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Design and implementation of an IoT-based automated monitoring and control system of an aeroponic greenhouse

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Abstract

Nowadays modern agriculture is plagued by several challenges. Global climate changes, rapid population growth, the reduction of the labor force, as well as the energy crisis, pose vast challenges to the agricultural sector. However, taking into consideration the latest advances in digital technologies, including Information and Communication Technologies (ICT), under the framework of industry 4.0 it has become apparent that the development of Precision Agriculture could facilitate in overcoming the global challenges, as well as to facilitate the global community in achieving the Sustainable Development Goals (SDG) as they have been announced by the United Nations (UN), heading towards Industry 5.0 and Society 5.0. Further to that, the adoption of Precision Agriculture practices could significantly aid the agricultural sector to overcome these barriers and enhance its resilience. Therefore, in the research work the automated aeroponic plant growing system based on the integration of Internet of Things (IoT), for monitoring, analyzing data, and adjusting the operational parameters of a smart greenhouse is presented. Concretely parameters such as moisture content in the roots, acidity level, temperature are among other the key parameters controlled in near-real time and provide to the farmers a useful tool for the optimization of crop yields. The proposed architecture is applied in a greenhouse connected to the cloud.

1. Introduction

Many research studies have suggested that the challenges of modern agriculture could be overcome by adopting precision farming methods [1-4]. Currently, many countries are increasing their productivity in the agricultural sector by applying precision farming methods. Taking into consideration the emerging trends around consumption (such as the shift in food pyramids – increasing uptake of proteins, growing salience of food safety, need for traceability, and localization opportunities), new opportunities in the private sector players across the value chain are emerging [5]. More specifically, focus on expanding their product portfolio with a nutritional focus, deepen links with producers, and improve efficiency. The recent advances in technologies and methods will pose the key enablers across the entirety of the value chain members with various emerging use cases [6]. Moreover, the government can play a key supporting role across the agribusiness ecosystem by providing incentives and policy support. One of the most important challenges the global society has to face is the increasing number of the global population. In Figure 1 the increasing trend of the global population is presented, in particular within the next three (3) decades, it is estimated that an increase of approximately two (2) billions is expected.

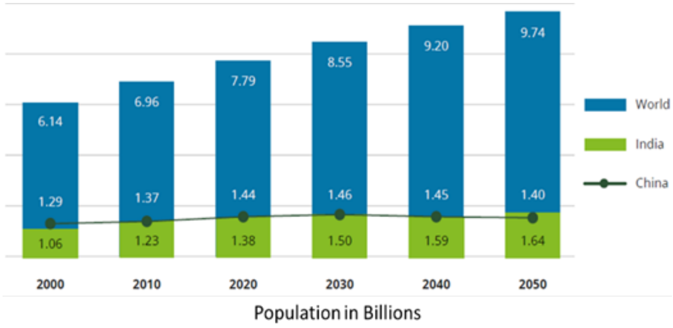

Figure 1: World population projection per decade, values beyond 2020 are forecast

Having identified the challenges and opportunities related to the integration of aeroponics in modern agriculture, the contribution of this research work is focused on the design and development of an architecture based on the utilization of IoT devices, Edge computing and low power wireless networks for the monitoring and optimization of an aeroponic greenhouse. In the present work, into a new automated greenhouse, as experimental system we installed and developed our earlier aeroponic system, the «Automated Aeroponic Plant Growing System».

The rest of the manuscript is structured as follows. In Section 2, the most pertinent literature is investigated. Then in Section 3 the requirements for an aeroponics installation are presented and discussed. Then in Section 4, the proposed system architecture is presented and discussed. Then in Section 5 the case study of a real-life greenhouse is presented. Then in Section 6, the implementation steps are discussed. In Section 7, the presented research work is concluded, and an outlook is provided. In this study we determine the feasibility of the intelligent sensors, for the measurement of climatic conditions in the external and internal greenhouse environment, irrigation and crop yields, in order to provide favorable conditions for crop growth in aeroponic systems with IoT-based technologies. Considered variables for our proposal are temperature and relative humidity, photosynthetic active radiation(PAR), temperature, pH and EC in the nutrient solution tanks, controlling parameters of root atmosphere temperature, and irrigation time.

2. State-of-the-Art

Technological innovations are reshaping the way modern farming is done. With the Internet of Things (IoT), Artificial Intelligence (AI) and Robotics, it is now possible to automate agricultural systems in order to strengthen their weak points [7- 10]. Some of the key challenges and opportunities for Smart Agriculture can be summarized as follows [11]:

1. Increase yield: Increase production per square meter by automatically controlling environmental factors to optimize growth.

2. Improving sustainability: Information and sensors allow farmers to conveniently monitor and manage real-time animal and land welfare.
3. Relieve work stress: Autonomous machines and remote monitoring can support routine inspections and harvesting to relieve labor-intensive tasks.
4. At the beginning of its development, the IoT in the agricultural sector mainly focused on the implementation of a single entity, which led to the scalability and interoperability of the whole system, gradually failing to meet the increasing demand of agricultural production. In the subsequent years, a new hierarchical structure model of IoT for the agricultural sector was proposed, based on the special needs of agricultural production and marketing, combined with the principles of security, reuse and extension of IoT systems as well as the practical experience gained during the last years.
5. As shown in Fig. 2, the model is divided into three layers from top to bottom, including i) detection layer, ii) transport layer, iii) application layer, etc. Data are transmitted between different layers using unique communication protocols.
6. The sensing layer consists of various sensors, mainly based on the utilization of Wi-Fi, GPRS and ZigBee technologies for data transmission. The main purpose of the sensing layer is the transmission of the collected data to the access layer of the IoT system structure. The access layer consists mainly of hardware gateways and embedded middleware. The middleware can effectively shield the complexity of the underlying heterogeneous sensing network and provide a unified management interface, providing the foundation for the rapid creation of agribusiness IoT applications.

In addition to the technologies and techniques examined so far, another promising technology, the so-called Edge Computing, has emerged in the last decade. A systematic literature review by [12] reveals the basic concepts involved in fog and edge computation. The framework of Edge Computing comes from the increasing computing power of mobile devices. The concept of Edge Computing focuses on harnessing the computing power of smart devices, following the concept of decentralization, in order to eventually offload the main computing systems, such as Cloud servers, etc. Edge computing involves fewer processes running in the Cloud. It also moves these computing processes to edge devices, such as IoT devices, edge servers, or user computers. This way of bringing computation closer to the edge of the network reduces long-distance communication between server and client, therefore reducing bandwidth usage and latency. In their research paper, [13] have proposed an adaptive framework for sequential offloading of mobile networks, achieving excellent efficiency and scalability as the Edge network expands. Similarly, in the literature review of [14], where Edge Computing architectures have been investigated, one of the authors' main conclusions is that the combination of Edge Computing with Artificial Intelligence techniques, such as Reinforcement Learning, is a powerful tool, capable to deal with the increased complexity of real-world systems. Miori et al. in 2017 [15] have based their research on integrating Raspberry Pi single board computers to create an Edge network/cluster. Although the experimental results were not promising relative to a common laptop computer, it is concluded that there is still further room for performance improvement for such devices. In the interesting literature review presented by Chen et al. in [16], it becomes clear that the development of Mobile Edge Computing frameworks is necessary for society, due to the increased volume of data generated by connected devices and the need for data processing. The main goal of the Fourth Industrial Revolution (Industry 4.0) is to increase efficiency by incorporating the features of cutting-edge technologies in all processes, as well as to provide a better understanding of production processes in all their production facilities in near real time. The deployment of 5G has raised expectations that it will open up new opportunities for building business models, given the expected increase in data requirements ranging from mission-critical to massive machine connectivity [17]. As shown in Table 1, 5G promises faster download speeds, lower latency and increased capacity.

Figure 2: High-level architecture for smart agriculture

Network Type	Average Download Speeds	Peak Download Speeds	Theoretical Download Speeds	Milliseconds (ms)
3G	8 Mbps	~20 Mbps	42 Mbps	60 ms (Typical)
4G	32.5 Mbps	90+ Mbps	300 Mbps	50 ms (Typical)
5G	130–240 Mbps	599+ Mbps	10-50 Gbps	1 Ms (Theoretical)

Table 1 Comparison of 3G, 4G, and 5G latency times and data speeds

3. State of the art in aeroponics-Aeroponics system requirements

Unlike field crops, which have been the main source of crops so far and can be grown with little attention for extended periods of time, hydroponic crops require daily management, and the yield results will be better, both in terms of quality and quantity, if specific environmental variables are precisely adjusted to the specific needs of the crop [18-24]. Consequently, variables such as temperature, pH, light intensity, daily light integral (DLI), electrical conductivity (EC) and nutrient composition are of great importance [25]. For example plants such as basil prefer warm temperatures, a moderately acidic pH [26], relatively low EC levels and respond well to high light levels. Specific requirements may vary, however, depending on the growing system adopted, the time of the year, and other factors. Consequently, ideal conditions for hydroponic basil can be summarized to the following:

- Temperature: 65–70°F (18–21°C). pH: 5.8–6.2 (slightly higher in hydroponic and organic systems).
- Light: At least 14 hours a day.
- DLI (Daily Light Integral): Minimum 12 mol per m2 per day or higher. basil performs well with high light levels.
- EC (Electrical Conductivity): 1.0–1.4 mS/cm, depending
  on the season. during winter, crops need higher EC than in summer.

- Nutrient Solution: Choose a solution specific to herbs and leafy greens and suitable for your water type and follow package directions to achieve the EC level listed above.

In the present work we developed an automated greenhouse, and we installed our earlier aeroponic system, the «Automated Aeroponic Plant Growing System». (PCT/GR2013/000069). Earlier experiments were conducted at the aeroponic farm of the TEI of western Greece with this «Automated Aeroponic Plant Growing System», a unique fully automated cutting edge aeroponic farming technique, to produce massive vegetable crops and fruits yields. The results showed that lettuce, basil and tomato plants cultivated aeroponically gave significantly higher yields in comparison with hydroponics, with limiting water and nutrient consumption. The ideal conditions of absorption of oxygen, water and nutritious elements by the roots, resulted in more rapid growth and maturation rates of the plants, bigger density of planting and highest total yields. Moreover, high nutrition quality characteristics of the products were determined, suggesting that aeroponic plant growing method produces organic nutritious and healthy foods [27]. We also have investigated the impact of the available root-zone volume on the yield and nutritional quality of sweet basil plants grown aeroponically [25].

The inclusion of the Internet of Things (IoT) in greenhouses has become a fundamental tool for improving cultivation systems, offering information relevant to the greenhouse manager for decision making in search of optimum yield. In addition, the IoT architecture represents a potential tool for the study of aeroponic farming systems through IoT-assisted monitoring. The aeroponics is an effective and efficient process for farming to growing plants in a closed or open area without using any type of soil. When we design an aeroponics system along with IoT technology, many improvements as likely to happen, such as increasing plant yield, minimum usage of water, growing workforce, and maximizing growth rate. In a recent work, the new automatic aeroponics system implemented by using sensors along with IoT networking technology [28]. In earlier works, considering the yield and the growth of plants in aeroponics, an efficient approach is provided for the accurate growth of plants with less water usage and minimum need of nutrients using machine learning based aeroponics technique with multiple input parameters like humidity, temperature, airflow, nutrients, carbon dioxide, and light intensity [29]. Another recent study describes the implementation of an automated aeroponic cultivation system for a green leaf lettuce culture, controlling parameters of temperature, humidity, and irrigation time, by misting nutrients to the plant roots. It is a low-cost Arduino-based system with an Internet of Things (IoT) tool for remote monitoring variables by connecting to a web server [30]. A monitoring system applied to an aeroponic greenhouse based on an IoT architecture that provides user information on the status of the climatic variables and the appearance of the crop in addition to managing the irrigation timing and the frequency of visual inspection using an application developed for Android mobile devices called Aeroponics Monitor, has been recently found [31]. In aeroponics systems, the root development process is crucial for the plant's growth performance. To optimize the plant's aerial parts in aeroponic culture, the appropriate value definition of irrigation water pressure, droplet size and fogging interval is needed to improve the continuous water and nutrient availability [32-34].

4. Proposed aeroponics IoT-based greenhouse monitoring Architecture

In this work, a smart greenhouse architecture is proposed in an attempt to constantly monitor and adjust the aeroponic growing parameters within the greenhouse equipment. Essentially, the greenhouse is considered as a closed-loop control system, which produces green products.

However, this system is subject to external disturbances, mainly caused by the climatological and weather changes. As such, it is imperative to adjust the system parameters quickly and sufficiently in order to ensure high quality of the products. It is stressed out that system monitoring and control is required throughout the plant growth process in order to ensure optimal parameters. In addition, it provides farmers with data on external environmental conditions and cultivation parameters, which limits the risk of pests and avoids the occurrence of diseases. The general system architecture, illustrating the individual modules, including the communication protocols and the information exchange are presented in Figure 3. As presented in Figure 3, the proposed system architecture consists of three (3) main layers, in particular i) the physical layer, ii) the communication layer, and iii) the application layer.

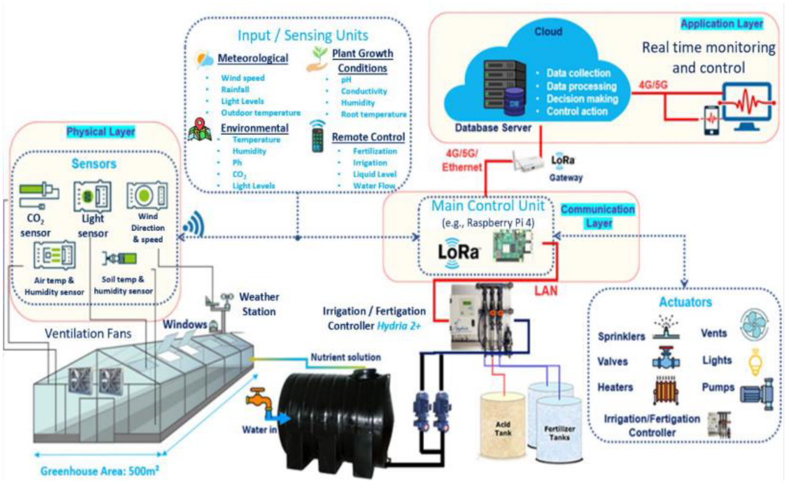

Figure 1: Proposed aeroponics greenhouse architecture

4.1 Physical Layer

The physical layer consists of the greenhouse installation (Figure 4), which includes the cultivation channels. The physical layer is also comprised by the sensor cluster. The sensor cluster includes a light sensor for calculating the light intensity, the photosynthetic active radiation (PAR). A wind direction and speed sensor are also integrated for tracking the wind patterns and therefore, to enable the farmer to adjust the vent openings (i.e., windows). The wind speed sensor determines the wind speed on the field surface. Concretely, in a field, it is necessary to observe weather phenomena and especially modifications in wind speed and direction.

Furthermore, an air temperature and humidity sensor are used for the air conditioning or ventilation fans control and monitoring the inner bioclimate plant growth conditions. By adopting this strategy, information fusion from the similar sensing systems is enabled and therefore more informative insights can be provided to the farmers.


Figure 4: Aeroponic cultivation system, cultivation channels

4.2 Communication Layer

The communication layer is the central point of the proposed IoT-based architecture since it is responsible for overseeing the entire greenhouse and subsequently to communicate the information to the farmers and control the various subsystems for the adjustment of the greenhouse parameters.

This layer is based on the setup of a Wireless Sensor Network (WSN). The implemented topology is the star topology. Concretely by adopting the above-mentioned topology, the Micro-Processor Unit (MPU) becomes the master device of the WSN, and the various sensors are the slaves of the network. Consequently, the sensors (i.e., the slaves) are only capable of communicating and sending data to the network's master. An instance of the WSN star topology is presented in Figure 5.

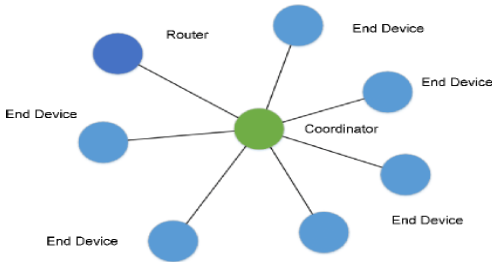

Figure 5: WSN star topology

Another functionality of the Communication layer is the transmission of commands to the subsystem that controls nutrient solution. More specifically, this subsystem consists of a smart controller that communicates with the MPU via a Local Area Network (LAN). Afterwards, the nutrient controller controls a series of electrical vanes that are responsible for regulating the flow of clean water, acidic solution, and fertilizer.

4.3 Application Layer

The third layer of the proposed architecture is the application layer, which can be realized as the Human-Machine Interface (HMI). More specifically, it entails a mobile and a stand-alone application as well as the accompanying Cloud services to support the handling of the data and communicate user commands to the greenhouse. For the applications a set of Graphical User Interfaces (GUI) are provisioned which enable the farmers visualize the current as well as historical data regarding the operation of the greenhouse. Furthermore, the application users through the GUIs are provided with additional functionalities for adjusting the greenhouse parameters in near-real time.

However, among the most important modules of the smart agriculture architecture are the Cloud services. With the assistance of the above-mentioned services, the data acquired from the field, i.e. the sensing system installed on/in the greenhouse, are stored, cleaned, and grouped appropriately in order to enable pattern recognition. For these purposes a Cloud Database is also necessary.

4.4 Types of Sensors Used

A rain sensor or rain switch is an actuating device that is activated by rainfall. Soil moisture sensors measure the volumetric water content of the soil. The available oxygen concentration for the root environment is an extremely important factor, as low concentrations affect root respiration, nutrient absorption and, consequently, plant growth. In the aeroponic system, plant productivity is closely related to nutrient uptake and pH regulation of the nutrient solution.

5. Case Study

In this Section the detailed presentation and discussion of an existing greenhouse used for the implementation of the developed IoT-based aeroponics framework is provided. Concretely, a 240 square meter greenhouse, constructed by multiple metal trusses without an intermediate post is used. The plot dimensions is 6.60 meters wide by 3.0 meters long. It consists of two (2) pyramids, each 6.60 m wide. This arrangement is adopted in order to facilitate the installation and efficient operation of any type of equipment and automation for climate control, as it has been discussed in the previous paragraphs. The metal frame is entirely made of hot-dip galvanized steel, quality S235. Similarly, the gutters are manufactured using galvanized grade Z275, 2.0 mm thick sheet metal. The general layout of the greenhouse is presented in Figure 6.

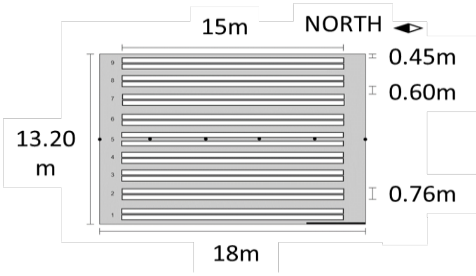

Figure 6: Layout of the aeroponics greenhouse, with visible cultivation channels

With regards to the cover of the greenhouse, polyethylene sheets have been installed on top of the metal construction, on the roof. The cover made of polyethylene sheets has the best elasticity properties than any other type of cover, thus enabling the whole structure to withstand great stresses caused by extreme weather conditions. Covering the roof of the greenhouse with new technology polyethylene sheet (PE) 8 layers, 180 microns thick, with a system to prevent the formation of moisture drops on the surface of the material presenting a special anti-drip and anti-fog property for their entire lifespan.

In order to cover the facades and sides of the greenhouse, polycarbonate sheets, 8 mm thick, with UV protection, which offer increased resistance to solar radiation as well as increased lifespan are recommended. Polycarbonate is the hardest type of plastic to date, with excellent mechanical properties and a lifespan in the range of ten up to twenty (10-20) years. Its light transmittance exceeds 90% and remains undiminished for at least 12 years.

The natural ventilation of the greenhouse is achieved with roof windows 1.80 m wide, in each pyramid which are electronically operated. For better air circulation and most importantly, in order to avoid humidity, axial fans were installed on the roof of the greenhouse. Furthermore, pest control is mandatory, thus protection nets have also been installed on the windows and on all opening parts, e.g. the greenhouse entrance, etc. The cooling system of the greenhouse comprises of a combination of a passive system and active system. More specifically, the passive system consists of a water evaporation panel. Similarly, the active system entails a dynamic ventilation for temperature reduction, and to ensure production quality as the temperature reduction goes down to 8ºC. The cooling and ventilation system is among the most important features of the greenhouse, thus requiring careful design. Therefore, cooling panels made of compressed special cellulosic paper, impregnated with special resins and additionally with anti-mold and anti-moisture components, which increase the service life have been integrated. In order to get the air close enough to the dew point, the thickness of the above-mentioned panels is between 150 up to 200mm (millimeters).

Side vents to give the required air changes (50-60 per hour) Cooling panels made of cellulose which is very easily wetted by water and leaves large air passages. Distributors made of special pressed paper for the correct distribution of water in the Panel as well as PVC pipes. You also need a 1000-liter plastic tank with a filling float and a submersible pump to recirculate the water.

There must be a thermostat with a maximum and minimum temperature set according to which the automation panel in the greenhouse gives orders to open or close the windows respectively.

There should be an air-heated greenhouse heating system, to exclude strong fluctuations in the temperature of the greenhouse. There should be a shading curtain consisting of shading fabric motor reducer middle support, push pull curtain mechanism is a modern one for better control of solar radiation and heating of the greenhouse. In this particular greenhouse, for the best security in case of power outages, due to the aeroponic cultivation system that will be tested, it is absolutely necessary to install a 12 kwa oil power generator.

Finally, the Greenhouse should have a complete meteorological station, for the automatic control of the climate of the greenhouse and all its individual systems.

6. Implementation

In the following paragraph the implementation steps for the realization of the proposed aeroponics architecture are presented and discussed. Concretely a sensor cluster has been created and distributed throughout the existing cultivation channels comprising the greenhouse. The sensor cluster is connected to a microprocessor unit (MPU) for the data acquisition. The MPU selected is a Raspberry Pi 4, and it was selected due to its connectivity capabilities. Further to that, additional equipment has also been used for the support of irrigation and fertilization processes. A Hydria 2+ fertigation system has been connected in series with the MPU via Local Area Network (LAN). As discussed in the previous paragraphs the fertigation system, is essentially a closed-loop control system that is capable of adjusting the Ph levels of the soil in the cultivation channels via the remote transmission of suitable acidic solutions, fertilizers, and water.

7. Conclusions and Outlook

The aim of this work was to present an automated aeroponic cultivation system based on the Internet of Things (IoT). Aeroponic cultivation is an innovative method of growing plants in modern agriculture. We designed and implemented an automated aeroponic cultivation system to collect data from each sensor in the system. A Raspberry Pi 4 was used, and we designed the system to measure and online monitor key parameters such as humidity, temperature, light intensity, humidity, ventilation, and CO2 (carbon dioxide) and control them in real time. The proposed system is a promising application that is expected to support farmers increase crop production assisted by a smart farming system. We believe that this work will contribute to the adoption of advanced monitoring technology with Internet of Things (IoT) devices in agricultural systems.

Taking into consideration the key findings of the presented research work and the implications future research work will be focused on the development of a cluster of smart greenhouses in order to automate the monitoring and control of multiple site simultaneously, from a central unit, minimizing the equipment required. In addition to that, the possibility to implement a federated learning framework will also be investigated in an attempt to enable edge computing as well as to enable engineers train more robust AI models based on the collective knowledge from the different greenhouses.

Acknowledgment

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References

[1] M. Pala, L. Mizenko, M. Mach, and T. Reed, “Aeroponic greenhouse as an autonomous system using intelligent space for agriculture robotics,” in Robot Intelligence Tech-nology and Applications 2. Advances in Intelligent Systems and Computing, vol 274, J. H. Kim, E. Matson, H. Myung,P.Xu, and F. Karray, Eds., pp. 83–93, Springer, Cham, 2014.

[2] H. S. Kim, E. M. Lee, M. A. Lee et al., “Production of high-quality potato plantlets by autotrophic culture for aeroponic systems,” Journal of the Korean Society for Horticultural Sci-ence, vol. 123, pp. 330–333, 1999.

[3] Kerns, Stephen C., and Joong-Lyul Lee. "Automated aeroponics system using IoT for smart farming." In 8th International Scientific Forum, ISF, pp. 7-8. 2017.

[4] M. W. Mbiyu, J. Muthoni, J. Kabira et al., “Use of aeroponics technique for potato (Solanum tuberosum) minitubers pro-duction in Kenya,” Journal of Horticulture and Forestry, vol. 4, no. 11, pp. 172–177, 2012.

[5] Deloitte 2021, How vertical farms can lead a more resilient food supply, Available online at: https://www2.deloitte.com/global/en/pages/about- deloitte/articles/food-supply-resilience-david-rosenberg.html [Accessed 20 July 2022]

[6] Mourtzis, D. (2021). Design and operation of production networks for mass personalization in the era of cloud technology. Design and operation of production networks for mass personalization in the era of cloud technology (pp. 1-393) DOI: https://doi.org/10.1016/C2019-0-05325-3

[7] V. Doknić, Internet of Things Greenhouse Monitoring and Automation System. Internet of Things: Smart Devices, Processes, Services, 2014

[8] Méndez-Guzmán, H.A., Padilla-Medina, J.A., Martínez-Nolasco, C., Martinez-Nolasco, J.J., Barranco-Gutiérrez, A.I., Contreras-Medina, L.M. and Leon-Rodriguez, M., 2022. IoT-Based Monitoring System Applied to Aeroponics Greenhouse. Sensors, 22(15), p.5646.

[9] M. Ryu, J. Yun, T. Miao, I. Y. Ahn, S. C. Choi and J. Kim, "Design and implementation of a connected farm for smart farming system," 2015 IEEE SENSORS, Busan, 2015, pp. 1-4.

[10] C. Cambra, S. Sendra, J. Lloret and L. Garcia, "An IoT service-oriented system for agriculture monitoring," 2017 IEEE International Conference on Communications (ICC), Paris, France, 2017, pp. 1-6.

[11] Boursianis, A. D., Papadopoulou, M. S., Diamantoulakis, P., Liopa- Tsakalidi, A., Barouchas, P., Salahas, G., ... & Goudos, S. K. (2022). Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: A comprehensive review. Internet of Things, 18,

100187. Doi: https://doi.org/10.1016/j.iot.2020.100187
[12] Zonta, Tiago, da Costa Andre Cristiano, da Rosa Righi, Rodrigo, de Lima, Miromar Jose, da Trindade, Silveira Eduardo, Li Pyng Guann (2020). Predictive maintenance in the Industry 4.0: A systematic literature review. Computers & Industrial Engineering, Volume 150, DOI: https://doi.org/10.1016/j.cie.2020.106889
[13] Mourtzis, D, Angelopoulos, J, Panopoulos, N. (2022) Design and Development of an Edge-Computing Platform Towards 5G Technology Adoption for Improving Equipment Predictive Maintenance, Procedia Computer Science, Volume 200, pp. 611-619, doi: https://doi.org/10.1016/j.procs.2022.01.259
[14] Lin, H. Zeadally, S., Chen, Z., Labiod, H., and Wang, L. (2020). A survey on computation offloading modeling for edge computing. Journal of Network and Computer Applications, Volume 169, DOI: https://doi.org/10.1016/j.jnca.2020.102781
[15] Miori, Lorenzo, Sanin, Julian, Helmer, Sven (2017). A Platform for Edge Computing Based on Raspberry Pi Clusters. In: Calì A., Wood P., Martin N., Poulovassilis A. (eds) Data Analytics. BICOD 2017. Lecture Notes in Computer Science. Springer, Cham. DOI: https://doi.org/10.1007/978-3- 319-60795-5_16
[16] Chen, Q.; Wang, Z.; Su, Y.; Fu, L.; Wei, Y. Educational 5G Edge Computing: Framework and Experimental Study. Electronics 2022, 11, 2727. https://doi.org/10.3390/electronics11172727
[17] Mourtzis, D.; Angelopoulos, J.; Panopoulos, N. Smart Manufacturing and Tactile Internet Based on 5G in Industry 4.0: Challenges, Applications and New Trends. Electronics 2021, 10, 3175. https://doi.org/10.3390/electronics10243175
[18] W. Baudoin, R. Nono-Womdim, N. Lutaladio et al., Good Agricultural Practices for Greenhouse Vegetable Crops: Princi-ples for Mediterranean Climate Areas (No. 217), Food and Agriculture Organization of The United Nations, Rome, 2013.
[19] M. Lee and H. Yoe, "Analysis of environmental stress factors using an artificial growth system and plant fitness optimization," BioMed Research International, 2015
[20] Stanghellini, "Horticultural production in greenhouses: efficient use of water," Acta Horticulturae, vol. 1034, pp. 25–32, 2014.
[21] J. L. Reyes, R. Montoya, C. Ledesma, and R. Ramírez, "Development of an aeroponic system for vegetable production," Acta Horticulturae, vol. 947, pp. 153–156, 2012.
[22] M. Raviv and L. Lieth, "Significance of soilless culture in agri-culture," in Soilless Culture: Theory and Practice, M. Raviv and J. H. Lieth, Eds., pp. 117–156, Elsevier, Amsterdam, 2007.
[23] V. Valenzano, A. Parente, F. Serio, and P. Santamaria, "Effect of growing system and cultivar on yield and water-use efficiency of greenhouse- grown tomato," The Jour-nal of Horticultural Science and Biotechnology, vol. 83, no. 1, pp. 71–75, 2008.
[24] I. A. Lakhiar, J. Gao, T. N. Syed, F. A. Chandio, and N. A. Buttar, "Modern plant cultivation technologies in agriculture under controlled environment: a review on aeroponics," Journal of Plant Interactions, vol. 13, no. 1, pp. 338–352, 2018.
[25] G. Salachas , D. Savvas , K. Argyropoulou , P., A., Tarantillis , and G. Kapotis, "Yield and nutritional quality of aeroponically cultivated basil as affected by the available root-zone volume," Emirates Journal of Food and Agriculture. 27(12): 911-918, 2015.
[26] Barla, SA., Salachas, G. & Abeliotis, K. Assessment of the greenhouse gas emissions from aeroponic lettuce cultivation in Greece. Euro-Mediterr J Environ Integr 5, 29 (2020). https://doi.org/10.1007/s41207-020-00168- w
[27] J. Osvald, N. Petrovic, and J. Demsar, "Sugar and organic acid content of tomato fruits

(Lycopersicon lycopersicum mill.) grown on aeroponics at different plant density," Acta Alimen-taria, vol. 30, no. 1, pp. 53–61, 2001.

[28] G. Salachas, P. Barouchas, S. A. Barla and G. Kapotis . VEGTABLE PRODUCTION AND QUALITY CHARACTERISTICS IN AEROPONICS, AGRICULTURE & FOOD 5th International Conference 20–24 June 2017 Bulgaria

[29] Suresh M., Singh, Rajesh, and Gehlot, Anita, "Automated Aeroponics System Using IoT for Smart Agriculture",*Internet of Things for Agriculture 4.0: Impact and Challenges*, Pages 207 - 2391 January 2022

[30] Gour, Mahesh S., Reddy, Vittal, Vamsi M., Sridhar N.,Vishuvardhan, Tarak Ram V, "IoT based farming techniques in indoor environment: A brief survey", *Proceedings of the 5th International Conference on Communication and Electronics Systems, ICCES 2020*, Pages 790 - 795June 2020

[31] Lucero, Lenyn, Lucero, Dora, Ormeno-Mejia, Eliana, Collaguazo, Gerardo, "Automated aeroponics vegetable growing system. case study lettuce" *2020 IEEE ANDESCON, ANDESCON 2020*13 October 2020 Article number 92721802020 IEEE

[32] Méndez-Guzmán, Hugo A., Padilla-Medina, José A., Martínez-Nolasco, Coral, Martinez-Nolasco, Juan J., Barranco-Gutiérrez, Alejandro I., Contreras-Medina, Luis M. and Leon-Rodriguez, Miguel, "IoT-Based Monitoring System Applied to Aeroponics Greenhouse,"*Sensors*, *Open Access*Volume 22, Issue 15August 2022

[33] Kuncoro, C.B.D.; Sutandi, T.; Adristi, C.; Kuan, Y.-D. Aeroponics Root Chamber Temperature Conditioning Design for Smart Mini-Tuber Potato Seed Cultivation. Sustainability 2021, 13, 5140.

[34] Martinez-Nolasco, C.; Padilla-Medina, J.A.; Nolasco, J.J.M.; Guevara- Gonzalez, R.G.; Barranco-Gutiérrez, A.I.; Diaz-Carmona, J.J. Non- Invasive Monitoring of the Thermal and Morphometric Characteristics of Lettuce Grown in an Aeroponic System through Multispectral Image System. Appl. Sci. 2022, 12, 6540.