# IoT-based system for monitoring conditions in an industrial painting booth

# IoT-based system for monitoring conditions in an industrial painting booth

Gustavo Velasco-Hernandez*†, Akseer Ali Mirani*, Anshul Awasthi*‡ and Joseph Walsh*†‡

*IMaR Research Centre, Munster Technological University, Tralee, Ireland
†Lero, The Irish Software Research Centre, Limerick, Ireland
‡CONFIRM Research Centre, Limerick, Ireland
gustavo.velascohernandez@mtu.ie
ORCID 0000-0002-2177-6348

***Abstract*—During the last decades, the Internet of Things (IoT) has evolved significantly and the advances in sensors, networking and processing technologies have enabled the adoption of IoT-based concepts and solutions across different fields. Temperature and humidity monitoring is an application that is found in sectors like the food industry, environmental monitoring, agriculture, manufacturing, among others. In the industry, product painting is not only for the visual aesthetic of products but it is intended for protecting the items against corrosion, damage and for extending their lifetime. In order to get the best painting results, variables like temperature, relative humidity and dew point must be controlled in the environment. In this project, an IoT-based system for monitoring those variables is developed and evaluated, from the sensor level up to the end-user application level. By using Bosch CISS sensors, a Raspberry Pi SBC and the ThingsBoard platform, we developed and tested this solution. After presenting the requirements of the system and the architectural design, we detail on the implementation stage of each component of the solution, and share the results of the testing and evaluation. Finally, we discuss the limitations of the system and the future work envisaged for this project.**

***Index Terms*—Data visualisation, Dew point, Humdity, Internet of Things, Industrial Internet of Things, Industry 4.0, Painting, Remote Monitoring, Temperature.**

## I. Introduction

The last few decades have witnessed the rapid evolution of the Internet of Things (IoT), term coined by Kevin Ashton in 1999 [1] and refering to the set technologies that enable all sort of devices to exchange information to the internet in consumer- or business-related applications. Now, the ubiquitous efforts of researchers around the globe in taking IoT and Cyber-Physical Systems (CPS) solutions to an industrial setting, has resulted in the creation of the Industrial IoT or IIoT [2]. This concept, along with the transition to Industry 4.0, are laying the foundations for industries in both the developed and developing countries to boost their production and manufacturing processes, enhancing the quality of products and services, reducing costs of operation and improving safety conditions in factory floors [3].

On the other hand, temperature and relative humidity monitoring is an application of interest in different industrial and non-industrial scenarios, and multiple developments of this application under the umbrella of IoT and IIoT have been done. Some fields of applications are poultry farming [4], gardening, [5], [6], agriculture [7]–[11], food industry [12], health and wellbeing [13]–[15], weather stations [16], Smart Home and appliances [17], [18], and monitoring in industrial scenarios [19]–[21].

One process where temperature and humidity monitoring is required and that is common to various fields in the industry is painting. The purpose of paint is not just limited to decoration and art, but also to protect things from corrosion, damage, and humidity for extending their operational life. For example, to guarantee the product finishing in the automotive industry, accurate control of humidity and temperature is required for the paint as changes in the chemical composition of the paint result in changes in relevant mechanical properties [22]. Also, as different coatings tolerate different weather environments in automotive paint systems [23], it is crucial to know about the temperature, humidity, and dew since these parameters directly affect the painting result. If these issues are efficiently resolved and looked after, many industries can enhance their productivity and the quality of their products.

Some work has been done in monitoring and controlling these variables in painting booths scenarios, for instance, in [24], [25], the authors monitor the temperature for refining the painting process and simulate the effects of temperature variations inside the paint booth. In [22], they propose a system to control temeperature and humidity in an automotive paint booth. Wahab et al [26] provide a hardware-based prototype that shows the real-time data from a painting booth on a local PC. Outside the literature, there are also some developments in the topic, for example in patents [27], and from companies offering industrial solutions for monitoring painting booths [28] and [29].

However, there is a gap in the literature that focuses on providing these solutions based on IoT and IIoT. As mentioned before, there are different fields benefiting from IoT-based applications, including the industry. Some usages of temperature and humidity monitoring in industry are environment monitoring [19], safety and surveillance [20] or storage [21]. But in the specific case of IoT applied to painting, the company Dürr offers an IIoT-based software solution for robotic painting cells, which provides information from the robotic arms and the painting process [30], [31]. The table I summarises related work in the area of temperature and relative humidity monitoring within the IoT context or related to painting process.

TABLE I
RELATED WORK TO IOT-BASED TEMPERATURE AND RELATIVE HUMIDITY MONITORING IN A PAINT BOOTH

| Reference | IoT/IIoT | Application |
|---|---|---|
| [5]–[11] | IoT | Gardening and Agriculture |
| [13]–[15] | IoT | Health and Well-being |
| [19]–[21] | IoT | Industrial Scenarios |
| [16], [18], [32] | IoT | Other applications |
| [22], [24]–[29] | | Paint Booth |
| [30], [31] | IIoT | Paint Booth |
| **Our solution** | IIoT | Paint Booth |

In this paper, we propose an IoT-based temperature and humidity monitoring system for a painting booth in an industrial setting. Within the scope of this project it is included the design, implementation and testing of the solution, with special interest in the evaluation of the system performance, reliability and long-term operation with little or no supervision, which is what is expected if it is deployed in an industrial application. The rest of the document is structured as follows: section II will present the architecture of the system, the requirements for the design and the description of each component of the solution. In section III the results of the evaluation of the system are considered, both for the system as a whole and for each element in it. Finally, in section IV, the document is concluded by highlighting the contributions and limitations of this project along with some proposals of work for improvement and enhancement of the system.

## II. SYSTEM ARCHITECTURE AND DESIGN

Internet of things systems are usually composed by three main elements, from a bottom-up view, they are devices, gateways/controllers and administration platform (IoT platform). The devices interact with the physical world, either by sensing a variable or as an actuator device. When devices are not able to exchange information directly with the IoT platform, a gateway or controller is required to gather information from multiple sensors using a specified communication protocol and then forward their data to the IoT platform by connecting to an intranet or the Internet. The IoT platform is the software stack that collects and stores the information sent by the sensors but also provides features like, device registration and configuration, user and device authentication, and integration to frontends and 3rd-party services.

The requirements for this project are to measure temperature, relative humidity and dew point in two points inside a paint booth with dimensions 5m x 9m x 5m. The required temperature range is from -4 to 80 degrees Celsius and the relative humidity range is from 20% to 90%. From the user side, the requirement is to create a dashboard where the user could check the real-time values with an update rate of 1 minute, but also review and access historical data in a graph. Based on the components previously described and the requirements, a general block diagram for the solution is presented in figure 1 below.

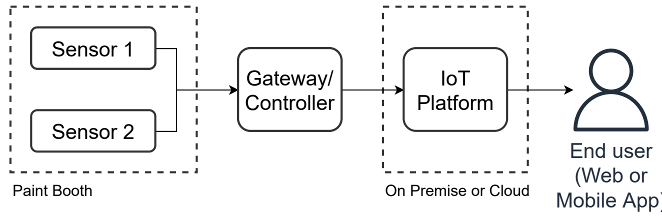


Fig. 1. Block diagram of the solution

In the following subsections the components of the solution, both hardware and software will be described.

### A. Sensors

The selected sensor for measuring the variables is the CISS sensor manufactured by Bosch GmbH [33]. This is a multisensor device for environment monitoring as well as acceleration and vibration detection. It comes in a rugged enclosure, suitable for industrial environments and for applications like condition monitoring and predictive maintenance. This device has USB and Bluetooth connectivity options and the vendor provides a Python library for configuring the sensor and collecting the data.

### B. Gateway device

As the sensor is connected using USB, a Raspberry Pi 4 Single Board Computer (SBC) is selected for interfacing to the sensors, read the data and forward it to the IoT platform. This SBC includes a 1.5Ghz processor, 4GB of RAM, 4 USB ports, 1 Gigabit Ehternet port and 2 mini HDMI ports. These features makes the board suitable to be used both as a gateway device and also as a local monitoring station when a screen is connected to it. However, as the USB cable included with the sensors is 2m long, a USB extender device [34] is used to interface the sensors with the Raspberry Pi across a longer distance.

### C. IoT platform

ThingsBoard is an open-source IoT platform for data collection, processing, visualization, and device management. It offers integration with protocols like HTTP, MQTT and CoAP, and provides scalability, security and fault-tolerance features. It can be installed on-premises, own cloud or their cloud in two versions, Community edition and Professional edition [35]. For the scope of this project, the Community Edition of thingsboard is used as there are no high requirements in number of devices, users, data rate and processing nodes. Their demo platform is available at http://demo.thingsboard.io/. A complete diagram of the proposed solution including all the components is presented in figure 2.

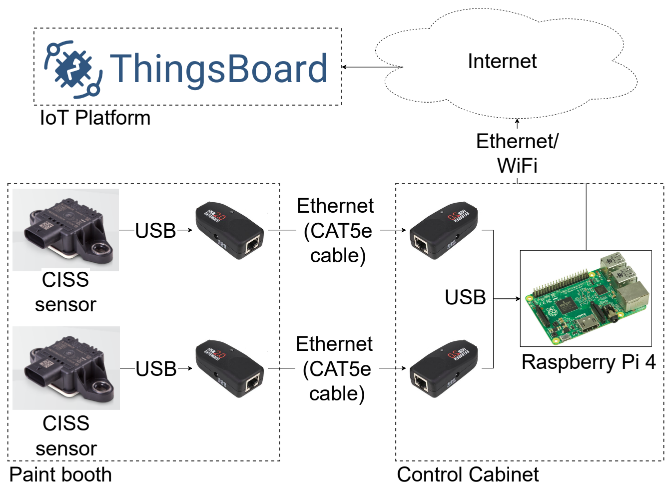


Fig. 2. Defined setup for the IoT-based system for monitoring the paint booth

## D. Software

For this system, there are two main pieces of software involved: Thingsboard as the IoT platform, and the application running at the gateway device for reading the data from the sensors and forwarding it to the server.

In order to setup ThingsBoard to collect and visualise data from the sensors, there is a series of steps that needs to be completed. First, a device entity should be created for each sensor used. Once done, ThingsBoard generates an access token that is used as a credential for sending telemetry data belonging to the sensor, but also for configuring its parameters. The next step is to create an Asset entity to represent the paint booth, and create a "contains" relation between the paint booth asset and the two sensor devices, named as Sensor Top and Sensor Bottom.

The third step is to create a processing rule for handling the temperature and humidity information received from the sensors. This is done in the "RuleChain" section of Things-Board. In this processing step, the information is labeled as "top" or "bottom" depending on which sensor generated it. Then, the data is propagated to the asset entity that contains the sensors, and finally, the dew point value is calculated by using the approximation described by equation 1, along with the difference of the variables between both sensors, this is, *temperature_delta*, *humidity_delta* and *dew_point_delta*.

$$T_{dp} \approx T - \frac{100 - RH}{5} \quad (1)$$

The fourth step is to create a dashboard to visualise both the actual values and a plot of the recent values reported by the sensors. For this regard, ThingsBoard offers a set of widgets to display current and historical data from the telemetry information asociated to entities, as well as real-time update of the information and filtering and zooming features for plots.

The second piece of software, the application at the gateway, was created using the shell scripting language and Python language version 3 on top of the Raspberry Pi operating system. The main application uses the libraries provided by Bosch GmbH for interfacing with the sensors and it also uses the `requests` Python package for creating the HTTP requests for sending the data to ThingsBoard. Also, a shell script is created for identifing the USB devices as serial ports and pass this parameters to the main Python app.

Another feature implemented is the automatic start of the application after powering up or rebooting the system. This is done by creating an entry for starting the shell script in the crontab provided by cron, the job scheduler tool available in Unix-like operating systems. Additionally, as the Raspberry Pi will be used as a local monitoring station, Chromium web browser was configured to open the URL of the created dashboard after booting up. Figure 3 presents the process flow of the software running at the gateway device.

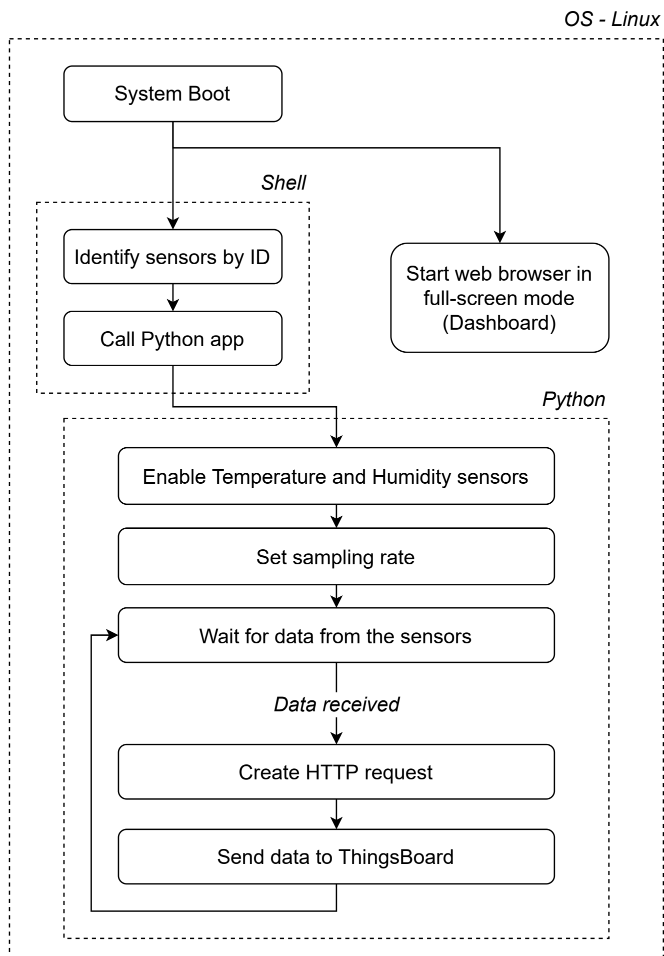


Fig. 3. Block diagram of the software on the gateway device

## III. Results

After the design and development stages, the system was installed for testing and evaluating its components and their functional aspects. During the testing stage, the system was

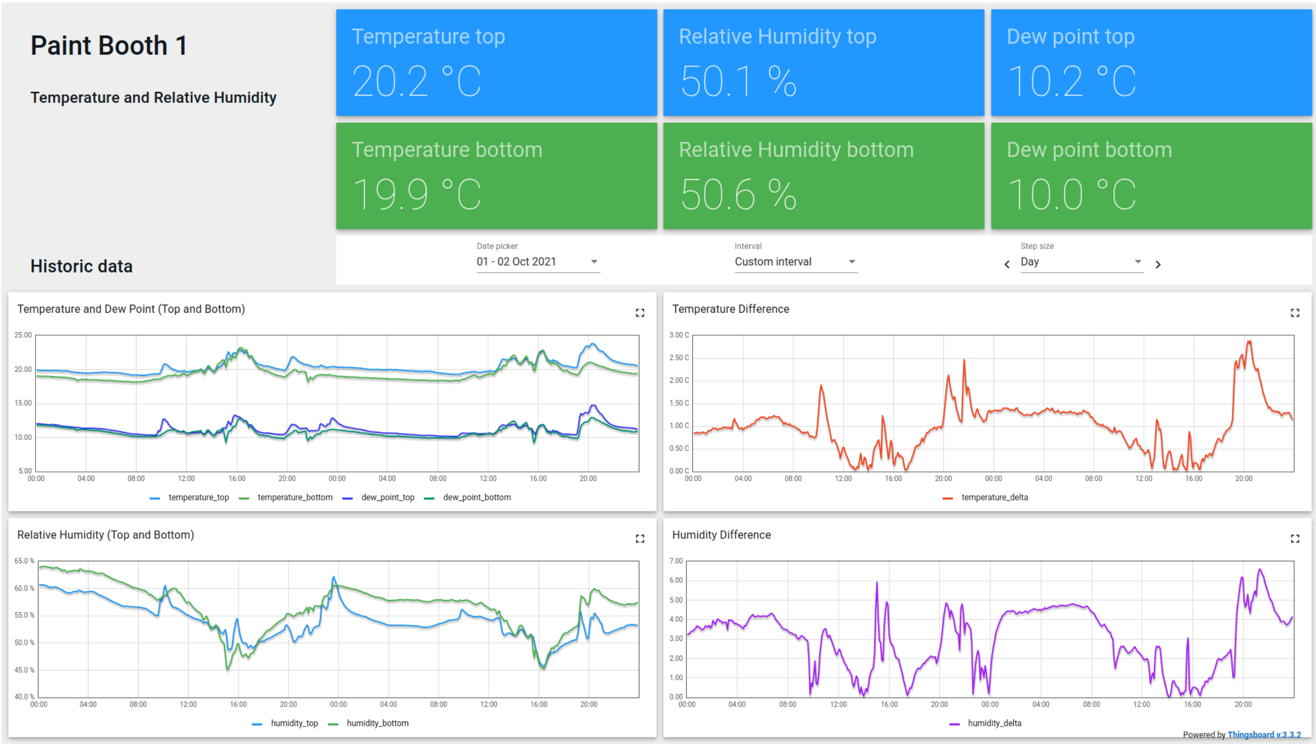


Fig. 4. Screenshot of the dashboard. On the top the real-time values are displayed and on the bottom historical values are plotted in charts.

able to operate continuosly for more than a month with little supervision and troubleshooting.

In a more detailed evaluation, due to the functioning of the sensor library, each variable from the sensors is reported in a separate function to the Python application, this means that after the value of each variable is received, the HTTP request to send the data to ThingsBoard is generated, thus, the system generates four requests per minute for transmitting the data. This equals to 172.800 messages/month to ThingsBoard, which is below the limit of messages or datapoints for the demo account of the platform, 10M per month. Also, the execution of custom nodes and rules has a limit of 4M per month, but in this case there are about ten executions per message received (for filtering and labelling the messages, calculating the dew point and calculating the deltas). This is equivalent to around 1.73M rule executions per month which is also below the limits of the platform.

On the sensors side, although the communication between the sensors and the Raspberry Pi was working most of the time, there were a couple of scenarios where the system required human intervention. The first case is related to how the operating system recognise and register the USB devices connected. As the sensors work by creating a serial interface on top of USB, the operating system registers the connected devices as `/dev/ttyUSBx` or `/dev/ttyACMx` where `x` is a consecutive number for each device. These resource names are used to access the sensor from the Python application but it is not guaranteed that after each reboot the sensors will obtain the same resource name. This issue caused the data read from sensor A will be reported as if it was from sensor B and viceversa, requiring someone to check. However, the problem was solved by identifying the relation between the devices serial numbers and the resource names, found in the path `/dev/serial/by-id/`.

The second case where human intervention was required, relates to sudden disconnections of the sensors reported by the program, but this issue was only present when the USB extenders were used. When checking the problem by exploring the logs of the system, it was found that USB communication errors appeared and the USB driver then attempted to restart the USB port. After consulting different sources about the cause of the issue, there was no consense but most of the sources pointed to a power-related issue. In this case, the application stopped when the sensor was no longer detected so it was necessary to start it again.

Overall, the system performed as required, collecting temperature and humidity information from both sensors and pushing the data to ThingsBoard, where additional parameters were calculated and where the final user could access the information for monitoring and visualisation, either from the local station or through the web using a laptop or mobile. Figure 4 presents a screenshot of the dashboard created for the user, showing the real-time and historical information of the variables in the paint booth.

## IV. Conclusions

In this paper, the development and testing of an IoT-based monitoring system for a painting booth was presented.

Although temperature and humidity monitoring is an already proven concept and there are many IoT-based implementations and demonstrations, the target application for this project is an industrial scenario, and this environment has stricter requirements in terms of quality, operating conditions and reliability, so not all types of sensors used in IoT prototypes are suitable for industrial applications [36]. Thus, the main contribution is that our proposal is the one of the few that approach the usage of IoT-based solutions for monitoring the painting process in an industrial environment, evaluating the continuous operation and performance of the system as part of a long-term solution.

The developed system will provide valuable information about the painting process to companies that require to monitor this step of the production. This is done by displaying realtime feedback about the conditions in which the painting process is executed but also by creating a database of historical information in which the company could trace back in time defects or issues found in the paint of their products. Finally, by the continuous evaluation of systems like the one presented in this paper and detailed testing of the components involved in an IoT solution, the adoption of these new technologies by the industry will be quicker and seamless. In this way, companies will improve their processes, increasing the quality of their products and services and as a result, the Industrial Internet of Things will become an established part of every company in the future.

### *A. Future work*

As the operation and testing of the system is in progress, there are still some aspects of the system that can be improved in the short term, like removing the usage of USB extenders as they might be a point of failure, optimising the HTTP requests for sending all the data in one message and create an alarm event when data is not received after certain amount of time. As future work, additional features can be included in the mid-term, for example, to use an industrial communication protocol between the sensors and the gateway device to overcome the limitations of USB, migrate from HTTP to MQTT, create a set of rules for generating alarms if the variables values are outside a defined interval, notify appointed users via email, SMS or app when alarms are present, perform analytics on the collected data to identify activity, trends and anomalies in the process, or integrate the information given by the system with external applications from the factory like the Manufacturing Execution System (MES) or the Enterprise Resource Planning (ERP) system. This will make our system more realiable for its use in the industry and will provide higher value to the customer.

## Acknowledgements

This work was supported, in part, by Science Foundation Ireland grant 13/RC/2094 and co-funded under the European Regional Development Fund through the Southern & Eastern Regional Operational Programme to Lero - the Science Foundation Ireland Research Centre for Software (www.lero.ie)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754489

## References

[1] A. Karmakar, N. Dey, T. Baral, M. Chowdhury, and M. Rehan, "Industrial internet of things: A review," *2019 International Conference on Opto-Electronics and Applied Optics, Optronix 2019*, 3 2019.

[2] H. Boyes, B. Hallaq, J. Cunningham, and T. Watson, "The industrial internet of things (iiot): An analysis framework," *Computers in Industry*, vol. 101, 2018.

[3] A. Lopez-Vargas, M. Fuentes, and M. Vivar, "Challenges and opportunities of the internet of things for global development to achieve the united nations sustainable development goals," *IEEE Access*, vol. 8, pp. 37 202–37 213, 2020.

[4] M. N. Elham, M. S. Sabeghi, F. S. Al-Rasbi, S. M. Daud, N. Q. Noor, R. Sahak, and A. A. Mazlan, "A Preliminary Study on Poultry Farm Environmental Monitoring using Internet of Things and Blockchain Technology," *ISCAIE 2020 - IEEE 10th Symposium on Computer Applications and Industrial Electronics*, pp. 273–276, 2020.

[5] M. Danita, B. Mathew, N. Shereen, N. Sharon, and J. J. Paul, "IoT Based Automated Greenhouse Monitoring System," *Proceedings of the 2nd International Conference on Intelligent Computing and Control Systems, ICICCS 2018*, no. Iciccs, pp. 1933–1937, 2019.

[6] Yanshori, D. W. Nugraha, and D. Santi, "Iot-based temperature and humidity monitoring system for smart garden," *IOP Conference Series: Materials Science and Engineering*, vol. 1212, p. 012047, 1 2022. [Online]. Available: https://iopscience.iop.org/article/10.1088/1757-899X/1212/1/012047

[7] T. Akbar, I. Gunawan, and S. Utama, "Prototype System of Temperature and Humadity Automatic in Oyster Mushroom Cultivation using Arduino Uno," *Journal of Physics: Conference Series*, vol. 1539, no. 1, 2020.

[8] T. H. Nasution, M. Yasir, Fahmi, and Soeharwinto, "Designing an IoT system for monitoring and controlling temperature and humidity in mushroom cultivation fields," *ICECOS 2019 - 3rd International Conference on Electrical Engineering and Computer Science, Proceeding*, pp. 326–331, 2019.

[9] R. K. Jha, S. Kumar, K. Joshi, and R. Pandey, "Field monitoring using IoT in agriculture," *2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies, ICICICT 2017*, vol. 2018-January, pp. 1417–1420, 2018.

[10] P. Abinaya and P. Swathik, "Smart irrigation and temperature control for a greenhouse system," *Journal of University of Shanghai for Science and Technology*, vol. 23, 2021. [Online]. Available: https://jusst.org/wp-content/uploads/2022/02/Smart-Irrigation-and-Temperature-Control-for-a-Greenhouse-System.pdf

[11] J. Kim, D. Minagawa, D. Saito, S. Hoshina, and K. Kanda, "Development of kosen weather station and provision of weather information to farmers," *Sensors*, vol. 22, no. 6, 2022. [Online]. Available: https://www.mdpi.com/1424-8220/22/6/2108

[12] C. M. Endres, C. Pelisser, D. A. Finco, M. S. Silveira, and V. J. Piana, "Iot and raspberry pi application in the food industry: a systematic review," *Research, Society and Development*, vol. 11, pp. e0 411 124 270–e0 411 124 270, 1 2022. [Online]. Available: https://rsdjournal.org/index.php/rsd/article/view/24270

[13] H. Patel, S. Sheth, and S. M. Farhad, "Cloud based temperature and humidity alert system to prevent food poisoning," *Proceedings - 2019 Cybersecurity and Cyberforensics Conference, CCC 2019*, no. Ccc, pp. 1–5, 2019.

[14] J. Prinyakupt and K. Roongprasert, "Verification Device for Temperature and Relative Humidity Inside the Infant Incubator via IoT," *BMEiCON 2019 - 12th Biomedical Engineering International Conference*, 2019.

[15] D. K. S. Nadiger, J. Dhanush, R. Vikas, S. K. B. V, A. R. Naik, and C. G. M, "E-health tracker: An iot-cloud based health monitoring system," *2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT)*, pp. 35–39, 1 2022. [Online]. Available: https://ieeexplore.ieee.org/document/9716540/

[16] S. Halder and G. Sivakumar, "Embedded based remote monitoring station for live streaming of temperature and humidity," *International Conference on Electrical, Electronics, Communication Computer Technologies and Optimization Techniques, ICEECCOT 2017*, vol. 2018-January, pp. 284–287, 2018.

[17] D. H. M. Anh, "Mesh network based on MQTT broker for smart home and IIoT factory," *ASEAN Journal of Science and Engineering*, vol. 2, no. 2, pp. 173–180, Aug. 2021. [Online]. Available: https://doi.org/10.17509/ajse.v2i2.39080

[18] C. He, G. Zhong, H. Wu, L. Cheng, and Q. Huang, "A smart reheating and defrosting microwave oven based on infrared temperature sensor and humidity sensor," *Innovative Food Science & Emerging Technologies*, vol. 77, p. 102976, 5 2022.

[19] K. Gayathri, "Implementation of Environment Parameters Monitoring in a Manufacturing Industry using IOT," *2019 5th International Conference on Advanced Computing and Communication Systems, ICACCS 2019*, pp. 858–862, 2019.

[20] M. Mahbub, M. A. Rouf, and M. M. Saym, "Industrial Plant Environment Surveillance and Safety Assurance System Based on IoT," *2020 2nd International Conference on Sustainable Technologies for Industry 4.0, STI 2020*, vol. 0, pp. 19–20, 2020.

[21] A. Roy, P. Das, and R. Das, "Temperature and humidity monitoring system for storage rooms of industries," *2017 International Conference on Computing and Communication Technologies for Smart Nation, IC3TSN 2017*, vol. 2017-October, pp. 99–103, 2018.

[22] S. Alt and O. Sawodny, "Model-based temperature and humidity control of paint booth hvac systems," *Proceedings - 2015 IEEE International Conference on Mechatronics, ICM 2015*, pp. 160–165, 4 2015.

[23] M. E. Nichols, J. L. Gerlock, C. A. Smith, and C. A. Darr, "The effects of weathering on the mechanical performance of automotive paint systems," *Progress in Organic Coatings*, vol. 35, pp. 153–159, 8 1999.

[24] S. Jaszczak and P. Nikończuk, "A model of the refinishing spray booth as a plant of automatic control," *Measurement Automation Monitoring*, vol. 61, pp. 7–361, 08 2015.

[25] ——, "A preliminary analysis of spray booth temperature control using pwm modulation with dynamic trigger period," *MEASUREMENT AUTOMATION MONITORING*, vol. 62, 07 2016.

[26] Y. Abdul Wahab, "Automatic humidity and temperature monitoring in automotive painting spray booth," *Journal of Tomography System and Sensor Application*, vol. 3, Nov. 2020. [Online]. Available: http://tssa.my/index.php/jtssa/article/view/72

[27] R. Valachovic, "Us6502629b2 - paint booth temperature control system," 2003. [Online]. Available: https://patents.google.com/patent/US6502629B2/en

[28] CAREL Industries SpA, "Carel website." [Online]. Available: https://www.carel.com/web/guest

[29] Rotronic Instruments (UK) Ltd, "Measurement solutions - feuchte-, temperatur-, co2- und differenzdruck-messung." [Online]. Available: https://www.rotronic.com/de-ch/

[30] Dürr Systems AG, "Iiot solution dxqequipment.analytics monitors paint booth online - dürr." [Online]. Available: https://www.durr.com/en/media/news/news-detail/view/iiot-solution-dxqequipmentanalytics-monitors-paint-booth-online-2440

[31] ——, "Iiot comes to paintshops — article — automotive manufacturing solutions." [Online]. Available: https://www.automotivemanufacturingsolutions.com/paintshop/iiot-comes-to-paintshops/36925.article

[32] P. Ch.B.V., G. Sreekar, G. Jatin, and J. Shah, "Iot based environment monitoring system to protect heritage artefacts," in *2021 5th International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEECCOT)*, 2021, pp. 145–150.

[33] Bosch GmbH, "Connected Industrial Sensor Solution — CISS," 2020. [Online]. Available: https://www.bosch-connectivity.com/media/downloads/ciss/ciss_datasheet.pdf

[34] RS Pro, "RS PRO 50 Metre USB2.0 CAT5 Extender - Black," 2021. [Online]. Available: https://docs.rs-online.com/36ca/A700000007817347.pdf

[35] ThingsBoard, Inc., "ThingsBoard Open Source IoT Platform," 2022. [Online]. Available: https://thingsboard.io/

[36] Y. A. Ahmad, T. Surya Gunawan, H. Mansor, B. A. Hamida, A. Fikri Hishamudin, and F. Arifin, "On the Evaluation of DHT22 Temperature Sensor for IoT Application," *Proceedings of the 8th International Conference on Computer and Communication Engineering, ICCCE 2021*, pp. 131–134, 2021.