





Proceeding Paper

Basic Integration of Artificial Intelligence of a Plant Experimentation Chamber with LEDs and Sensors through Connection to the IoT with Node-RED and Securing Access to Data [†]

Cristobal Javier Solano ^{1,*} , Gregorio Barba-Espín ² , Juan Suardíaz ¹  and José A. Hernández ² 

¹ División of Innovation in Telematic Systems and Electronic Technology (DINTEL), Technical University of Cartagena, Campus Muralla del Mar, s/n, E-30202 Cartagena, Spain; juan.suardiaz@upct.es

² Fruit Tree Biotechnology Group, Department of Plant Breeding, CEBAS-CSIC, Campus Universitario de Espinardo, P.O. Box 164, E-30100 Murcia, Spain; gbespin@cebas.csic.es (G.B.-E.); jahernan@cebas.csic.es (J.A.H.)

* Correspondence: cristobaljavi.solano@murciaeduca.es

[†] Presented at the 1st International Online Conference on Agriculture—Advances in Agricultural Science and Technology, 10–25 February 2022; Available online: <https://iocag2022.sciforum.net/>.

Abstract: Experimental chambers play an important role in plant science and agronomy by maintaining and providing ideal conditions so that experimental data can be collected under specific and controlled conditions. To ensure that the environmental parameters inside the chamber are within the required control limits, the best solution is to be able to record and monitor them. This recording and monitoring task are carried out in order to increase the repeatability of the experiments in the future, in addition to providing researchers with real-time information about the conditions in which the trials are found under in vivo and in vitro conditions.

Keywords: node-RED; Raspberry Pi; Google Cloud Platform; Datalogger; IoT; Arduino; experimental chamber; sensor; artificial intelligence



Citation: Solano, C.J.; Barba-Espín, G.; Suardíaz, J.; Hernández, J.A. Basic Integration of Artificial Intelligence of a Plant Experimentation Chamber with LEDs and Sensors through Connection to the IoT with Node-RED and Securing Access to Data. *Chem. Proc.* **2022**, *10*, 5. <https://doi.org/10.3390/IOCAG2022-12228>

Academic Editor: Francesco Marinello

Published: 10 February 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The Raspberry Pi is a highly versatile minicomputer [1] that can interact with other devices at the same time. Internet of things, henceforth (IoT), and cloud computing are emerging technologies. IoT is a concept in which electronic devices communicate, identify, and process with each other without human interruption. Cloud computing is a technology that consumes resources from remote servers, such as virtual machines, applications, storage, and public services hosted on the Internet. IoT becomes very powerful when it converges with cloud computing.

Several research groups have used Raspberry Pi to monitor environmental conditions in the laboratory [2–4], plant growth chambers, and greenhouses [1,5–7], including detection of accurate barometric pressure, light intensity, ambient temperature, and humidity. This is used especially in combination with automated messaging to notify researchers when variables go out of range [1,8,9], which helps to minimize variations in environmental factors that can influence the experiments, and therefore improves the reproducibility and precision of the experiments. Based on these capabilities, Ghosh et al. (2018) [10] developed a special plant growth cabinet (Growcab), which uses a Raspberry Pi to help control intensity, light quality, and the photoperiod for optimize growth rate parameters. Leitch et al. (2020) [11] used the Raspberry Pi to collect data on wind speed using an anemometer. Finally, Griffiths et al. (2017–2020) [12,13] mounted underwater environmental sensors and a GPS sensor in boats to map the acoustic environment for artistic purposes. In general, the

use of the Raspberry Pi seems relatively under-utilized in autonomous environmental monitoring solutions, despite its great potential. For example, Sethi et al. 2018 [14] developed a system real-time and an autonomous monitoring of ecosystems with an open, low-cost, networked device.

Chatbots [15] can be defined as a virtual assistant that simulates human behavior. Since these systems have been endowed with Artificial Intelligence (AI), they closely approximate human behavior, and their ability and fame have increased. Machine Learning (ML) integration allows us to create and train AI models.

2. Methods

For the basic integration of AI in the experimentation chamber [7], an architecture defined by Cisco System [16] as 4-level fog computing has been used. The simplified diagram of the system is shown in Figure 1. Raspberry Pi is the main node that controls our system. The sensor network is integrated by several sensors that monitor temperature, relative humidity (RH) (DHT-22 AM2302, Aosong Electronics Co., Guangzhou, China), light intensity (Lux; TSL-2561, Texas Advanced Optoelectronic Solutions Inc., Plano, TX, USA), photosynthetic active radiation (PAR, $\mu\text{mol m}^{-2} \text{s}^{-1}$) in the 400–700 nm range (SQ-421-SS SDI-12 Digital Output Quantum Sensor, Apogee Instruments, Logan, UT, USA), and an ultraviolet light (mW/cm^2 ; UV) in the 240–370 nm range (GUVA-S12SD, Roithner Lasertechnik GmbH, Vienna, Austria). The sensors are connected to analog and digital inputs in the Arduino Uno board, whereas the Raspberry Pi is interconnected with the Arduino Uno through the serial wire type USB. The data acquired by the sensors are continuously transmitted through the Raspberry Pi to the cloud via the Internet due to its good IoT network connectivity, based mainly on Wifi and Ethernet. In addition, Raspberry Pi not only sends data to the Cloud, but also acts as a server and as a human machine interface, as will be discussed below.

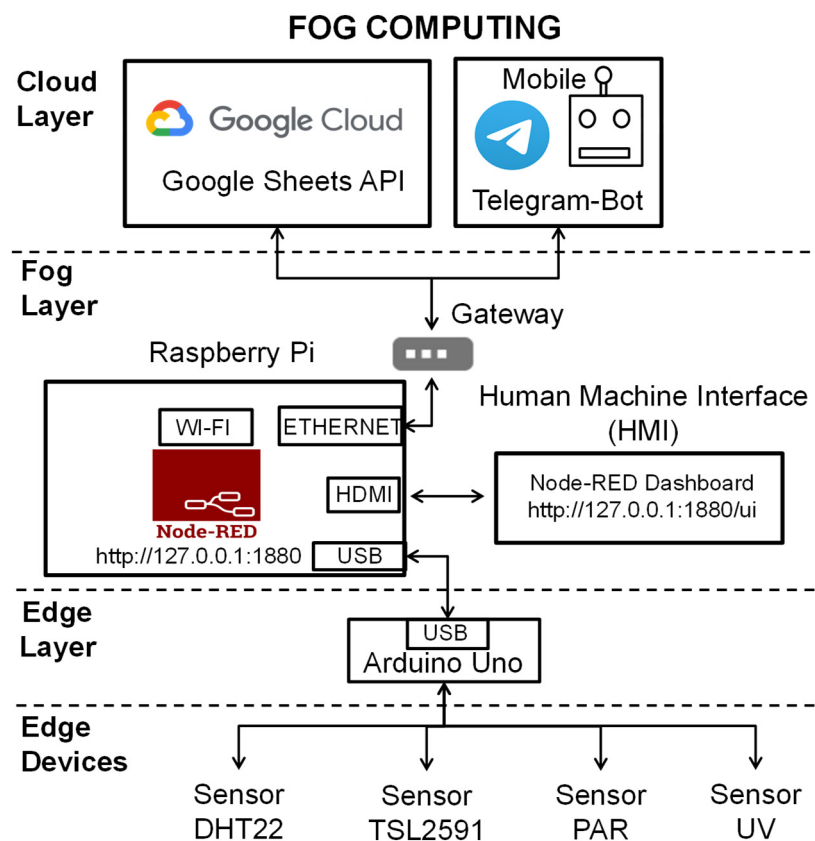


Figure 1. Simplified diagram of the proposed system.

The Raspbian operating system (OS) installed on the Raspberry Pi can be downloaded from the official Raspberry Pi website [17]. The installation file with the .zip extension must be unzipped to retrieve the .img file and the image must be copied to the SD card. Since October 2021, the Raspbian image (an exact copy of the operating system and content) installed on the SD card comes pre-installed with node-RED and needs to be updated. When Raspberry Pi starts up with the command `sudo systemctl enable nodered.service`, node-RED starts to run automatically. The access to the node-RED programming environment from the Raspberry Pi will be done by typing the IP and the address of the port (<http://127.0.0.1:1880>). By default, access by user and password authentication to the source code is disabled. This authentication method represents a serious security problem for the IoT and AI applications that have been developed since they could be violated and affect the proper functioning and even the sensitivity of information and data. Therefore, it is advisable to secure access by username and password to node-RED. For this, you have to go to `$ HOME/.node-red/settings.js` and access the `settings.js` file with a text editor and uncomment the lines from 76 to 83 (Figure 2a). The password is safely encrypted using the bcrypt algorithm [18], and the hashing is carried out by writing the command `node-red admin hash-pw` in the terminal. It will then ask us to insert a password and will return an encrypted password that will be the one that will be inserted in the uncommented password line of the `settings.js` file; with this, we will have secured the node-RED network (Figure 2b).

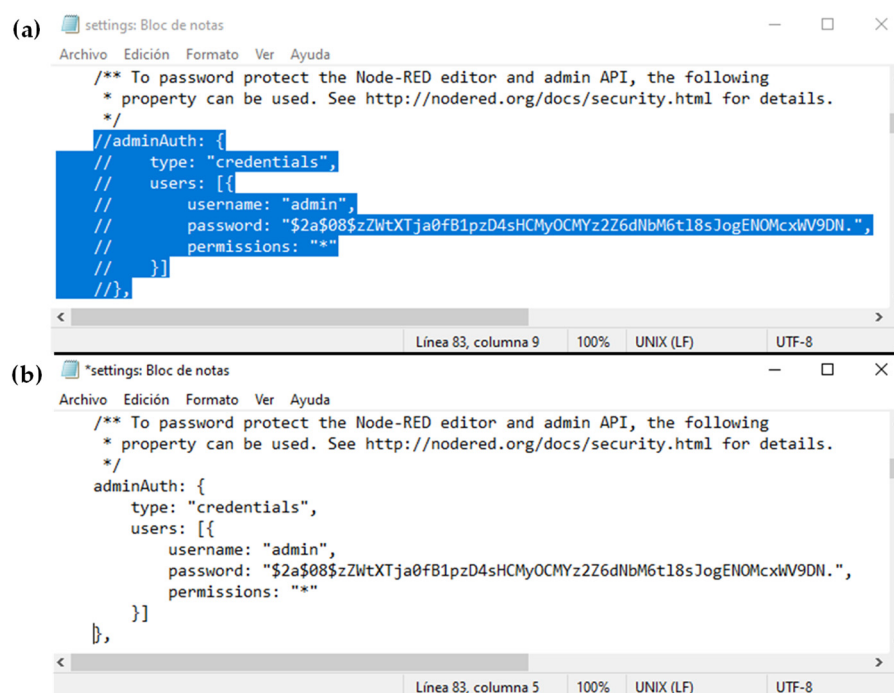


Figure 2. (a) Node-RED security disabled; (b) Node-RED security enabled.

To use the cloud services of Google Cloud [19], an account and a project in Google Cloud must be created. This platform will recognize the user by providing the authentication token that can be used for data communication from the device to the Google Sheets API. In node-RED, the GSheet [20] node will be configured, which is a basic node to write and read from these specific sheets, previously loading the library from the Linux Operating System terminal with the command `npm install node-red-contrib-google-sheets`. To configure the security authentication of this node, a Google service account is used following a series of steps such as: create a service account from this page, download a JSON credential object [21] for the service account, give that account access to the sheet's API, and share the sheet with the email address of the service account, for example, `nodered@nodered-12345.iam.gserviceaccount.com`.

The Telegram Bot API [15] allows the creation of programs that use Telegram messages as an interface. In addition, it allows to create your own custom Telegram clients and connect bots to our system. These are special accounts that do not require an additional phone number to set up. These accounts serve as the interface to code running somewhere on your server. The main advantage of using the Telegram Bot API and the MTPROTO (Mobile Transport Protocol) is that no further knowledge about complex transmission protocols is required. Thanks to this, the intermediary server will take care of all the encryption and communication with the Telegram API and communication with this server will be performed using a simple HTTPS interface.

3. Results and Discussion

If the node-RED network security process has been carried out correctly, when we access the address <https://127.0.0.1:1880> where our program code is located, we will be requested to authenticate by means of username and password (Figure 3).



Figure 3. Node-RED network security authentication.

Once the sensors have been connected to the Arduino Uno board and the Raspberry Pi has been interfaced with the Arduino Uno, a stream of data enters through the serial port of the Raspberry Pi that is processed by the *serial node* which in turn is connected to the *GSheet node* that sends the data to the cloud (Figure 4a) and processes with the *Receive Watchdog_bot node*. The user writes commands to the bot in the Telegram chat (Figure 5a,c) and the *Send Watchdog_bot node*. The bot writes in the Telegram chat with the user and gives the information requested by the user in addition to the system alerts (Figures 4b and 5b). The bot acts as a basic unit of AI as support to the user during the tests in the experimentation chamber.

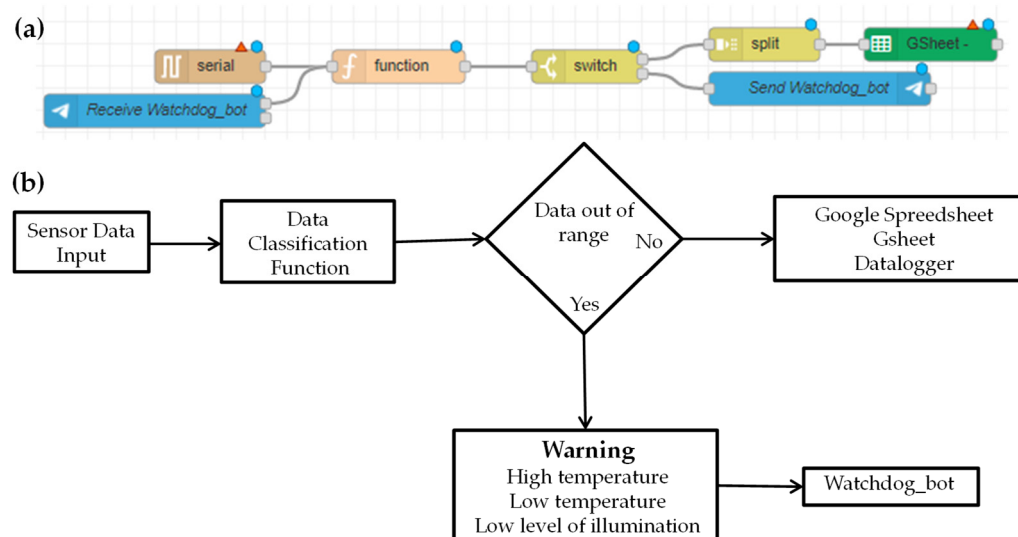


Figure 4. (a) System flow in node-RED. (b) System flow diagram.

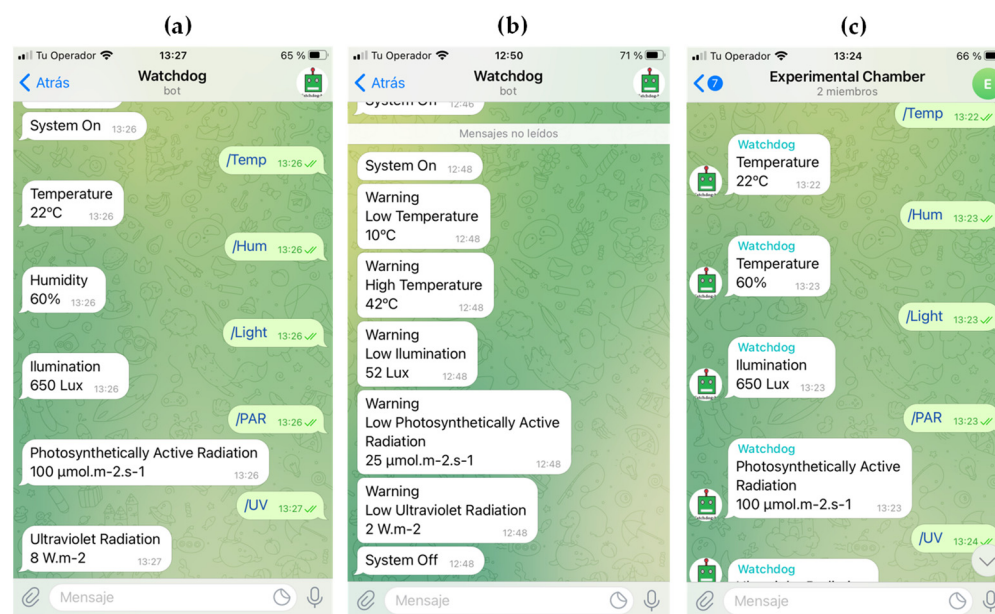


Figure 5. (a) Chat between the user and the bot. (b) The bot warns of out-of-range values. (c) Chat group in which there are several members with the bot.

The data and alerts of the system can be queried from any place in the world. The only requirement is that the device is connected to the internet and has the Telegram application installed.

As a result of the software developed, the embedded code loaded in Arduino Uno represents 12.5% (4 Kbytes) of the memory space, leaving 87.5% (32 Kbytes) of the remaining memory free. As for the program code developed and executed in node-RED, it represents less than 1% (33 Kbytes) of the memory space, leaving 99% (4 Gbytes) of the remaining memory free for other tasks.

The system has an approximated cost of Euro 600, which contrasts with other commercial solutions for environmental data logging, such as Argus (Argus Control Systems Ltd., Surrey, BC, Canada), with prices ranging from USD 10,000 to more than USD 1,000,000. Democratizing science [22] for some researchers, the allure of do-it-yourself (DIY) is a technical research challenge of building and maintaining custom equipment. However, for others, it is a financial matter, as DIY equipment at home tends to be substantially less expensive and therefore more accessible than commercial alternatives. The system cost had been assembled and configured for approximately Euro 600.

Low-cost hardware is sometimes of little use if it cannot generate reliable and replicable data. Sometimes, however, low-cost hardware is not a good option. You need to know how accurate the tool is for a given task.

The experimental chamber prototype was successfully validated in germination experiments with pea and melon seeds [7].

4. Conclusions

The proposed system has a low cost, low energy consumption, is compact, and is highly accurate to monitor the environmental variables with the appropriate sensors remotely from any place in the world. A perfect balance between accuracy and cost is achieved through the use of free, cost-effective, and open-source resources. Researchers are in an excellent position to take advantage of these tools to revolutionize the plant science area and improve reproducibility in experimentation tasks with little impact on their budgets.

Supplementary Materials: The poster presentation can be downloaded at: <https://www.mdpi.com/article/10.3390/IOCAG2022-12228/s1>.

Author Contributions: Conceptualization, C.J.S., J.A.H., J.S. and G.B.-E.; Formal analysis, J.A.H. and G.B.-E.; Methodology, C.J.S.; Software, C.J.S. and J.S.; Supervision, J.A.H., J.S. and G.B.-E.; Writing—original draft, C.J.S.; Writing—review and editing, G.B.-E., J.A.H. and J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fundación Séneca (Project 21632/PDC/21).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are available from the authors upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Grindstaff, B.; Mabry, M.E.; Blischak, P.D.; Quinn, M.; Chris Pires, J. Affordable remote monitoring of plant growth in facilities using Raspberry Pi computers. *Appl. Plant Sci.* **2019**, *7*, e11280. [CrossRef] [PubMed]
- Longley, M.; Willis, E.L.; Tay, C.X.; Chen, H. An open source device for operant licking in rats. *PeerJ* **2017**, *2*, e2981. [CrossRef] [PubMed]
- Gurdita, A.; Vovko, H.; Ungrin, M. A simple and low-cost monitoring system to investigate environmental conditions in a biological research laboratory. *PLoS ONE* **2016**, *11*, e0147140. [CrossRef] [PubMed]
- Wilshin, S.; Shamble, P.S.; Hovey, K.J.; Harris, R.; Spence, A.J.; Hsieh, S.T. LimPing following limb loss increases locomotor stability. *J. Exp. Biol.* **2018**, *221*, jeb174268. [CrossRef] [PubMed]
- Shah, N.P.; Bhatt, P.P. Greenhouse automation and monitoring system design and implementation. *Int. J. Adv. Res. Comput. Sci.* **2017**, *8*, 468–471. [CrossRef]
- Cabaccan, C.N.; Cruz, F.R.G.; Agulto, I.C. Nanotechnology, information technology, communication and control, environment and management. In Proceedings of the 9th International Forum on Shipping, Ports and Airports (IFSPA), Hong Kong, China, 22–25 May 2017; pp. 1–5. [CrossRef]
- Solano, C.J.; Hernández, J.A.; Suardiáz, J.; Barba-Espín, G. Impacts of LEDs in the Red Spectrum on the Germination, Early Seedling Growth and Antioxidant Metabolism of Pea (*Pisum sativum* L.) and Melon (*Cucumis melo* L.). *Agriculture* **2020**, *10*, 204. [CrossRef]
- Tausen, M.; Clausen, M.; Moeskjær, S.; Shihavuddin, A.; Dahl, A.B.; Janss, L.; Andersen, S.U. Greentyping: Image-based plant phenotyping using distributed computing and deep learning. *Front. Plant Sci.* **2020**, *11*, 1181. [CrossRef] [PubMed]
- Jolles, J.W. Broad-scale Applications of the Raspberry Pi : A Review and Guide for Biologists. *Methods Ecol. Evol.* **2021**, *12*, 1562–1579. [CrossRef]
- Ghosh, S.; Watson, A.; Gonzalez-Navarro, O.E.; Ramirez-Gonzalez, R.H.; Yanes, L.; Mendoza-Suárez, M.; Simmonds, J.; Wells, R.; Rayner, T.; Green, P.; et al. Speed breeding in growth chambers and glasshouses for crop breeding and model plant research. *Nat. Protoc.* **2018**, *13*, 2944–2963. [CrossRef] [PubMed]
- Leitch, K.; Ponce, F.; Van Breugel, F.; Dickinson, M.H. The long-distance flight behavior of *Drosophila* suggests a general model for wind-assisted dispersal in insects. *BioRxiv* **2020**. [CrossRef]
- Griffiths, A.G.F.; Kemp, K.M.; Matthews, K.; Garrett, J.K.; Griffiths, D.J. Sonic Kayaks: Environmental monitoring and experimental music by citizens. *PLoS Biol.* **2017**, *15*, e2004044. [CrossRef] [PubMed]
- Griffiths, A.G.F.; Garrett, J.K.; Duffy, J.P.; Matthews, K.; Visi, F.G.; Eatock, C.; Robinson, M.; Griffiths, D.J. New water and air pollution sensors added to the Sonic Kayak citizen science system for low cost environmental mapping. *BioRxiv* **2020**. [CrossRef]
- Sethi, S.S.; Ewers, R.M.; Jones, N.S.; David, C.D.L.; Picinali, L. Robust, real-time and autonomous monitoring of ecosystems with an open, low-cost, networked device. *Methods Ecol. Evol.* **2018**, *9*, 2383–2387. [CrossRef]
- Available online: <https://telegram.org/> (accessed on 1 September 2021).
- Available online: <https://www.cisco.com/> (accessed on 15 September 2021).
- Available online: <https://raspberrypi.org> (accessed on 1 October 2021).
- Provos, N.; Mazières, D. Proceedings of 1999 USENIX. *Annu. Tech. Conf.* **1999**, 81–92. Available online: https://www.usenix.org/legacy/events/usenix99/provos/provos_html/node1.html (accessed on 15 October 2021).
- Available online: <https://console.cloud.google.com> (accessed on 1 November 2021).
- Available online: <https://nodered.org> (accessed on 15 November 2021).
- Available online: <https://www.json.org/json-es.html> (accessed on 1 December 2021).
- Sandeep, R. How DIY Technologies are Democratizing Science. *Nature* **2020**, *587*, 509–511. [CrossRef]