of plants in a smart greenhouse environment.

A. Requirements

Essentially the testbed solution plays a key role in giving the capability to control the dimming and color ratio for LED

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lights. In the meantime, the system should have the ability to control a wide range of environmental parameters for plant growth. A series of requirements and expectations that we consider for the choice of hardware and the design of the testbed infrastructure are listed below.

Scalability: Ideally, the testbed should support for expanding the sensors and control nodes to a larger scale without changing much of the existing system structure. This is a quite realistic requirement, as we aimed to develop it into a prototype application for the use of horticulture researchers in a large scale greenhouse environment.

Low maintainability: The LED lighting control testbed should provide all the necessary configuration and measurement features to fulfill the requirements in terms of the lighting characteristics while being easy to maintain and operate for different scenarios.

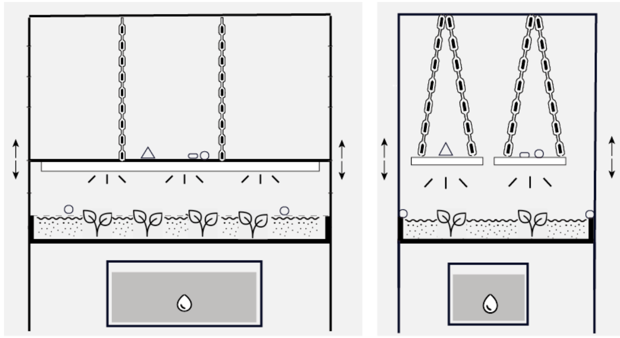
High flexibility: The system design should be such that it can support a high degree of flexibility for experiments and their evaluation for wide range of research topics. For instance, how the light can affect plant growth and how different control actions can be planned and implemented such as shading and moving light fixtures.

Automation and remote control: To evaluate the performance of a lighting control method and the effect of a specific lighting recipe on plant production, one would need data logging to be run for a long time period– typically from a few days to a couple of weeks. It is not possible that the staff supervise the testbed environment on-site all the time and run the system manually. This brings up the requirement that the testbed should run in full, or semi-automated, mode. Considering that the greenhouses are usually located in rural areas, the remote control and monitoring feature through cellular networks is a great feature.

Low cost: With all the requirements listed above, we aim to minimize the cost of the solution to make it feasible when used on a large scale. To achieve this, calibration process for low cost sensors with professional light measurement equipment are conducted. This is part of the implementation that highly supports development of alternative solutions for replacing expensive components.

B. Development process

The development and implementation of a testbed for intelligent LED lighting systems is a multi-disciplinary and multi-stage process from lab environments to real greenhouses. To this end, there exist technical challenges such as control strategies for LEDs, system reliability, stability, energy-efficiency, and uniformity of light distribution which are are of prime importance. Furthermore, the functionality and convenience of use has to be brought to the end user in the agriculture field. These features include customization of light recipes for different plants, and data logging to evaluate crop quality and production, and data to analyze their health are highly important topics. In this section, two stages of the development process are introduced as follows:



(a) (b)

Fig. 1: Front view (a) and side view (b) of the design layout of the proposed testbed.

a) Stage 1- Design of daylight harvesting-based lighting control strategy on a simulated environment:: In the very beginning stage, a daylight harvesting based lighting control system was studied. The results published in [22] has shown that the energy saving is possibly achieved through daylight harvesting while keeping the illuminance level in the office room environment at a acceptable level. The control algorithm was running on a simulated office environment with a clear sky daylight model. According that, the author in this paper has designed a multi-input-multi-output(MIMO) feedback control system for a group of red and blue mixed colored LED light fixtures in order to investigate the control and stability performance [23]. A series of different light conditions, which stand for indoor farm environment, constant peak sunlight exposure environment, ideal daylight environment from sunrise to sunset, respectively has been modelled in the MATLAB/Simulink environment. The control performance running in the MATLAB/Simulink simulation have shown that the proposed feedback MIMO lighting control is able to achieve the desired set points on both red and blue channel with daylight harvesting.

b) Stage 2- Implementation of embedded lighting control system for energy-efficiency and daily light integral(DLI) control:: As the simulation results have shown, the feasibility of the proposed control algorithm on mixed color LEDs, an embedded lighting control system which consists a microcontroller, a group of RGB light sensors, and dimmable LED fixures with red and blue channels was implemented and run in a emulated daylight environment by the authors [24] . Two 1kW halogen lamps installed in a 5'x5' grow tent emulated the daylight change, according to a sunlight modelling that was built based on the hourly solar PPFD data collected locally. Additionally, a time delay, which was caused by the reading process from the sensors and control signal delivery to the actuator, was found to destabilize the controller during the hardware implementation phase of the project. We utilized a Smith predictor along with the proposed control function to fix the issue and maintain closed-loop stability. The results in the energy saving performance has proven the concept while the system runs in a smooth and stable response.

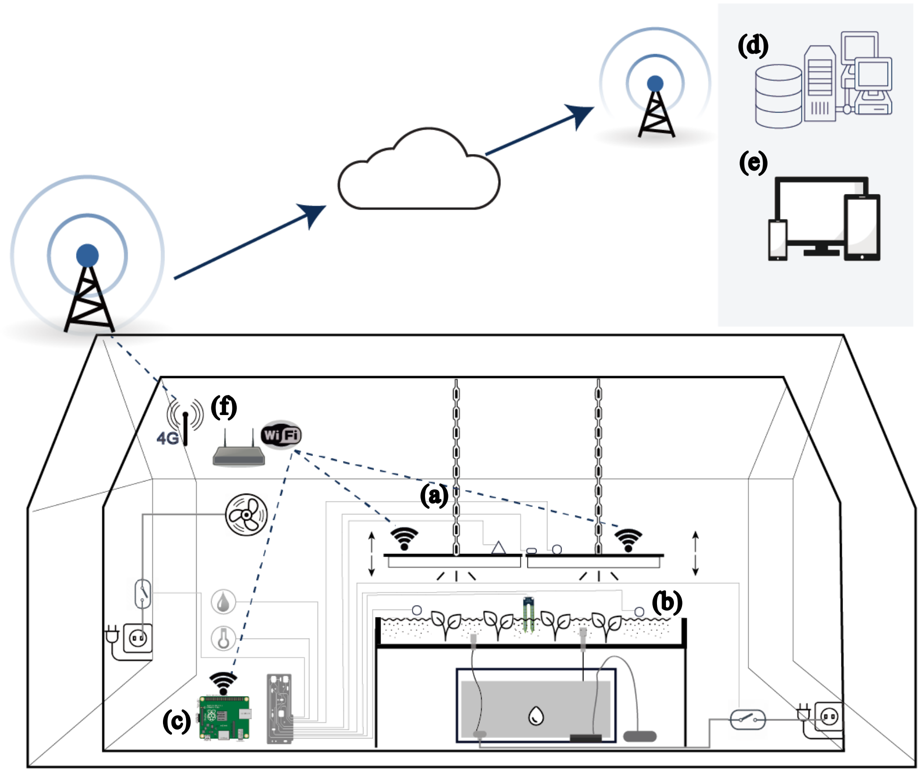


Fig. 2: Overview of the testbed greenhouse environment: (a) An intelligent lighting control system, (b) Plant growth system, (c) Local controller, (d) Remote data server, (e) End-user with access through a cellular network, (f) A 4G cellular network.

III. Design Implementation of the Testbed System

Based on the foundation built in stages 1 and 2 described above, the proposed testbed was designed as shown in Fig. 1. The testbed system will be used as a simple platform toward developing more sophisticated IoT smart greenhouse systems, by integrating the lighting control system that we have developed with other control factors such as environmental data, plant health and growth status, information from end users, and capability of remote access and monitoring. Specifically, the features of the proposed testbed system are as follows:

a) An IoT based controller platform for running different LED lighting control strategies:: The proposed MIMO feedback lighting control method is optimized for the real daylight environment, although it has been studied and tested using simulations and emulated sunlight environment during stages a and 2, respectively. Additionally, we consider the testbed as an evaluation platform that can contribute to the study of different lighting control algorithms in the future; for instance, using neural network control and machine learning algorithms. To support that, sensor groups that covers a wide range of factors to the plant growth were considered in the design such as soil moisture and the distance between LED fixture and plant canopy.

b) Environmental monitoring and control:: In addition to the mixing ratio of different color lights and light intensity, there are some other environmental factors that trigger the optimal performance of plant growth, such as temperature, humidity, and CO_2 concentration. In the proposed testbed, a humidity sensor with temperature output, a UV light sensor, and soil moisture sensor are installed and the collected data is transmitted via I2C and external ADC to the main controller.

c) Small scale hydroponics system for leafy green plants and microgreen:.: Running with time scheduling and ON/OFF control, a small scale hydroponics system is set up as part of the test bed to provide plant grow environment. We consider leafy greens and microgreens as the primary plant subject to evaluate the performance of proposed control methods for two reasons. Firstly, microgreens show a relatively high sensitivity to the different mixing red/blue ratio for the growth and fresh mass yield output to the different light PPFD within a relatively short growth cycle [18], [25], [26]. Secondly, leafy greens have shown that the leaf size and leaf color are both affected significantly by the supplemental grow lights with specific spectral and intensity control [27].

d) Customized light recipe for the research of light affect on plant growth and crop productivity:: In addition to conducting experiments and development of lighting control and IoT applications, the proposed testbed is designed for building as a mini garden environment for plant growth. The plant ecosystem is designed in the system that provide the opportunities for the interdisciplinary research. There is a great need in the study of light recipe applied on the plant growth

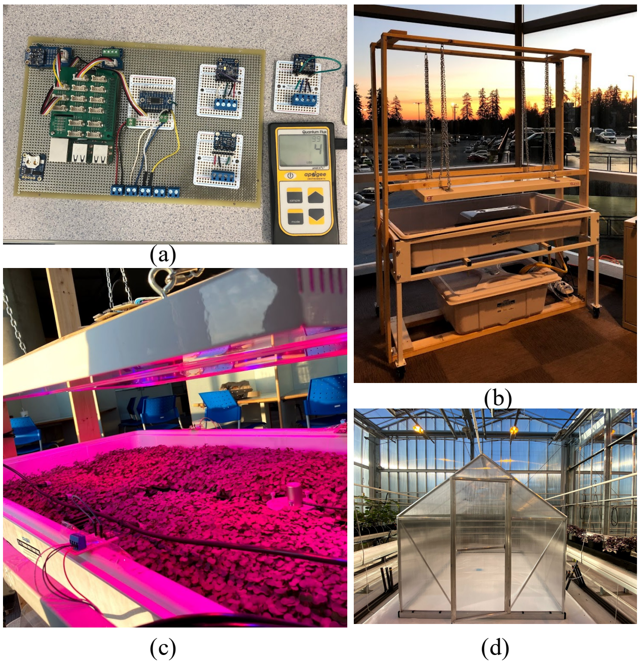


Fig. 3: Overview of the implementation of the proposed testbed with (a) Controller and sensor board, (b) Testbed set up, (c) LED fixture, (d) Greenhouse setup.

and crop productivity. In this stage, the correlations between the measurements of light RGB sensors with the readings from quantum meter is investigated to build a mapping for the reference use of *light recipe*. The proposed feedback control with a new identified model is processed to offer lighting control actions while energy saving is achieved. We utilized a Raspberry Pi module in the development of the IoT system and lighting control application in the proposed testbed to support the wireless network communication and IoT technology.

e) Internet of Things (IoT) based remote monitoring platform: : As a key component that can provide support for unattended operation and remote control and monitoring, the main control system embedded in the proposed testbed would enable IoT technology to allow users to acquire the status of real time plant data and to take manual settings for control applications via a 4G LTE mobile network. This feature offers the convenience in scenarios that require data analysis to be conducted by research staff working remotely from a greenhouse.

Fig. 3 (a) shows the assembled main controller with sensor board and Photosynthetically Active Radiation (PAR) meter. The PAR meter is installed to conduct the calibration process for the correlations between readings from RGB sensors and PPFD from the quantum sensor. Additionally, it is open for use as part of the PAR control in the future work.

The testbed was built and deployed in a corner of the school building with plenty of sunlight exposure. As shown in Fig. 3 (b), the plant grow environment in the proposed testbed system is built on a 2'x4' flood tray with a 40 gallon capacity based hydroponic system assembled for the irrigation. Two LED units are fixed by adjustable steel wire ropes and hang on top of the flood tray. The direction and height of the LED fixture are controlled by DC motors and the control actions are generated by the main controller. Temperature and humidity sensor are installed at the corner of the testbed and the RGB light sensors are installed at each corner of the plant canopy area. A additional RGB light sensor and UV sensor are installed on top of the LED panel. All of them are wired to the a I2C multiplexer board for the data transmission to the main controller via I2C protocol.

The Raspberry Pi controller is installed with a 4G LTE cellular mobile router together as the control and network center. As a low cost, IoT friendly microcomputer, it brings more convenience and provide affordable solution for supporting a variety of features added in this stage, such as the wireless communication with WiFi enable control nodes, integration of different types of GPIO sensors, remote access and local data sever etc. To ease the limitation of wired communication, a RESTful communication based wireless network is built for the LED light units , as a upgrade of the UART communication in the second stage. It offers the system with plug-and-play feature and increase the number of control nodes. The installed LED fixtures and the color ratio is customized by the main controller, as shown in Fig. 3 (c). A communication module is programmed in Python3 to support for control of the detectable LEDs in the WiFi network via RESTful API communication. The overview of the proposed testbed structure and related set up in greenhouse scenario is designed and targeted for the use in a greenhouse environment located at Langley, BC, Canada, as shown in Fig. 3 (d).

IV. Testbed Evaluation and Experimental Results

A sunny day in December with clear sky conditions was selected to conduct the experiment for testing the lighting system performance in the proposed testbed system. Fig. 4 shows results of the total Photosynthetic Photon Flux Density (PPFD) on the plant canopy level in 24hours, based on the testbed system with the proposed built in feedback lighting control system and daylight harvesting feature. The overall PPFD in the performance results have shown the system is capable of keep the PPFD stably at 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Occasionally the PPFD was below the targeted value a bit, as we can see that at time 9AM and 12PM. We believe this is because of the lack of sampling rate from the PAR meter logger and the sunlight blocking by the dark clouds.

Fig. 5 shows a overview of the LED dimming output change from dawn to solar noon. It shows that the plant tray area in the proposed testbed have received high supplemental light ouputs from the LED fixtures in dawn, when the time that the sunlight was weak or not available. By taking advantage of the daylight harvesting, after the sun rose up, the dimming level gradually went down and reached to fully dim off at the time of solar noon. Combined with the PPFD output result shown in Fig. 5, we conclude that the lighting system is capable of achieving

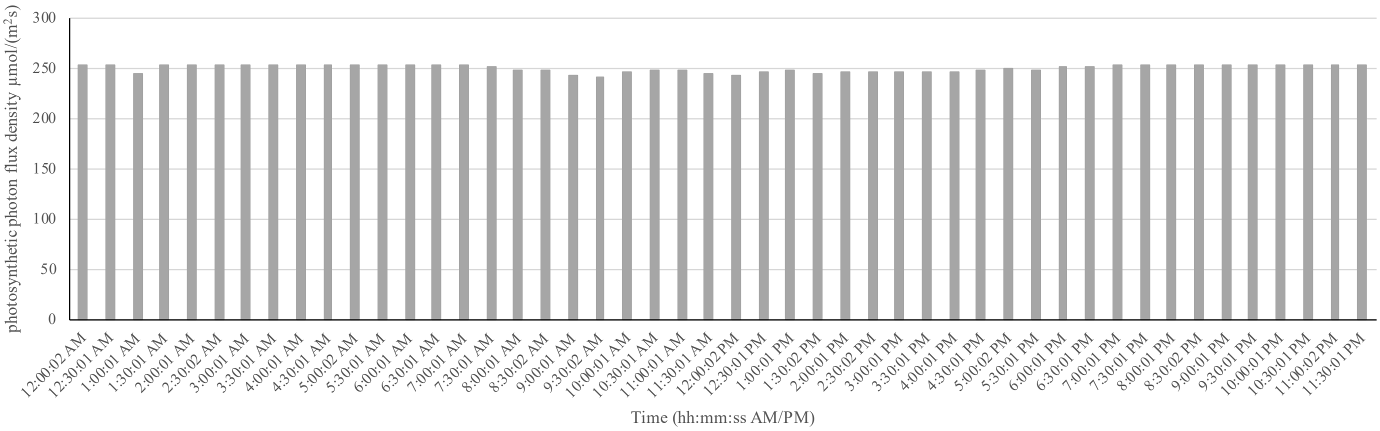


Fig. 4: Total Photosynthetic Photon Flux Density (PPFD) including both sunlight and supplemental light output on the plant canopy level in 24 hours.

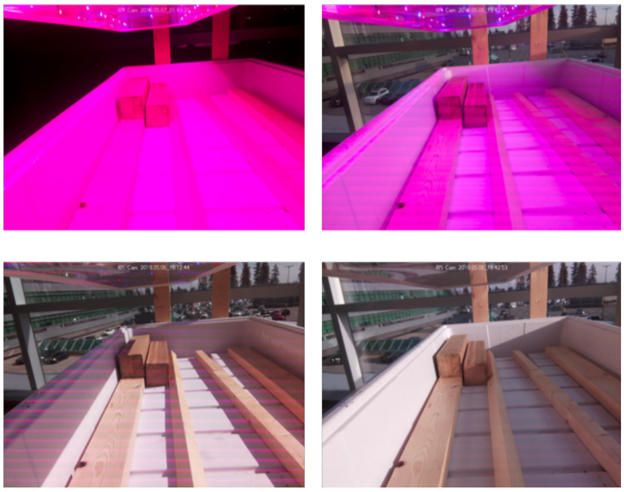


Fig. 5: Light control performance on the proposed testbed from dawn to solar noon.

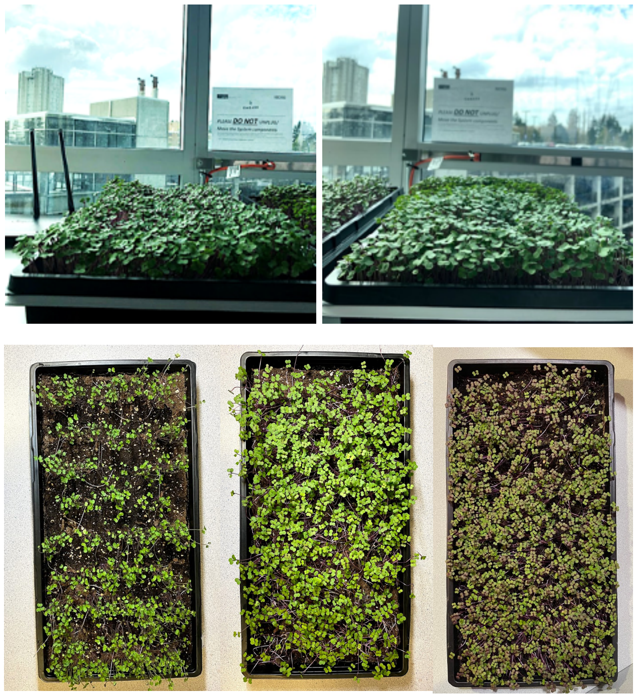


Fig. 6: Plant growth results under three different light conditions: solo sunlight (left side), supplemental LED lighting with emulated sunlight environment (middle side), supplemental LED lighting running on the proposed testbed in the sunlight environment (right side) .

the targeted light requirement and as well as reducing energy consumption by dimming the LEDs.

In addition, microgreen kale is selected as the plant object to testify the growth performance. Three identical plant trays with identical amount of microgreen kale seeds are placed in three different different light scenarios: solo sunlight environment, mixing color control of LEDs in a grow tent with emulated daylight environment as developed in stage two, mixing color control of LEDs with calibrated PPFD desired point setting in a real sunlight environment as the proposed testbed in this paper, respectively. All of the three sets are started and ended simultaneously with lasting for a two-week grow cycle. The growth status in the harvest day for each plant tray is shown in Fig. 6. As we can see that the microgreen kale grow in good conditions under all of the three environments, especially it shows a higher plant productivity in the proposed testbed.

V. Conclusion and Future Work

The study in this paper addresses the applicability of a testbed with a intelligent LED lighting control system. The design concept has been depicted and different stages of the forming process has been illustrated. With the implementation of the testbed, a intelligent LED control strategy has been testified with the growth of real plant in a real daylight environment. The microgreen kale has been selected as the test object and the performance have shown that the proposed testbed is capable of achieving desirable light requirement for the tested plant and maintaining the plant at a better growth performance compared to the reference set.

Acknowledgment

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Article

Design of a Novel Remote Monitoring System for Smart Greenhouses Using the Internet of Things and Deep Convolutional Neural Networks

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Abstract: To support farmers and improve the quality of crops production, designing of smart greenhouses is becoming indispensable. In this paper, a novel prototype for remote monitoring of a greenhouse is designed. The prototype allows creating an adequate artificial environment inside the greenhouse (e.g., water irrigation, ventilation, light intensity, and CO_2 concentration). Thanks to the Internet of things technique, the parameters controlled (air temperature, relative humidity, capacitive soil moisture, light intensity, and CO_2 concentration) were measured and uploaded to a designed webpage using appropriate sensors with a low-cost Wi-Fi module (NodeMCU V3). An Android mobile application was also developed using an A6 GSM module for notifying farmers (e.g., sending a warning message in case of any anomaly) regarding the state of the plants. A low-cost camera was used to collect and send images of the plants via the webpage for possible diseases identification and classification. In this context, a deep learning convolutional neural network was developed and implemented into a Raspberry Pi 4. To supply the prototype, a small-scale photovoltaic system was built. The experimental results showed the feasibility and demonstrated the ability of the prototype to monitor and control the greenhouse remotely, as well as to identify the state of the plants. The designed smart prototype can offer real-time remote measuring and sensing services to farmers.

Keywords: deep learning; Internet of things; mobile application; photovoltaic system; plant diseases classification; remote monitoring; smart greenhouse

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1. Introduction

Currently, the problems of climate change and environmental damage (due to CO_2 emissions when burning fossil sources such as gas, oil, coal, etc.) have further serious problems of food and agricultural productivity [1]. The procedure of producing high-quality crops is very important to meet the increasing demand of food products around the world. The industry of greenhouses is become a more fast-growing sector around the world. The greenhouse splits the crop from the environment, thus providing some sort of housing from the direct influence of external weather conditions. A greenhouse is mainly designed as a light transparent shelter to improve environmental conditions for plant production quality. Greenhouses are used to make a suitable atmosphere for planting and preventing plants from exposure to harsh environmental conditions, such as heavy rainfall or high solar radiation [2].

High or low temperatures, high humidity, CO_2 concentration, aeration, condensation of water, and water evaporation inside the greenhouse are among the major challenges faced by traditional greenhouses. Therefore, to achieve maximum returns from greenhouse cultivations, it is vital to maintain an environment that minimizes energy consumption [3].

Many parameters such as air temperature (Ta), relative humidity (RH), soil moisture (SM), light intensity (LI), and carbon dioxide (CO_2) concentration are involved and dependent on each other; this makes the greenhouse climate control a complicated procedure [4].

In the last decades, greenhouse climate monitoring and control problems have received considerable attention in agriculture engineering research [5]. Recently, researchers are more and more attracted to the application of the Internet of things (IoT) [6] to modernize greenhouses by designing smart monitoring systems [7] and creating artificial environments [8].

For example, Castañeda-Miranda and Castaño-Meneses [9] developed an automatic system for monitoring crops inside a greenhouse using solar energy and the IoT technique so that users could easily monitor the temperature, watering, and light through a mobile application. A wireless system enabling communication between the central control unit and four robots that worked in a model greenhouse was developed by Kumar et al. [10]; the results showed the potential of the system for application in real-life greenhouse operations. Chie et al. [11] designed an IoT-based system to monitor the environmental factors of an orchid greenhouse and the growth status of *Phalaenopsis* at the same time. As indicated by the authors, the system shows a great potential to provide quantitative information with high spatiotemporal resolution to floral farmers. Liao et al. [12] compared microclimate parameters inside two different tropical greenhouses using a custom-built wireless sensor for data fusion. A detailed review about the use of the IoT in the agricultural sector including greenhouses, various sensors which aid the IoT and agriculture, their applications, challenges, advantages, and disadvantages are reported in this paper [13].

Diesel is mainly used to supply greenhouses (e.g., for water pumping, irrigation, etc.) in remote areas, which is costly (e.g., in Saharan regions) [14]; however, currently, the utilization of solar energy (such as photovoltaic) for supplying greenhouses in remote areas is considered to be among the important applications of renewable energy sources [15]. The possibility to apply photovoltaic energy and the IoT to monitor greenhouses was shown by Aschilean et al. [16].

Another issue is the greenhouse crop diseases identification and early classification; recently, attempts have been made to design efficient approaches based on the IoT technique and image processing [17], for example, Mishra et al. [18] designed an IoT-based strawberry disease prediction system for smart farming; the capability of the model in disease prediction was shown. Kim et al. [19] used the IoT technique and a machine learning algorithm to classify plant diseases at an early stage. An IoT-based monitoring system for precision agricultural applications such as epidemic disease control was developed by Pavel et al. [20]; an expert system was also developed to make decisions regarding the diseases. A survey on the current techniques and prediction models based on image processing and the role of the IoT being applied for identification, detection as well as quantification of tomato plant diseases was shown by Khattab et al., Verma et al., and Diyan et al. [21–23].

The objective of this work was to design an effective smart monitoring system for modern greenhouse applications. To do this, the IoT technique, a clean source of energy, and deep convolutional neural networks (DCNN) were used. The proposed modern greenhouse will help farmers to:

- control different environmental parameters inside the greenhouse,
- ensure remote sensing and easy analysis of the collected data in real time,
- ensure early detection and classification of tomato diseases in plants,
- receive notifications about the state of the greenhouse.

The main contributions are listed below:

- design of a low-cost monitoring prototype,
- development of a webpage for monitoring parameters inside the greenhouse,
- development of deep neural networks for diseases detection and classification,
- development of an Android application for notifications about anomalies.

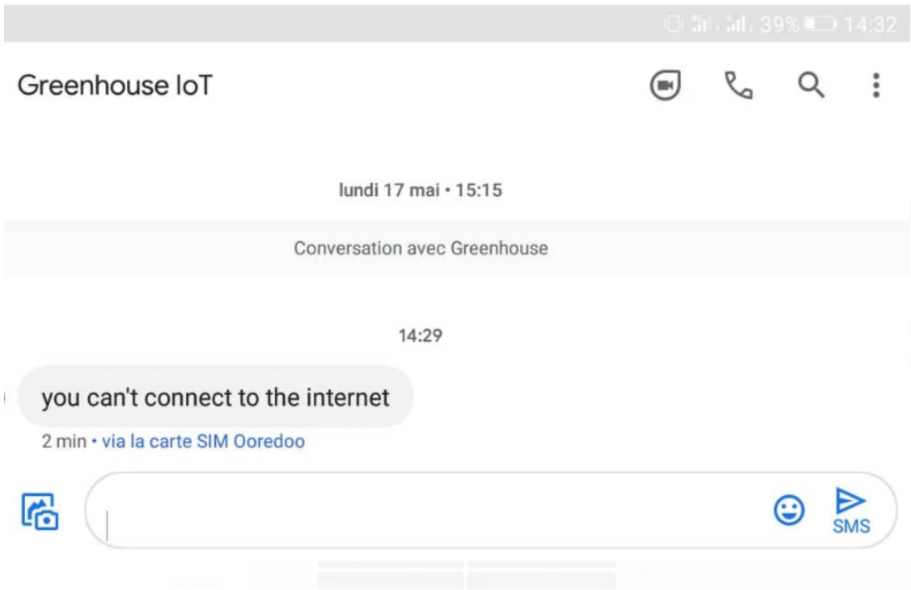

Figure 10. SMS notification (e.g., no Internet connection).

3.4.2. Mobile Application (Android)

The main Android screens of the developed mobile application are depicted in Figure 11. This application can help farmers to visualize the collected parameters and monitor the greenhouse remotely.

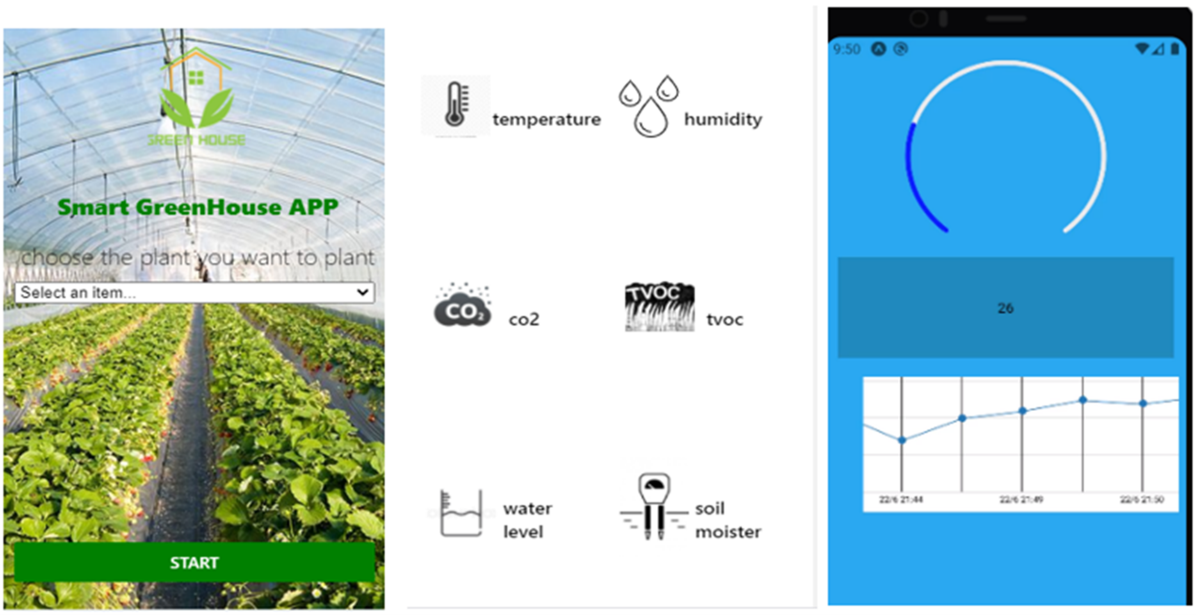

Figure 11. The main Android application screens for the designed smart greenhouse.

3.5. Plant Diseases Classification

The database used in this study consists of six categories (five disease classes and one health class). It contains a single leaf, multiple leaves, a single background, and a complex background. All the images were unified to 227 × 227 pixels. The diseases examined (in case of tomato plants) were bacterial spot, black leaf mold, gray leaf spot, late blight, and powdery mildew.

Figure 12 shows an example of the images (diseases of tomato plants) available in the database.

The code was implemented and run under Google Colab, which is a free online cloud-based Jupyter Notebook environment. The DCNN model was trained under a GPU (Tesla K80 with 12 GB of GDDR5, Intel Xeon Processor with two cores @ 2.20 GHz and 13 GB RAM).

Figure 13 shows the loss and the accuracy during the training process. The loss was close to 0.001 and the accuracy was about 0.99. These results confirm the good training of the model; thus, the DCNN model was ready to classify and identify the diseases of tomato plants.

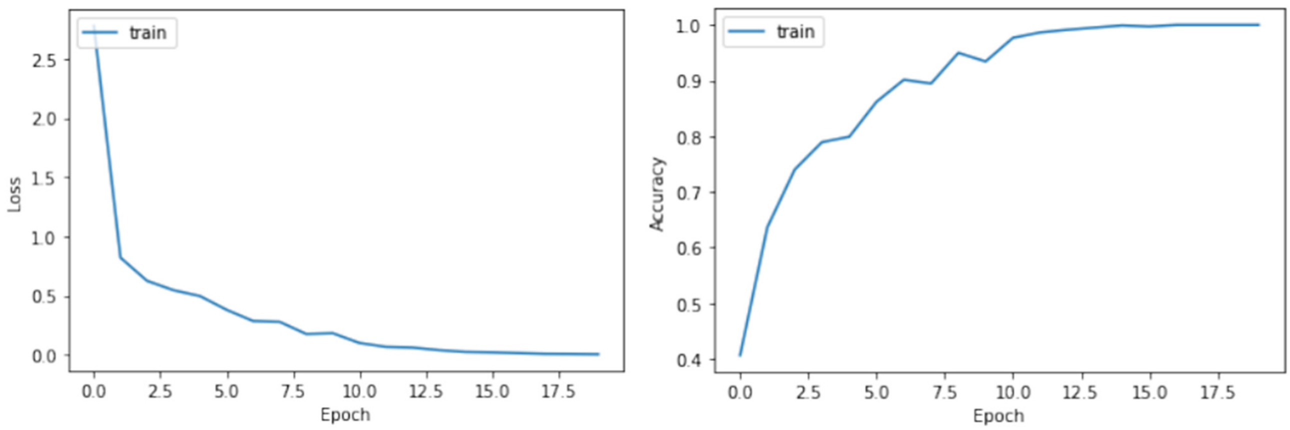

Figure 13. Loss and accuracy functions of the DCNN model for the classification of diseases (tomato plants).

To evaluate the performance of the developed DCNN model, we calculated the following error metrics:

$$Accuracy = \frac{(TP + TN)}{(TP + FP + TN + FN)} \tag{1}$$

$$Precision = \frac{TP}{(TP + FP)} \tag{2}$$

$$Recall = \frac{TP}{(TP + FN)} \tag{3}$$

$$F1 - score = 2\frac{(Precision * Recall)}{(Recall + Precision)} \tag{4}$$

where *TP*—number of true positive, *TN*—number of true negative, *FP*—number of false positives, *FN*—number of false negative.

The results of the calculated error metrics are listed in Table 1.

Table 1. Error metrics: precision, recall, F_1 score, and accuracy.

Category of Disease	Precision (%)	Recall (%)	F_1 Score (%)	Accuracy (%)
Bacterial spot	87	85	86.88	88
Black leaf mold	85	87	83.35	
Gray leaf spot	82	85	83.51	
Healthy	90	89	92.73	
Late blight	83	86	84.47	
Powdery mildew	82	85	83.51	

According to Table 1, good accuracy (88%) was obtained for diseases classification of tomato plants. However, the results could be improved by using a large database with high-quality images.

Appendix

Table A1. Used components specifications, accuracy and prices.

Item	Reference/Specification	Accuracy/Resolution	Price (USD)
Microcontrollers	Arduino Mega 2560	Accuracy of ± 2 LSB The maximum error is 2 bits (4 decimal) in 10 bits (1024 decimal). The worst-case accuracy of the converter is 4/1024, or 1 part in 256 i.e., 0.25%.	14
Processor	Raspberry 4 pi 2 Go	Resolution up to 1080p at the 60 Hz refresh rate.	70
LED	12 V	-	3
GSM module	A6	Sensitivity < −105	5
Wi-Fi module	NodeMCU ESP8266	14-bit resolution. The minimum resolution could reach as much as 44 ns. External clock accuracy between 15 and +15 ppm	2.5
Relative humidity and air temperature sensor	(DHT11)	± 5% RH, ± 0.5 °C accuracy	1.5
Position sensor	Ultrasonic HC04	Absolute accuracies of 1–3% in the operating range from −25 °C to +70 °C.	0.75
Relay	5 V	-	10
Light sensor	BH1750	Accuracy: ± 20%. This sensor can accurately measure the lx value of light up to 65,535 lx.	0.95
CO_2 sensor	CCS811	2% tolerance due to accuracy of the internal clock in Mode timings	4
Valve	12 V	-	2.5
Water pump	12 V	High accuracy	8
Fan	12 V	-	3
Servomotor	MG960R	Servos operate accurately at speeds up to 5000 rpm or more. Its stopping accuracy is within ± 0.05 degrees (with no load).	5
Voltage sensor	25 V	Resolution of 0.00489 V	1.5
Current sensor	ACS 7120 (30 A)	Accuracy < 2%	2
LCD	4 × 16	-	2.5
Screen	1.3 inch	-	3
Capacitive soil moisture	V 1.22	2–3% of the actual soil moisture	3

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Keeping data at the edge of smart irrigation networks: A case study in strawberry greenhouses

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ABSTRACT

Strawberries are widely appreciated for their characteristic aroma, bright red color, juicy texture, and sweetness. They are, however, among the most sensitive fruits when it comes to the quality of the end product. The recent commercial trends show a rising number of farmers who directly sell their products in the market and are more interested in using smart solutions for a continuous control of the factors that affect the quality of the final product. Cloud-based approaches for smart irrigation have been widely used in the recent years. However, the network traffic, security and regulatory challenges, which come hand in hand with sharing the crop data with third parties outside the edge of the network, lead strawberry farmers and data owners to rely on global clouds and potentially lose control over their data, which are usually transferred to third party data centers. In this paper, we follow a three-step methodological approach in order to design, implement and validate a solution for smart strawberry irrigation in greenhouses, while keeping the corresponding data at the edge of the network: (i) We develop a small-scale smart irrigation prototype solution with off-the-shelf hardware and software equipment, which we test and evaluate on different kinds of plants in order to gain useful insights for larger scale deployments, (ii) we introduce a reference network architecture, specifically targeting smart irrigation and edge data distribution for strawberry greenhouses, and (iii) adopting the proposed reference architecture, we implement a full-scale system in an actual strawberry greenhouse environment in Greece, and we compare its performance against that of conventional strawberries irrigation. We show that our design significantly outperforms the conventional approach, both in terms of soil moisture variation and in terms of water consumption, and conclude by critically appraising the costs and benefits of our approach in the agricultural industry.

1. Introduction

Irrigation is crucial for agricultural production in order to ensure that greenhouse farmers can meet crop water demands. However, poor irrigation scheduling and inefficient utilization of water resources are two of several ubiquitous parameters restricting production in many agricultural regions. farmers can use sensed information such as light, moisture and temperature levels to modify irrigation schedules and avoid the risk of damaging crops [1]. For example, soil sensors can be used to collect information on how water flows through the land and can be used to track changes in soil moisture, temperature, and levels of nitrogen and carbon. This allows the monitoring, optimization, and precise control of sensitive crops like strawberries and facilitates farmers in maximizing their crop production while maintaining very high quality in their end product.

A common approach for collecting large volume of agricultural data is based on the assumption that some network infrastructure is already present and is able to support the collection and delivery of all these data. Usually, data are pushed towards the cloud, which is intended to be the back-end aiming at processing and getting value from such data, as well as at controlling the field actuation devices. Moving all computing tasks to the cloud has been an efficient way to process data because there is more computing power in the cloud than in the devices at the network edge, where the

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field devices are deployed. Typically, for Internet of Things (IoT) enabled systems, this backbone is a wideband cellular network such as LTE. In the case of Smart Irrigation Network (SIN) environments an alternative may also include more localized wideband infrastructures, such as WiFi. In any case, an approach relying exclusively on global cloud providers to provide smart irrigation services has limitations mainly from two standpoints. On the one hand, wideband wireless networks may not provide sufficient bandwidth, particularly in rural areas, to support the data traffic demand. On the other hand, relying only on global clouds deployed may make SIN owners and operators lose control over their data, as those data are transferred to data centers without any control on behalf of the data owner. In addition, meeting the farmer's requirements in terms of storage and computation capacity may have a significant impact on the cost incurred to the farmer for ICT services, which, if reduced, could be more profitably invested in the core production process. Consequently, keeping the data at the network edge yields shorter response times, more efficient processing and actuation, less pressure on the backhaul network and more robust data ownership guarantees [2].

The concerns regarding moving the agricultural data away from the edge of the network are discussed in depth at the position paper "Cloud of Things in Smart Agriculture: Intelligent Irrigation Monitoring by Thermal Imaging", authored by M. Roopaei et al., [1]. The authors examine key technical and legal issues and requirements supporting the use of Cloud of Things for managing water source-related data. They present the advantages of cloud-based approaches for smart irrigation; however, they identify the security and regulatory challenges which come hand in hand with sharing the crop data with third parties, outside the edge of the network. Regarding the security aspects, the authors state that, unfortunately, cloud-based smart irrigation systems potentially have more attack vectors (e.g., hardware, firmware, and applications running on Cloud of Things devices) that can be remotely exploited by attackers, particularly during early stages and in comparison to traditional, isolated, irrigation systems (which keep the data at the edge). Regarding the regulatory aspects (e.g., data protection and the Internet governance), the authors state that the time required to develop an appropriate legal and regulatory framework is significantly longer than the time it takes to develop the next-generation SIN cloud systems.

Strawberries are widely appreciated for their characteristic aroma, bright red color, juicy texture, and sweetness. The recent commercial trends show a rising number of farmers which directly sell their products in the market and are more interested in using smart solutions (like SINs) for a continuous control of the quality related factors.[1] In fact, strawberries cultivated in greenhouses are very susceptible to water irrigation amounts which are very important both during the first months after planting and before harvesting. Water amounts have to be constantly maintained within optimum ranges, in order to avoid loss of product which otherwise can reach up to the 80% of the yield, caused by the presence of misshapen, plant collapsed and small fruit. Farmers need to know the level of greenhouse temperature and soil water content many times a day, in order to make decisions about temperature management and water supply.[2]

1.1. Contributions and roadmap

In this paper, contrary to the traditional cloud-based solutions, we propose a decentralized smart irrigation approach for strawberry greenhouses, the core idea of which is to keep the agricultural data within the range of the edge of the network. Decentralized data management, a key component of edge computing, can be a very suitable approach to cope with the aforementioned challenges. In the context of SINs, one could leverage the set of nodes present at the edge of the network to distribute functions that are currently being implemented in remote data centers [3]. More specifically, we adopt a three-step methodological approach which leads to our three following contributions:

- In the first step, we develop a small-scale SIN prototype with off-the-shelf hardware and software equipment. We test the performance of this prototype on different kinds of plants in order to investigate and evaluate the feasibility of our ideas and to gain some insights for larger scale deployments. We focus on maintaining small variability in terms of soil moisture levels compared to the conventional timed watering approach.
- In the second step, using the experience gained from the small-scale prototype, we introduce a SIN reference architecture, specifically targeting edge data distribution for strawberry greenhouse applications. We analyze the different electromechanical and networking components needed for implementing such a SIN and we tailor the architecture to the modern strawberry greenhouse requirements.
- In the third step we implement a full-scale SIN system in an actual strawberry greenhouse environment in Greece, by adopting the proposed reference architecture. Building upon the lessons learnt during the small-scale pilot of the first step, and the evident need for a hardware design that would facilitate interfacing different types of sensors and actuators with IoT development platforms, while at the same time providing a sufficient degree of physical robustness, we propose a new hardware design for sensing and actuation in SINs, the control cube. We implement the hardware design and we setup the system in two greenhouses: In the first greenhouse the process is supervised by the farmer. The second greenhouse is managed by the developed SIN system. Based on the final results, our SIN significantly outperforms the conventional approach both in terms of soil moisture variation and in terms of water consumption.

The roadmap of the paper is the following: In Section 2, we present some representative works related to this paper. In Section 3, we design and evaluate the performance or our small-scale SIN prototype. In Section 4, we introduce the reference architecture which can serve as the foundation of SIN systems targeting strawberry greenhouses. In Section 5, we present the implementation and the performance evaluation of the full-scale SIN system in real strawberry greenhouses environment by adopting the proposed reference architecture. Finally, in Section 6 we conclude the paper. We also critically appraise the costs and benefits of our approach in the agricultural industry.

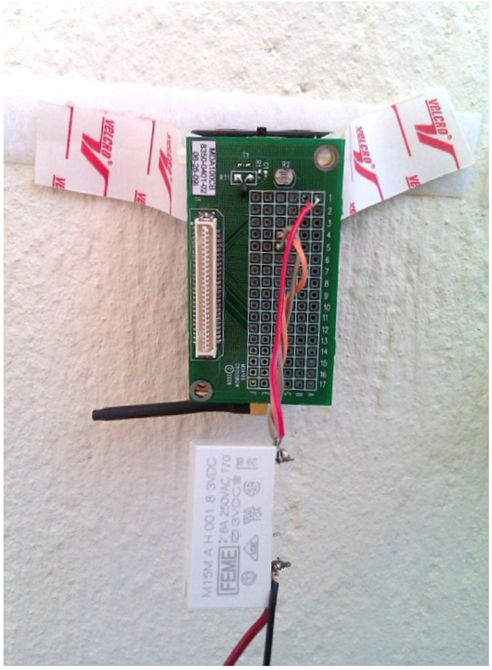
2. Related works

In this section, we present some selected previous research works. At first, we present some recent works on cloud-based irrigation solutions (which prefer to push the data in the cloud or to third party systems for conducting smart irrigation). Then, we present some interesting past works focusing on the exact topic of strawberry smart irrigation. Finally, we conclude the section with some IoT device and system designs targeting smart agriculture in general.

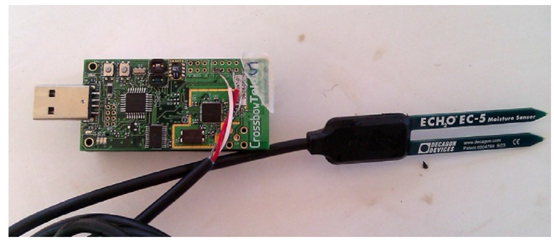
Cloud-based solutions. Researchers at Colorado State University have created an online evapotranspiration-based irrigation scheduling tool called Water Irrigation Scheduling for Efficient Application (WISE) that uses the soil water balance method and data

[1] FA.MO.S.A. sarl: http://www.famosasrl.com/en/.

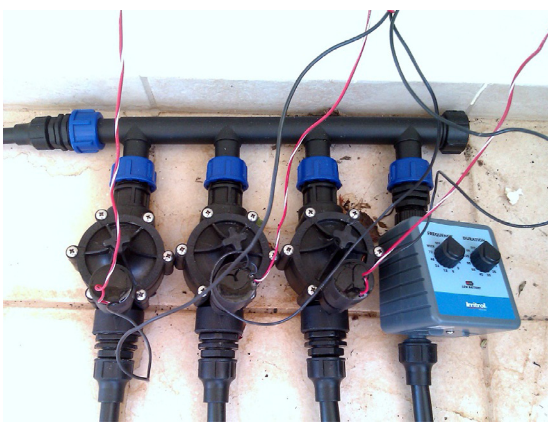
[2] Innovation Centre for Sensor and Imaging Systems (Censis): https://censis.org.uk.



(a) Relay shouldered on the MDA100CB board of the IRIS mote.



(b) The EC-5 soil sensor shouldered on a TelosB mote.



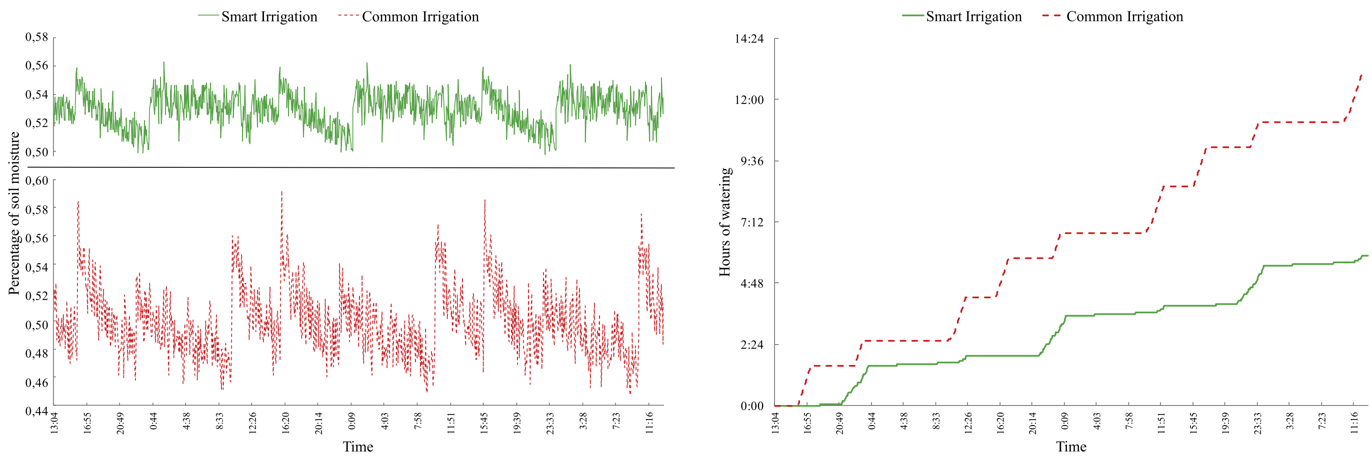
(c) Installed electrovalves and common irrigation programmer. The red and black cables of the solenoids are connected in series with the relay and the external power source (batteries or AC-DC converter).

(d) The entire small-scale SIN.

Fig. 1. Sensing and actuating devices used at the installation.

4. An architectural design for the strawberry greenhouses case

The second step in our methodological approach has been to design a reference architecture which can serve as the foundation of SIN systems targeting strawberry greenhouses. The proposed architectural design is displayed at Fig. 3. The core assumption of our design lies on the fact that we opt for keeping the data within the range of the edge network (green-dotted rectangle in Fig. 3) and not share them with the global network (red-dotted rectangle in Fig. 3). Typically, strawberry plantations consist of parallel, long, rectangular greenhouses (green/gray-colored rectangles in Fig. 3). Each greenhouse consists of multiple lines with strawberry plants, where each line has its own watering hose. The watering hoses of each greenhouse are connected to the main water supply through a valve. If a valve is open, the water supply is able to pass through the watering tubes to the greenhouse and to the watering hoses of the strawberries. In traditional deployments, the valve opening/closing schedules are configured either manually (by the farmer), or through common irrigation programmers which can be set to irrigate at regular time intervals for fixed periods of time. However, in our SIN architecture, we replace this conventional functionality with actuators which are able to both control the valves and communicate with other devices via low power wireless communication. In order to acquire the necessary readings regarding ambient conditions in the greenhouse, like soil moisture, the architecture provisions the installation of sensor motes in the greenhouses. Each greenhouse should have more than one sensor mote for more accurate estimations. The sensor motes can



(a) Soil moisture. (b) Water consumption.

Fig. 7. Soil moisture and water consumption over time for a period of 3 days.

control and monitoring is able to perform the corresponding actuation unsupervised.

5.3. Cost-benefit considerations

Based on our deployment experience, further to the performance results, we now provide some insights about the estimation of the strengths and weaknesses of the two alternative SIN management approaches presented in Section 5. Our comments highlight that the smart irrigation approach can achieve greater benefits while preserving significantly higher savings than the manual irrigation approach. The main goal of an irrigation approach is to preserve efficient levels of expenditure while at the same time to provide high production benefits. This goal can be achieved by minimizing the long term costs related to the installation and the continuous operation of the irrigation facility, while maximizing the inherent benefits of each selected irrigation approach. Regarding the costs, on the one hand, the manual irrigation approach requires a greater investment in finding and employing on a regular basis specialized personnel for performing manually the irrigation tasks. Also, as demonstrated by the performance evaluation, the manual approach results in significantly higher water consumption costs, which can quickly escalate in large-scale strawberry plantations. On the other hand, the smart irrigation approach necessitates the purchase and (one-shot) installation of the related IoT equipment described in Section 5. Also, if the backhaul communication option with the global cloud is considered for additional functionality, we have to take into account the costs derived by the network connectivity and access. In many cases, and especially in remote rural areas with low connectivity and harsh terrains, those costs can significantly increase and require big investments. This setting can be particularly relevant to emerging product tracking mechanisms using, for example, the blockchain paradigm, whereby transaction records grow immensely in size, are not able to be stored locally on the edge of the network, and have to be moved to the global cloud. However, regardless of those costs, the smart irrigation approach comes with significant benefits which are absent from the manual irrigation approach. At first, as demonstrated in Section 5.2, the balancing of ground moisture can be significantly enhanced, leading to a final product of increased quality. Secondly, the smart irrigation solution can be highly scalable, leading to a convenient ease of replication of the irrigation process to numerous greenhouses and facilities. Last but not least, the data collection, which is an outcome of the smart irrigation process, can provide valuable insights as input for additional edge data analytics targeting business decision making; an input that in the manual irrigation case comes just from the personal experience of the farmer.

6. Conclusions

In this paper, contrary to the traditional cloud-based solutions, we propose a decentralized smart irrigation approach for strawberry greenhouses which keeps the agricultural data at the edge of the network. After having developed a small-scale smart irrigation networking prototype system and having designed a reference architecture targeting edge data distribution for strawberry greenhouse applications, we implement a full-scale smart irrigation system in an actual strawberry greenhouse environment in Greece. We then compare the performance of our approach to the performance of conventional irrigation methods managed by the farmer. We conclude that our smart irrigation approach significantly outperforms the conventional approach both in terms of soil moisture variation and in terms of water consumption.

Declaration of Competing Interest

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript

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IoT-based adaptive network mechanism for reliable smart farm system

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ABSTRACT

This paper presents an adaptive network mechanism for a smart farm system by using LoRaWAN and IEEE 802.11ac protocols. Generally, the internet of things (IoT) system for agriculture application is used in an environment where significant interferences can occur. These interferences can disrupt the network performance of the system. In this paper, an adaptive network mechanism is designed to improve the network performance of the system, in order to achieve a more reliable smart farm system. Specifically, the proposed adaptive network mechanism is implemented in the application layer. The system has the ability to adjust a protocol based on the network condition. For instance, the IEEE 802.11ac is suitable for transmitting data which require high data rate such as image or video. On contrary, the LoRaWAN protocol is suitable for sending data that only have small data packets such as sensor reading data. An adaptive mechanism, which combines advantages of both protocols, leads the system to achieve reliability while performing the monitoring task. The system has been evaluated for the real deployment scenario. The result demonstrates that the proposed system brings the reliability in terms of average latency and total gathered number of sensors' data.

1. Introduction

Recently, the Internet of Things (IoT) technology has been a popular approach to implement in the industrial area. IoT emerged to become a critical factor in the next industrial revolution, and the agricultural sector is already on board. According to the Food and Agriculture Organization of United Nations report (O'Grady et al., 2017), food production is expected to increase about 70% in 2050 to fulfill the demand of food necessity because of the growing population. Another essential aspect that must be considered is the extensive use of natural resources in agriculture such as water for future sustainability. Therefore, combining IoT technology with the agricultural sector can make a considerable improvement in production capabilities, and the efficiency of using natural resources can also be controlled (Ojha et al., 2015).

In the agriculture environment, commonly the IoT system is deployed in a large area and separated from the data control server due to long distances. Therefore, it is very sensitive to failures while transmitting the monitoring data. Besides that, the agriculture monitoring network application that uses a camera for surveillance may suffer from high energy consumption due to the high computation task requirement. Moreover, the system might be suffering from delay as well because it requires transmitting a high amount of data packets. The authors in Charfi et al. (2014) explained that IoT applications which use cameras for real-time monitoring are a strict requirement in term of delay loss and rate. In these circumstances, achieving the requirement of network performance for agriculture monitoring applications is a challenging issue.

Much extensive research has been done on IoT-based smart agriculture systems. Previous work mostly focused on designing and implementing the proposed system (Popovic et al., 2017; Bapat et al., 2017; Ferentinos et al., 2017). However, the network performance of the proposed scheme is not considered. Network performance parameters such as throughput and latency are necessary to be considered especially for real-time IoT applications. Compared to previous work, this paper considers network performance parameters for the proposed system. In comparison, the study from Ismail Ahmedy and Idris (2017) proposed a network model which considers Quality of Service (QoS) for the wireless agriculture monitoring system. However, QoS was only evaluated by computer simulation in this study.

LoRa technology, in particular, is an emerging low-power, wide-area (LPWA) technology which offers a long range, low power consumption, and secure data transmission (Raza et al., 2017). LoRa uses a specific protocol named LoRaWAN. It uses unlicensed radio spectrum in the Industrial, Scientific, and Medical (ISM) bands. Moreover,

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Table 1
Comparison among LoRaWAN, Sigfox and 802.11ac.

Feature	LoRaWAN	Sigfox	802.11ac
Modulation	SS Chirp	GFSK/ DBPSK	OFDM
Data Rate	290 bps - 50 kbps	100 bps 12/ 8 bytes Max	1 Gbps Max
Power Efficiency	Very High	Very High	Medium
Security/ Authentication	Yes (32 bits)	Yes (16 bits)	Yes (128 bits)
Interference Immunity	Very High	Low	Low
Scalability	Yes	Yes	Yes

Fig. 1. Deployment site of the proposed system.

Table 2
Statistics of the sample video stream.

Parameter	Value
Picture resolution	1280 × 720 pixels
Frame refresh rate	24 frame/s
Total frames	3016
Number of I-frames	252
Number of P-frames	754
Number of B-frames	2010
Avg. I-frame size	31,992 bytes
Avg. P-frame size	23,463 bytes
Avg. B-frame size	2623 bytes
GOP size	12 frames
GOP structure	IB BPB BPB BPB B
Total packets	22,848

LoRaWAN enables bidirectional communication between users and sensors on an individual or group level. Hence, LoRa is suitable for the IoT applications that only require transmitting small data packets and low power consumption. Even though LoRa can offer a long range and low power consumption, there are some disadvantages of LoRa. One of the disadvantages of LoRa is that it has only a small data rate compared to the IEEE 802.11 protocol. Therefore, this can cause a delay if it is used to transmit video data frames. Table 1 compares the features of different network technologies.

In this paper, adaptive network mechanism for smart farm is proposed. As mentioned above, the nature of agriculture monitoring network is deployed in the large area and because of that the monitoring node in the smart farm system is very sensitive for failures. For instance, if there was a faulty relay node, video image and sensors data could not be transmitted to the server via IEEE 802.11ac. Under these circumstances, the system cannot perform real time monitoring, which is essential for the agriculture application (Khanna and Kaur, 2019). In specific, real-time monitoring is essential since it provides timely information of the actual status inside of the greenhouse such as the crop, soil, temperature, and humidity. Moreover, real-time monitoring plays an important role in the decision for improving the crop production. Thus, sensor reading data still must be transmitted to the server via LoRaWAN. To mitigate the mentioned issues, the adaptive network mechanism is used to maintain the reliability. Each node can adaptively use two different protocols to communicate with the base station based on the situation which is using LoRaWAN as well as IEEE 802.11ac. In the proposed system, IEEE 802.11ac can be used to transmit the video images and sensors' reading data since this protocol has a higher data rate than LoRaWAN. On the other hand, LoRaWAN can be used to transmit sensor data. Detailed information will be elaborated in Section 4.

The rest of this paper is organized as follows. Section 2 discusses the IoT systems to realize smart farm. Section 3 elaborates performance comparison of IEEE 802.11ac and LoRaWAN protocol. Section 4 introduces the proposed reliable smart farm system. Section 5 presents the performance evaluation of the proposed reliable smart farm system. Finally, Section 6 presents the conclusions.

2. Internet of Things (IoT) to realize a smart farm

IoT is a phrase or jargon to explain situations where many things or devices are connected to the Internet. IoT technologies enable people to manage works and devices easily through internet. Various devices can be deployed over a large area to gather data. Algorithms that are used at the server side can analyze those data and provide monitoring results or even decisions to support control activities by users. Most of the existing solutions are addressing data analytic as well as control and monitoring issues to enable it. Hence, in this section, we review the existing solution to those issues.

Farming is one of many fields where IoT is utilized. Work in Ryu et al. (2015) proposed architecture of multiple connected farms. Each farm was monitored and controlled remotely in a centralized manner.

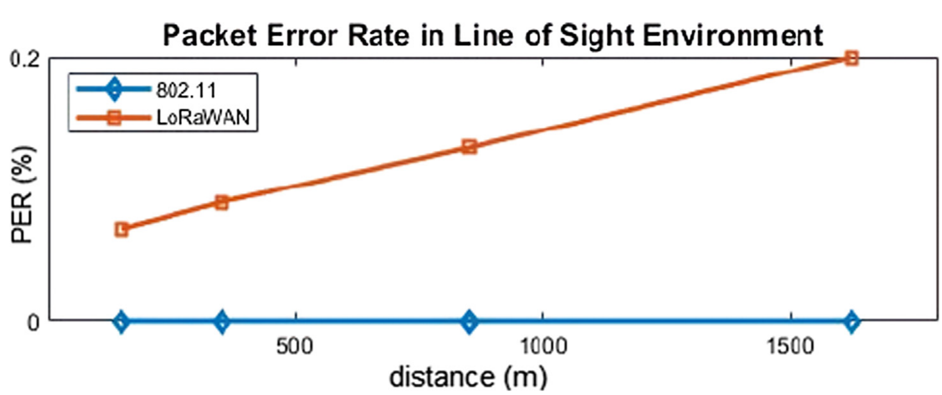

Fig. 2. Packet error rate of los protocol.

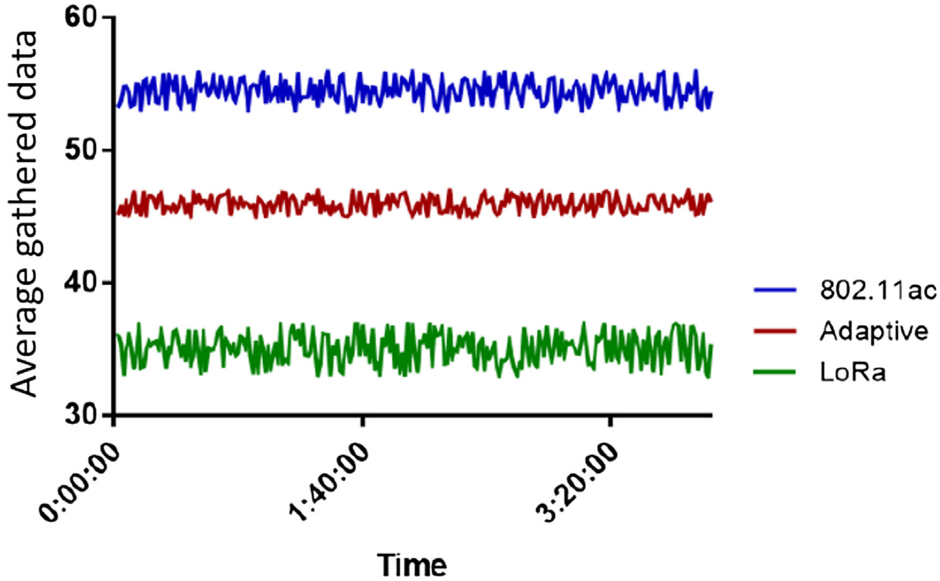

Fig. 10. Average sensors' data of each mode.

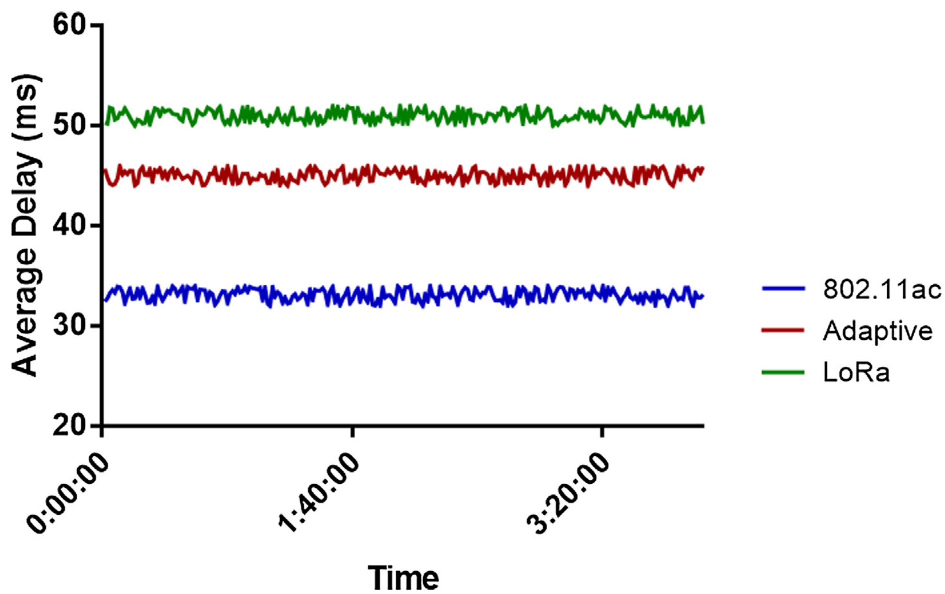

Fig. 11. Average delay of each mode.

Hence, all of the data can be stored in either server or cloud for further data analytic process. Moreover, the recent computing paradigms such as edge computing (Yu et al., 2018) and fog computing (Mouradian et al., 2018) can be considered to optimize the process of data analytics. The implementation of machine learning to assist data analytics can also be realized by combining these recent computing paradigms into the smart farm.

In our paper, we proposed an adaptive network mechanism for the smart farm that can adaptively change the communication protocol between IEEE 802.11ac and LoRaWAN depending on the situation. While wireless local area network protocol (WLAN) such as IEEE 802.11 has relatively high data rate, which allows it to carry large-sized data such as video file transmission in Yang et al. (2018), it is also prone to network failure at specific environments, such as the agricultural environment. Work in JiHye et al. (2017) gives possible causes of Wi-Fi network failure, such as high humidity that resulted in a decrease of signal intensity, or multiple layers of plants between devices significantly reduce the received signal strength. On the other hand, LoRaWAN has high interference immunity, even though the data rate is much smaller than IEEE 802.11ac network protocol (Sinha et al., 2017; Mekki et al., 2019). The proposed system in our paper will only transmit sensor data and video files when the IEEE 802.11 network protocol is in good quality. When the IEEE 802.11ac network protocol appears to be failing, the system will switch to LoRaWAN to transmit only the sensor data.

3. Performance comparison of candidates for the reliable smart farm system

Choosing a suitable network for reliable smart farm system is essential during the development stage. The network plays a crucial role in providing the connections between sensor nodes and server platforms. Considering several factors of the farm environment, we choose two network protocols to evaluate: LoRawan and IEEE 802.11 ac. LoRaWAN offers long-range communication with low energy during the operations. However, IEEE 802.11ac has better data rate than LoRaWAN. In this section, we provide an extensive performance comparison of LoRaWAN and IEEE 802.11ac. We conducted the experimental studies at the farming site at Cheonan, Korea. Fig. 1 depicts the greenhouse condition for our measurement test.

To estimate the suitability, we begin the test in line of sight (LoS) and non-LoS (nLoS) conditions. Then, we conducted two measurement tests in the indoor and outdoor of the greenhouse. We evaluated the performance in terms of delay and coverage of the network. Precisely, performance evaluation of LoRaWAN is measured based on receive strength signal interference (RSSI) level. On the other hand, IEEE 802.11ac is evaluated based on the delay metrics. Moreover, we used sensor data generated from DHT22 sensors for the packet data in this measurement test. As for the video data, we used webcam camera and the detail information of the video packet data is provided in Table 2.

3.1. Line of sight and non-line of sight measurement test

As mentioned above, we conduct a measurement test of both protocol in LoS and nLoS conditions. First, network performance is measured in the LoS condition. Both of the protocols are tested within 50 m to 1500 m in the distance respectively. Besides, the measurement is conducted by sending sensor reading data from each node to the gateway. As depicted in Fig. 2, the packet error rate (PER) of IEEE 802.11ac is lower than LoRaWAN in the case where there is no significant interference in the area of measurement. On the other hand, the PER of LoRaWAN is higher than IEEE 802.11ac. Both of the protocols are also tested in the area where there are significant interferences. Contrary to the LoS condition, both protocols in nLoS conditions are tested until 95 m as illustrated in Fig. 3. This is because of IEEE 802.11ac protocol only able to send the data up to 95 m. Thus, we conclude that the network performances of IEEE 802.11ac is close to the ideal when it is deployed in LoS conditions. However, LoRaWAN protocols can bring robustness and reliability in terms of sending sensor data of the farm condition.

Furthermore, we conduct a test for measuring the path loss for LoRaWAN in the nLoS condition. Then, we compare the result of path loss from measurement test with the theoretical results. In wireless channels, path loss refers to the power loss along the path between transmitter and receiver. Different propagation models for different situations considering different parameters have been discussed in the literature to predict the path loss (Rappaport, 2001; Goldhirsh and Vogel, 1998). The path loss between transmitter and receiver can be measured using the following equation:

$$PL_{measured} = P_t - P_r + G_t + G_r, \tag{1}$$

where P_t is the transmitted power, P_r is the received power, G_t is the transmitter gain, and G_r is the receiver gain. The value of both G_t and G_r are 4.5 dB.

The radio propagation environment between transmitter and receiver of this work is urban and includes mountains and trees. The propagation environment involves many buildings. For this reason, a Log- Distance path loss (Rappaport, 2001; Goldhirsh and Vogel, 1998) is used as an empirical model to compute the theoretical path loss by using the following equation:

$$PL_{measured} = PL_0 + 10\gamma log(\frac{r}{r_0}) + \sigma_f, \tag{2}$$

where PL_0 is the path loss at a reference distance r_0, γ is the path loss exponent, r is the distance between transmitter and receiver, and σ_f is the standard deviation due to shadow fading. Fig. 4 shows the measured and expected path loss during experimental time.

3.2. Indoor measurement test

Next, an indoor measurement test in a greenhouse was conducted to analyze the performance of both protocols. The measurement test was carried out with three different scenarios: a vertical, horizontal, and diagonal test, illustrated in detail in Fig. 5. The purpose of conducting the measurement test in these three scenarios is to analyze the transmission capability of two protocols in regard of the various distances tested inside the greenhouse. The results show that the distance between LoRa node and the gateway affects the signal of RSSI. It thus affects the number of successful transmission when the RSSI signal is poor. This can be observed from the Fig. 5 where the RSSI signal is deteriorated along with the increasing distance between LoRa node and the gateway. When the distance is at 50 m the average of RSSI signal is around −73 dBm which can be categorized as fairly reasonable signal. On the contrary, when the distance is at 100 m the RSSI signal reaches −90 dBm which can be categorized as a poor signal. Similarly with the LoRaWAN, as shown in Fig. 5, the distance between node and gateway also affects the delay network of IEEE 802.11ac. During the measurement test, IEEE 802.11ac requires another hop to cover the distance of 108 m inside of the greenhouse. This addition is necessary because there are many interference factors (i.e., tomato plants) inside of the greenhouse.

3.3. Outdoor measurement test

In the case of outdoor measurement test, we deployed the LoRaWAN node in the different particular distance outside of greenhouse while the gateway is placed inside of the greenhouse. Then, the RSSI signal is analyzed by continuously transmitting sensor data to the gateway within four hours. Fig. 6 depicts our testing scenario for the outdoor measurement test.

The results in Fig. 6 show that the lowest average RSSI value is obtained from the distance of 649 m. This is happened due to the interference factors (e.g., car and truck) that appeared during the test. Thus, the connection between LoRaWAN node and gateway got interfered. However, LoRaWAN's still able to achieve good RSSI value within the distance up to 1500 m from the gateway. From this test, the condition of the location should take into account to make the optimal placement of data center. We also tested the performance of IEEE 802.11ac protocol at outdoor of the greenhouse. As shown in Fig. 6, IEEE 802.11ac protocol is only capable to transmit the data up to 508 m even with the help of two additional hops.

4. Proposed solution for reliable smart farm system

4.1. Smart farm adaptive system

In this paper, the adaptive network mechanism is proposed to bring reliable communication for the smart farm system. The details topology is presented in Fig. 7. The adaptive network uses two different protocols: IEEE 802.11ac and LoRAWAN protocol. For the IEEE 802.11ac protocol, video bridge devices, raspberry pi, and webcam are used. As for LoRaWAN protocol, LoRa nodes and gateway, as well as raspberry pi, are used. As shown in Fig. 8, we implement the adaptive system in the application layer of the Operation System Interactions (OSI) model. Another layer is possible to apply the adaptive system such as medium access control (MAC) layer. However, this option is difficult to realize because it requires two compatible technologies that have to respect regarding standards and MAC layer concurrently (Gonzalez et al., 2016).

In the proposed system, initially, the system uses the IEEE 802.11ac protocol to transmits the sensors' reading data and video data. However, the system will shift to LoRaWAN protocol when any problem occurs during the transmission. Therefore, the sensor data can still be gathered in a real-time manner. This is because reliable communication is essential in farming so that the farmer is always able to monitor the plants' condition. Therefore, even though there is a fault during transmission, each node can send sensors' data to the server directly via LoRaWAN.

As depicted in Fig. 9, the system will check the failure counter within 10 min. In one hand, the counter will be incremented by one if there were any errors occurred until it reached the threshold. If the counter failure is reached more than the threshold value within 10 min, the system will change the protocol to LoRAWAN to maintain the data transmission. However, the video data cannot be transmitted when the system shifted to the LoRAWAN protocol due to the limited data rate of the protocol. On the other hand, when the transmission is successful, the sensor data will be stored in the server and also the raspberry pi will store the information on its log.

5. Performance evaluation

We evaluated the proposed system by deploying it at the farming site area for four hours to gather the data. Note that we only use sensor data to evaluate it without analyzing the QoS of video streaming. Then, a log file which contains a record of every successful transmission is used to analyze the performance of proposed system.

As shown in Fig. 10, LoRaWAN mode achieves the lowest average of gathered data. On the contrary, the highest average gathered data is obtained when the system is operated under 802.11ac mode. These differences are obtained because IEEE 802.11ac has higher data rate than LoRaWAN protocol. Hence, it can gather more data from the monitoring nodes. However, the adaptive mechanism makes the system more robust and reliable during the experimental test. This is because adaptive mode can make the system to change its network protocol adaptively based on the situations. For instance, if the initial protocol in which IEEE 802.11ac is not able to transmit the data due to the interference, then the system will switch its protocol to LoRaWAN adaptively.

Another factor that we evaluated during the test is the delay performance of the proposed system. As depicted in Fig. 11, the proposed system while operated under LoRaWAN mode obtains the lowest average delay. As mentioned above, LoRaWAN is more robust compared to the IEEE 802.11ac. However, the user cannot provide video streaming service under this operation due to the low data rate of LoRaWAN protocol. As for the solution, adaptive mode brings an adequate network performance to the system even though the average delay is not as low as LoRaWAN. Also, adaptive mode can provide video streaming service once the IEEE 802.11ac network become stable.

6. Conclusion

In this paper, an adaptive mechanism for reliable smart farm is proposed. The proposed system uses LoRaWAN and IEEE 802.11ac as the network protocols. The LoRaWAN protocol is responsible for sending the sensor data, which has a small data size with low energy. The IEEE 802.11ac protocol, which has a higher data rate than LoRaWAN, is responsible for sending video data. An adaptive mechanism combines both of those advantages and creates a reliable monitoring system that could maintain the network performance compared to a single protocol mechanism. Moreover, the extensive measurement test is conducted to analyze the performance of LoRaWAN and IEEE 802.11ac protocols to achieve a reliable network for a smart farm.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.compag.2020.105287.

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Article

Environment Monitoring of Rose Crops Greenhouse Based on Autonomous Vehicles with a WSN and Data Analysis

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Abstract: This work presents a monitoring system for the environmental conditions of rose flower-cultivation in greenhouses. Its main objective is to improve the quality of the crops while regulating the production time. To this end, a system consisting of autonomous quadruped vehicles connected with a wireless sensor network (WSN) is developed, which supports the decision-making on type of action to be carried out in a greenhouse to maintain the appropriate environmental conditions for rose cultivation. A data analysis process was carried out, aimed at designing an in-situ intelligent system able to make proper decisions regarding the cultivation process. This process involves stages for balancing data, prototype selection, and supervised classification. The proposed system produces a significant reduction of data in the training set obtained by the WSN while reaching a high classification performance in real conditions—amounting to 90% and 97.5%, respectively. As a remarkable outcome, it is also provided an approach to ensure correct planning and selection of routes for the autonomous vehicle through the global positioning system.

Keywords: ambient intelligence; autonomous vehicles; monitoring systems; roses crops; wireless sensor networks

1. Introduction

Rose cultivation has a great impact on the economy of Ecuador, as theses flowers are exported and cover 9% of the world's market. Rose cultivation brings approximately 500 million dollars to the national budget and covers 8000 hectares in the country [1]. With the growing demand for flower farming production, a natural environment is not always the optimum to achieve the necessary crop requirements. Extreme conditions such as direct sun exposure, hail, diseases, and pests can seriously affect the quality of the product and the volume of production [2]. For this reason, large-scale greenhouses are becoming increasingly more popular, because they can modify the environmental conditions of the interior by means of lights, ventilation, heating, among others. Thus, crop production cycles can be planned based on market needs [3,4].

Additionally, floriculture production must be carried out in an efficient and sustainable manner, causing the least negative impact on the environment. Bearing this in mind, the use of technology allows for innovating processes and decisions based on previously collected information. In this manner, the use of agricultural resources and supplies can be improved. However, the process of data acquisition requires great effort, especially when it comes to the implementation of connections and the distribution of sensors [5]. In some cases, these systems are made using cables and can be complex and expensive. Furthermore, it should be possible to modify the location of the points of measurement according to the particular needs of the crop. Due to their easy implementation and increased mobility, wireless sensor networks (WSN) are an alternative in this respect. A WSN is made up of nodes that have the ability to acquire data and send such data by means of wireless protocols [6,7]. Likewise, WSNs are low-cost, low current-consumption systems, and allow for different types of networks and more flexibility in the exchange of information. As a result, they are efficient electronic systems that can cover large growing spaces. Within the greenhouses, it is necessary to use several WSN nodes that help get reliable data to represent the state of the plant and the preventive actions that can be taken to improve production [5,8]. In addition, the implementation of autonomous-vehicles allows for the mobility of the WSN node, as they can select routes and avoid obstacles [9]. Next, the WSN node will be able to collect data from the entire crop and by means of a GPS module, store said information at its respective location. As a result, a robust data analysis methodology can be implemented that can be compiled in each WSN node in order to make decisions, learn from external stimuli, and adapt to changes [10,11].

The parameters needed for the proper development of rose plants are relative humidity, temperature, electrical conductivity, precipitation, CO_2, and light intensity [12]. In many cases, these are not taken into account in the implementation of irrigation systems. In fact, the systems are generally based on timers or criteria based on the experiences of the people in charge of the production of roses [13]. Due to this, the ground within a greenhouse does not have homogeneous conditions[14]. Consequently, rose plants may modify their functional cycle, and obtain buds in very early stages, which are vulnerable to the use of fungicides with humid and foliar acids. Therefore, in some cases, the harvest time of the plant is modified and causes delays during the seasons of greater commercialization [15].

The proposed system is made up of a WSN implemented on quadruped autonomous vehicle moving inside a greenhouse. Firstly, the WSN has a set of sensors that monitors relative humidity, CO_2, room temperature, light quantity, and soil moisture. This is done in such a manner that the entire data analysis process can be incorporated and executed within each WSN node with a low consumption of computational resources. Secondly, the quadruped vehicle is designed to avoid collisions and be able to move in the greenhouse through the global positioning system (GPS). For this, there are established points within the greenhouse considered as arrival objectives. As a result of this system, there is a 90% reduction in the training data matrix acquired during the entire rose growing cycle for the classification algorithm training, which obtained a performance of 98% under simulated conditions and 97.5% in actual operation.

The rest of the document is structured as follows: Section 2 shows related works. Section 3 presents the system's design. Section 4 shows the data analysis proposal for the implementation of machine learning algorithms. The tests and results are shown in Section 5. Finally, Section 6 highlights the most relevant conclusions and future works.

2. Related Works

Typically, roses meant for export are cultivated by means of precision agriculture, which includes the following stages: (i) data collection, (ii) processing, (iii) data analysis, and (iv) decision making. In chronological form, they are presented to the most relevant in the different years. Salleh et al. [2] presents a WSN for monitoring environmental conditions in greenhouses (2013). The nodes of the WSN have solar cells and Zigbee modules for communication. Their results focus on optimizing system resources to extend the system battery. On the other hand, in the same year, Pekosawski et al. [5] present a similar application of WSN but with the objective of analyzing gases such as CO, CO_2,

3.1. Sensor Network Design

The environmental parameters within a greenhouse for a rose plant are temperature, luminosity, ground humidity, relative humidity, and CO_2. Each of them influences the proper growth of the rose [21]. Consequently, if the temperature is lowered below the recommended value, this can cause irregularities in the rose blossom; if it is higher, the flowers increase in number, but their quality is affected. In addition, light intensity, relative humidity, and CO_2 directly influence the photosynthetic process. Likewise, ground humidity defines the amount of water contained in unit volume of soil. If its value is not adequate, there is less chance of increasing evapotranspiration (loss of water due to heat and crop perspiration) [22,23]. The optimal values for environment variables are: room temperature 17 °C–28 °C, light intensity 440 lx–680 lx, ground humidity 55%–65%, relative humidity 70%–80%, and CO_2 800 ppm–900 ppm [23].

For the adequate development of the WSN, the selection of the sensors must be done based on strictly-defined operating requirements. Among the main ones that were taken into account are reliability, precision, availability, ease of use, and scalability. In addition, for the selection of the WSN processor system, wireless connectivity and the protocol used were considered [14]. As a result, the sensors chosen were: `DHT 22` (relative humidity and temperature), `MQ 135` (CO_2), `YL 69` (soil humidity), `BH 1750` (luminosity). Finally, the `NodeMCu` was selected as a processor for its communication to WiFi networks. This way, data can be flexibly sent within an AD-HOC network created by the same devices, a greenhouse network, or stored in the cloud. As additional elements, an analog–digital multiplexer/converter (8 channels multiplexed at 1 output) is required in order to be able to read several sensors. This is because the `NodeMCu` only has a digital–analog converter. Additionally, a bipolar junction transistor (BJT-NPN) that works in cut and saturation is used to activate the sensors. For the power supply of the system, there is an LiPo type battery with a self-charging system that works by means of a battery manager and solar panels. Based on the datasheets of each of the electronic elements used, there is an approximate total consumption of 260 milliamps. The battery manager used is `Lio Rider` which supplies power from a solar panel until it reaches 400 milliamps. If this value is not enough, the battery can also get charged via USB-port.

3.2. Quadruped Vehicle Design

There is a wide variety of methodologies for the uniform sampling of crops. In relation to the proposed system, a grid-shaped path is defined, since it is effective with rose crops planted in a greenhouse and the vehicle can function properly [24].

The quadruped vehicle uses open hardware of the mePed version [25]. Its files of dimensions and cut-off points are free to modify in size and usability. In this case, the scale was increased 2.25 to have servo motors of greater force (8 in total). In addition, for route planning, it has a `Neo 6m` (GPS) module for its location, an `MPU-6050` sensor (accelerometer) to determine its orientation, a 3000-milliamperes LiPo battery, and an `ArduinoUno` as a processor. The armed vehicle used for testing is shown in Figure 2.

For notation purposes, henceforth the term "marks" is used to refer to the vehicle's turn, while "sub-marks" accounts for sampling. Inside of the greenhouse, the vehicle operation can be divided into two stages. The first stage is the movement and location of marks and sub-marks. Each of them is marked with their coordinates where the vehicle must arrive.

To achieve this, we use the active potential field, which means that an action vector is defined to direct towards the desired mark. This criterion has two imaginary fields (attractive potential and repulsive potential). The result is a simple real-time route planning approach. The action vector is found by applying a scalar based on the potential field to the position of the vehicle and then the gradient of that function [9]. Figure 3 shows attractive potential field action vectors pointing to the goal and theirs Equations (1) and (2).

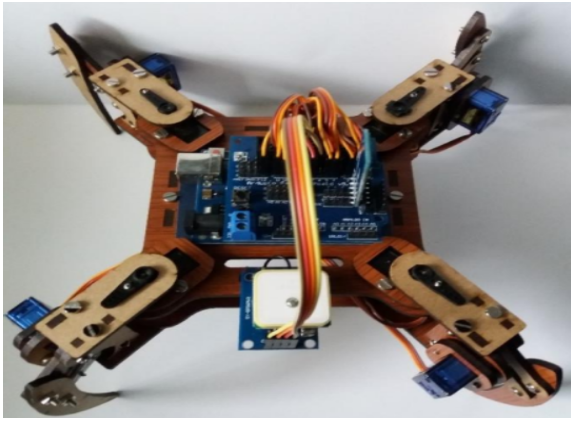

Figure 2. Quadruped vehicle in charge of collecting the greenhouse information.

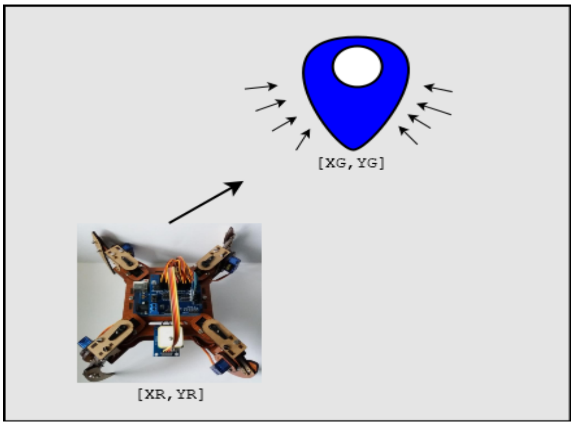

Figure 3. Potential field action vectors, white circle (goal), and blue region (potential field).

For the following statements, the following notation is considered: $[X_G, Y_G]$ as the position of the goal, r as the radius of the goal, $[X_R, Y_R]$ as the position of the vehicle, s as the size of the goal's area of influence, and α as the strength of the attractive field $(\alpha > 0)$. In this context, $[\nabla x, \nabla y]$ are the coordinates of the autonomous vehicle's movements.

The distance d from the mark to the autonomous vehicle is:

$$d = \left[(X_G - X_R)^2 + (Y_G - Y_R)^2\right]^{\frac{1}{2}}, \tag{1}$$

while the angle θ in between the two, is given by:

$$\theta = tan^1 \left(\frac{Y_G - Y_R}{X_G - X_R}\right). \tag{2}$$

As a result, the following planning rules are feasible:

- If $d < r$, then $\nabla x = \nabla y = 0$.
- If $r \leq d \leq s + r$, then $\nabla x = \alpha(d - r)\cos(\theta)$ and $\nabla y = \alpha(d - r)\sin(\theta)$.
- If $d > s + r$, then $\nabla x = \alpha s \cos(\theta)$ and $\nabla y = \alpha s \sin(\theta)$

The second stage is soil moisture acquisition, which is carried out by the proper sensor. To do this, the vehicle reaches every sub marks, the sensor located below the chassis can be inserted with the weight of the vehicle itself. Subsequently, the system sends an activation flag to the WSN to acquire place. Subsequently, this data passes through the CNN algorithm, which verifies the valid information that can improve the training matrix. If the algorithm decides so, it is stored in the matrix **Z**; otherwise, only the sending process is performed.

Consequently, we set specific times for the compliance of routes and battery saving modes in the sensors used. As a result, the quadruped performs 4 routes a day (morning, afternoon, night, and early morning), and each route takes approximately 1 h. In addition, given its energy-saving modes, the WSN was activated only when the vehicle sent a warning about a mark that it found. For this reason, the system as a whole can operate continuously for a duration of 3 days for the quadruped and 9 days for the WSN. By having the 3 nodes working simultaneously, these vehicles can cover between 80 to 100 square meters of crops daily. The operation of the autonomous vehicle in the greenhouse is shown in Figure 10.

Figure 10. Autonomous system with WSN.

As a second point, it is the correct decision of the system and its assessment with respect to the chosen action by experts (people holding practical expertise and background on crops and environmental measurement equipment). These tests were performed to define the correct action of the system in the different locations of the greenhouse. Forty functioning tests were performed to assess the decision-making capacity of the system. The system had 97.5% success in the actions taken inside the greenhouse. As a result, roses have higher stem growth and better leafiness in cultivation. In terms of return on investment, the implementation of this system had an initial margin of increasing 5% the net profit from the crop. This is related to the lower consumption of water (15% percent), less use of pesticides (8% percent), and the result of the sale of roses (3%). It should be noted that from an economic point of view, the implementation of autonomous vehicles is well below the cost of other monitoring systems within the Ecuador–Colombia market. In addition, it was possible to verify that the greenhouses do not have homogeneous environmental conditions, there are certain sectors that due to their location in relation to the sun or distribution of the irrigation system have certain moisture deficiencies that cause less amount of CO_2 for the photosynthetic process of the plant.

Regarding the movement of the quadruped, the error in reaching each established mark has a variability of 0.35 mrts. This is due to slight variations in the collecting of GPS data related to the turn towards the other marks in the rose growing-beds. The turning angle had an error of 2 degrees in total. However, this problem is corrected by searching for the next mark inside the greenhouse.

6. Conclusions and Future Work

Related to the selection of the sensors in conjunction with the autonomous vehicle, they provided adequate operation by meeting the established marks and sub-marks inside the greenhouse. With this, the data acquisition process provided information about the crop for the implementation of the data analysis stage. This is thanks to filtering reading errors by means of data smoothing.

The WSN with autonomous quadruped vehicles fulfills the objective of providing information on the cultivation of roses by sectors within the greenhouse. Consequently, the planned scheme for data analysis was adequate, since it allowed a significant reduction of redundant data and computationally lightweight classification algorithms that can be implemented in WSN nodes with limited resources. In addition, it allows for the collection of a large amount of information that can be useful for years to come, helping farmers modify their techniques with respect to climate change.

With the autonomous vehicle, it was possible to properly arrange the growing cycles of roses. In this way, we propose a new approach to the design and construction of greenhouses, which allows for the flexibility that the crop needs (fans and floodgates in different locations, not centralized). This way, a more extensive analysis can be made with regard to change of environmental parameters in order to find optimal growth values and improve product quality.

As far as future work is concerned, we recommend exploring the use of batteries, their charge, and weight, thus ensuring better design and movement. In addition, it should be noted that the quadruped could be mobilized on irregular ground, but it had balance issues and struggled depending on the distance from the planned route. With this in mind, we suggest using other mechanisms as tank chassis.

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