A review about the transition of CEA's from the field to indoors

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Abstract. In this article it is presented an overview of the literature regarding the topic of Controlled Environment Agriculture (CEA) and its shifting from open-field to indoors applications. The efforts to make agriculture, in all of its steps, more efficient combined with the technological advancement of the last decades led us to a situation where not only the monitoring and control of several aspects of cultivation is possible, but it can be achieved on a small scale with low-cost solutions. This increased the technological access of microcontrollers, such as Arduino and Raspberry Pi, which allowed the development for academy research prototyping and emerging of novel concepts, such as smart greenhouses. With that, this literature review shows some of the recent works done by researchers, representing the possibilities of main applications in precision agriculture. The main goal is highlighting important aspects of using the mentioned technological platforms as a way of showing their relevance, and then provide further explanation on how these studies empowered the transition from field to indoors. Finally, it is concluded that technological advance has made possible the reliable control of different environments and made more accessible the research of CEA. But, on the other hand, there is still a lack of incentives for students and universities studying and solving problems to provide even more innovations regarding the field.

Keywords. Precision agriculture, Agriculture 4.0, Smart greenhouses, Microcontrollers.

1. Introduction

Based on current efforts on more efficient and safe plant production systems to meet global food security, greenhouse cultivation has increased its capabilities from simple structures with open-field crops to highly sophisticated facilities. In [1], it was stated the relationship between ensuring world food security and the pace of technological transformation of agriculture. According to [2], closed-field agriculture is experiencing a breakthrough transition driven by the advances in precision farming technology, smart greenhouses, information and communication technology (ICT), and agricultural data processing.

Meanwhile, over the years, strategies have been developed to improve greenhouse control with sustainable and optimal growing conditions. In a general perspective, transition for smart agriculture in crop production will increase productivity, sustainability and energy savings. With that, Controlled Environment Agriculture (CEA) can accomplish plant cultivation of different types of crops, with high quality, in a shorter time and with high yields compared to conventional agriculture. On this perspective, advances in technologies aiming at precision farming came with the goal to raise the awareness for technology transfer and adaptation, which is necessary for a successful transition to urban agriculture. The integration of automated systems, sensors, robots, data-driven applications in the scope of farming digitisation is reducing the ecological footprint of farming and advancing farm operations around the globe. [2–8]

In sume, this paper will provide a review on literature on current transformations in open-field farming and how precision agriculture technologies have become a change maker for modern cultivation systems. Section 2 will be presenting how access for technological solutions, specially for Arduino microcontroller and Raspberry Pi, are unleashing the potential of precision agriculture.

Sequentially, section 3 will present the main capabilities and applications regarding CEA, such as monitoring, control and automation of the previous platforms in some practical examples; After the previously discussed topics, it will be described how the above mentioned solutions allowed the development of smart greenhouses, and the most modern and intelligent indoor cultivation systems. With that, Section 4 will provide further studies in essential efforts, findings and their implications that make possible the transition from conventional and open-field agriculture to going indoors.

2. Technological access

Precision agriculture basically consists of monitoring the field and subsequent management based on the observations. It is heavily dependent on sensors and/or data from satellites, as information from the field has to be collected. Technologies such as Internet of things (IoT), image processing and Artificial Intelligence (AI) and Unmanned Aerial Vehicles (UAV), also called drones, are also commonly used. With the information acquired and processed, the farmers can proceed to act on the field, applying pesticides, fertilisers, increasing or decreasing irrigation, for example [9–11].

Whether it is collecting and processing information, or using it to control a device which is going to apply some correction on the field, controllers are needed in precision agriculture. For several reasons microcontrollers are frequently used, specially for prototyping. Microcontrollers are cheap, easy to program and have low power consumption, which can be a decisive factor of choice. In IoT applications, for example, they are used as the computational component of sensor nodes, which, as the name indicates, are responsible for capturing the parameters of interest, processing it and sending it through the network [12, 13] as shown in Fig. 1.

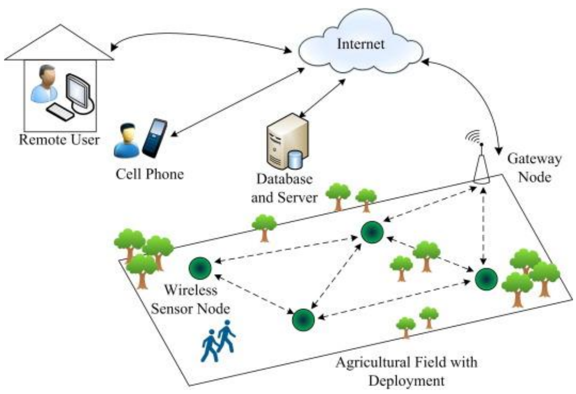

Fig. 1 - Typical Wireless Sensor Network (WSN) used in precision agriculture [12].

Regarding it, perhaps the most common deployed platforms are Arduino and Raspberry Pi boards.

2.1 Arduino

The Arduino board, produced since 2005 by a company of the same name, is basically a small circuit that contains a microcontroller, like ATmega328 in UNO, and other parts such as crystal, input/output pins and bootloader [14]. The company provides a software to program the controller, the Arduino Integrated Development Environment (IDE), where the user can write the code desired in a language modelled after the processing language, which is considered to be simple and easy for beginners. There are several variants of boards, the most popular being Uno [15]. Additional circuits, called shields, can be connected to the Arduino board and provide a variety of new functionalities. Besides that, as Arduino is an open-source hardware, various manufactures utilise its technology, even creating their own versions, like Lilypads, wearable versions of Arduino [16, 17].

2.2 Raspberry Pi

A Raspberry Pi board is a small computer initially developed for educational purposes. They are designed to run primarily with Linux and programmed in Python language (from where it comes its name “Pi”) although they are not limited to them. There are also a variety of Raspberry Pi boards that have been produced since 2012 by, again, a homonymous group. Differently from Arduino boards, to program with Raspberry Pi it is not necessary to have another computer (a “traditional” one), but as personal computers are now easily accessible, it can be rather inconvenient to buy components like keyboard and mouse just to program the microcontroller. One of the advantages of Raspberry Pi over Arduino is the higher processing power [14, 18, 19].

3. CEA applications

In this section it is presented some applications of precision agriculture that can be used to achieve controlled environment agriculture. All the selected examples use Arduino or Raspberry Pi boards, as a way to show how the academy adopted these platforms.

[20] created a moisture sensor that sends the output values to a database via Wifi, from which they can be fetched and shown in an android application. Similarly, [21] created a multisensor device to measure soil moisture and temperature of soil, vegetation and atmosphere, and send it wireless via General Packet Radio Service (GPRS). Both devices used Arduino as the microcontroller.

[22] evaluated and implemented four Convolutional Neural Networks models, which are deep learning techniques, to detect diseases in tomato leaves with a Raspberry Pi 4 as the microcomputer.

A lot of work has been done in the area of UAV for agriculture. The main uses of UAV, or drones in agriculture is mapping of field and crop monitoring. There are also some works about the spraying process [9, 23]. [24] developed a drone capable of performing autonomous trajectories over a field while capturing images, processing them and evaluating the health of the crops with several indices. It was also proposed in [25] a system that can adapt the route parameters of a UAV used for pesticide spraying based on weather conditions. The monitoring of the field is done with a WSN and the drone is controlled with a Raspberry board, but part of the correction algorithm runs on a station with more processing power. As it is shown in [23] and [9], control of drones have advanced to the point of now using AI-based solutions implemented in Arduino Uno and Raspberry Pi. The tendency is to shift from semi-controlled to fully automated systems.

In the water domain, a low cost system for irrigation purposes was developed in [26]. The user can send an order via email to water the plants and a Raspberry Pi will process it and send the output to an Arduino board which will control the pumps responsible for the task. The system also monitors the water level of the reservoir with ultrasound sensors. In sequence, a more elaborated work was done in [27], where a fuzzy logic irrigation system was proposed and tested. The device constructed has sensors to measure soil moisture, temperature, humidity and if it is raining. Based on weather and soil conditions, a motor responsible for pumping water to the field is turned on or off. Similarly, [28] developed a PID (Proportional, Integral e Derivative) controlled irrigation system, where the decision to water the field or not was based on the measurement of soil moisture, wind pressure, temperature and radiation. In both works Arduino boards were used, but in [27] the decision making was done in a computer with Matlab (a calculating software).

One of the challenges in the development of irrigation systems is that plants water uptake and stress does not depend solely on soil moisture, as some authors may assume in their systems' decision making, but on several conditions, such as atmospheric conditions (humidity, temperature), nutrient availability, root zone salinity, pest and disease infestation [29].

Smart irrigation systems like those mentioned above represent the transition to smart farming, which involves the connection of all machines and operations in the cultivation environment [4]. As presented in Fig. 2, in this kind of agricultural control system structure, and having other practical examples of greenhouse automated systems in [30], [31] and [32], microcontrollers are responsible to measure, monitor and control important parameters associated with CEA [33, 34].

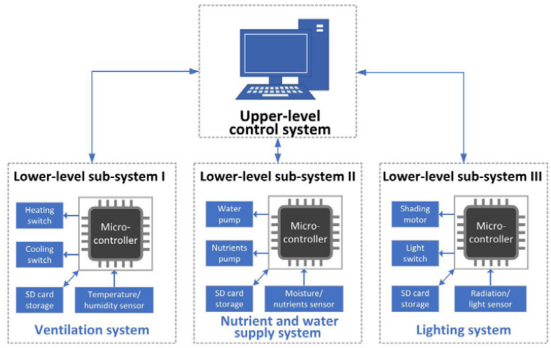

Fig. 2 - Overall control system structure for a smart greenhouse [39].

4. Going indoors

Some early studies on cultivation systems within greenhouses have been presented in [35] and technology for greenhouse food production is changing rapidly and producing even more yields. Compared with open-field agriculture, this is becoming increasingly popular and cost-competitive, especially in the United States, western Europe, and Japan. Nowadays, almost every aspect of the production system relies on a reliable monitoring system, with automation capabilities, artificial environment and growing system under computer control to achieve adequate greenhouse microclimate conditions, as presented in detail in Fig. 3. Such systems can be applied in smart farming and cultivation control techniques to regulate environmental control and energy optimization [36].

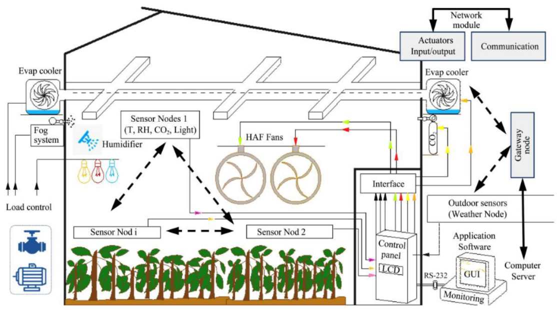

Fig. 3 - General integration of main components for environmental monitoring in a smart greenhouse [2].

Aiming at efficient, sustainable and resource-friendly development of smart greenhouses, it is essential that involved processes are adapted to a digital technology. According to this, to meet demands of reliability in a controlled cultivation environment, the integration of technological functionalities with the greenhouse physical environment will be required [8, 37]. Considering solutions for a closed-field production system, [38] categorised IoT applications to support decision making in the domain of air, water and crop growth based on illumination, irrigation and environmental monitoring and control system for agricultural management. And [39] used wireless sensing and IoT monitoring technology for indoor-cultivation with increased productivity and profitability.

In modern indoor crop production systems aiming at urban agriculture (UA), it is possible to mention vertical farming system (VFS) typologies, smart plant factory (SPF), container greenhouses, and building integrated greenhouses, such as in-store farm and appliance farms. In these systems, photosynthesis, nutrient and water supplies, and temperature are closely monitored and controlled using multiple sensors and microcontrollers. Both VFS and SPF are cultivation facilities that grow a high amount of plants and vegetables in a closed indoor space, with artificial light (mostly, LED lighting), on a daily basis, year-round, with high quality and precise control of the production environment. Although the increasing number of companies in the sector, these are still an up-and-coming sector with many opportunities for improvement and are getting attention from many investment companies due its preference by consumers in several regions and cultures [40–42].

Furthermore, many of these concepts can take advantage of space farming research, where closed plant cultivation facilities like plant factories will be a must. Considering the concept of CELSS, acronym for Controlled (or Closed) Ecological Life Support Systems, [40] present the influences of major physical environmental factors, and other factors that must be considered for establishing environmental control technology for efficient plant production in closed plant production chambers for space, which mimics plant factory systems on Earth. According to [43], an overall environmental control system will be required to manage the interactions between lighting, temperature, relative humidity, oxygen level, carbon dioxide level, pressure, the hydroponics system and plant growth. In this scope, some examples of these systems are: the research facility Arthur Clarke Mars Greenhouse, presented in [44], which is dedicated to the study of greenhouse engineering and autonomous functionality under extreme operational conditions, and also the Evolution and Design of Environmentally-Closed Nutrition-Sources (EDEN) initiative, an advanced container-based plant production system deployed in the German Neumayer Station III, as shown in [45]. In this perspective, in preparation for space-based bioregenerative life support systems, the deployment and operations of space greenhouses have considerable technological advantages over closed growth chambers and precision agriculture capabilities. This will consider systems and sensors on: network, communication and telemetry; data acquisition and control; plant growth, with the nutrient control, watering and reservoir control; and also environment monitoring and control system. Ultimately, the integration of novel CEA technologies targeting these operational production systems will provide not only long-term knowledge of these technologies, but also it will further extend the contribution of such production systems for more sustainable and smart agricultural systems.

5. Conclusion

From what was presented, the incorporation of technological solutions can assign functional reliability in order to ensure systems' intended performance, without failure, for the required activities in a specified environment, as it can be seen in [46]. Studies have shown that the development and use of electronic boards with open source hardware have increased. And also, these systems may offer various advantages in terms of easier data collection, monitoring and analysis in agricultural practices [47]. In summary, technology solutions, for instance, can be of great help to address emergency situations and solve problems that are increasing in urban environments. Because of it, with the rising global population and the decrease of available resources, this is an opportunity to pave the way towards new solutions to support self-sufficiency of cities and global sustainability [48, 49]. Then, [50] highlighted that both lack of students and institutions studying for CEA, and understanding of the capabilities and control of the technology and the implication of its implementation are still challenges for future innovations in CEA applications. Here, it was shown the importance of microcontrollers in precision agriculture and how technological access allowed CEA solutions, such as smart greenhouses, otherwise impossible to execute. Finally, in this paper we stated the importance in understanding the transition process of any ancient activity to better apply and take advantage of the most modern technological applications for it, either on Earth and also in future space settlements on Moon, Mars and beyond.

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