TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

Internet of Things Gateway for industrial communication protocol

Vasconcelos AA*, Carneiro JVP*, Santos VCG* and Santos BJ*.

**University São Judas Tadeu – Mooca, São Paulo, Brazil*

Abstract. The industrial sector usually suffers with the high cost of equipment and the high payback of them, in other words, the time in which the profits brought by the equipment will cover the amount initially spent is high, which can be a big problem since this sector is in constant development and evolution, new technologies appear all the time aiming to optimize the industrial processes. Taking this scenario into account, the project aims to unite low-cost hardware and software in order to leverage industrial technologies that do not have connectivity, thus making the data from them available in a cloud, for managerial access and quick decision-making, in a safe, fast and efficient way. Data are acquired through the Modbus TCP protocol on a raspberry with the aid of the "Py modbus" library, are sent to an AWS cloud through the MQTT protocol and its respective *broker*, finally displayed in a web environment in *dashboard* format using from Node.JS (a programming language that allows a robust, lightweight and flexible application)[1]. The project was implemented in an industrial place containing an extruder and seven frequency inverters, there was testing and acquisition of various data, thus, the response time in the system was monitored and considered satisfactory in terms of cost benefit.

Keywords. *Gateway; Internet of Things (IoT); Industry 4.0; MQTT; Broker.*

Introduction. The industrial sphere, like many other sectors, usually goes through changes, when they become abrupt and significant, it is usually called a revolution. The concept of industry 4.0 was coined by the german government, at the annual fair in Hannover that took place in 2012, classifying the fourth industrial revolution, so in 1999 a new concept of Internet application emerged in the industrial sector: The Internet of things (IoT), this term, according to the website WATTSON (2018), was created by researcher Kevin Ashton. The technology has been applied in the transmission of information and control through industrial and electrical devices used in the most varied types of equipment. With this integration, it became possible to manage decision-making based on data, monitor and act in the control of industrial processes.

According to a study carried out in 2018 by the Federation of Industries of the State of São Paulo (FIESP) in partnership with the National Service for Industrial Learning (SENAI); Of the Brazilian industrial companies interviewed, only 5% feel "very prepared" for industry 4.0, with 32% saying they do not know what the fourth industrial revolution is. This is due to the economic recession and the high cost of industrial equipment, which usually return the investment only in many years, making it often impossible to exchange a product that has not yet delivered the expected return.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

However, the project consists in the development of low-cost industrial equipment that will work together with Programmable Logic Controllers (PLCs) and private ones, using the industrial communication protocol, sharing data to a remote server, so that it is possible to have remote access to data and possible control interventions. The project's differential is the development of a system that can take advantage of the information provided by PLC devices that already exist in the industrial plant or in the control of electrical power systems, regardless of having different manufacturers or communication language, making the process more technological and efficient, without the need for a high-cost investment in the implementation of new compatible devices.

Literature review. In view of a theoretical framework, with the purpose of synthesizing, contextualizing and substantiating the theme of this work, some references and existing works will be provided, covering the spectrum of literature relevant to the IoT Gateway concept, in multiple branches and with different solutions, validating once again the application of this technology.

Santos (2020) carried out an agribusiness automation project auxiliary to the internet of things4. This work presents a proposal to facilitate the automation of aquaculture processes through information technology following the IoT concept. Therefore, it is possible to verify the integration of local processes of rural production with remote monitoring, applying IoT technology to agribusiness. The author uses arduino as main hardware and its sensor/actuator modules, while the software, they choose to use the MySQL database and Hypertext Transfer Protocol (HTTP) connection. With this, it is observed that although the tools, methodologies and the application itself are completely different in relation to this work, the concept and philosophy of the IoT Gateway are greatly similar.

Cortez (2021) developed an IoT device for monitoring the production status of water for pharmaceutical purposes[5]. The device was designed to obtain information from the Reverse Osmosis process, which is inserted inside the purified water production plant for the pharmaceutical industry, and make this information available to the customer's supervisory system. In the article Cortez mentions that he used NodeMCU to implement his device, an open-source hardware platform, similar to the Raspberry Pi (used in this project). For the application of the device, Node-RED was used, also different from this project, in this aspect, since the language determined for the construction of the WEB page of this project was Node.JS.

Vicentin (2021) implemented a Retrofit in industrial machines for insertion in the context of industry 4.0[6]. The Retrofit process consists of recovering or modernizing a machine with a focus on normalizing the performance, or even improving the operating state that constitutes it, as described (Gao and Wang, 2017). Alexandre chose a Computer Numerical Control (CNC) machine, used in the area of Mechanics, in the field of machining processes. The idea was to implement an IoT Gateway on this machine, allowing connectivity for remote control and

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

monitoring. In this case, Siemens equipment and devices were used, not being open-source, like the others mentioned so far. For the construction of the supervisory, they used Node-RED.

Therefore, through some scientific works, which greatly contributed to the construction of the IoT Gateway for industrial communication protocols, the emergence of the need that companies and industries are currently facing: the need for connectivity and insertion of their processes, plants , machines, elements, devices and equipment, which through the implementation of the IoT Gateway is remedied, enabling the acquisition of previously non-existent data from the processes and the storage of all this data in cloud infrastructure, through the internet.

It is also clear that despite various methodologies and ways of building an IoT Gateway, in this project, tools were used, both hardware, software, applications and concepts that promote an efficient, low-cost and modern Internet of Things interface for Industrial Protocols, also contributing to future research and similar implementations, in order to cooperate and further support the concept of Industry 4.0.

Methodology. To achieve the proposed objectives and ratify the functionality and application of the IoT Gateway, a study and implementation was carried out in three distinct phases. This section will present the study phases and the materials and methods used for the construction and development of the project.

The first step was to define the hardware to be used to collect and receive all parameters, variables and control and/or monitoring points of an industrial plant or electrical power system, aiming at a set of robust, versatile and low-cost equipment, devices and components.

The second phase was planned with the end user in mind, that is, a professional or person responsible for the control and monitoring of an electrical power system, which could be a substation operator, maintenance professional or an operational control center, for example. At this point, the way in which all information and data to be supervised will be displayed was taken into account. For this reason, the availability of a dashboard was defined, that is, a visual panel that centrally presents a set of information, such as indicators and metrics, to assist in decision-making and general planning in a managerial and objective way.

In the third and final stage of study and planning, the main task was the integration and association of ideas from the two initial phases, so that the concept of IoT Gateway for industrial protocols was established. This step aimed and focused on joining the local environment to be monitored and controlled (power substations, industrial plants, building systems, among others), that initially do not have machines and equipment with IoT connectivity or native remote access and which have protocols and industrial physical standards, with a remote environment that can be accessed from anywhere in the world, as long as there is an internet connection and the appropriate network access permissions. It is in this third phase that the Gateway was actually created, fulfilling its main function of interface and connection between these two environments.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

Figure 01 demonstrates the various communication protocols being integrated through the IoT Gateway, taking into account the practical application and case study of this project. Therefore, the Gateway is performing the function of creating an interface between two different environments: the local environment, where the PLC with the Modbus TCP communication protocol is located and the other is the cloud environment, through which it will be possible to visualize and monitor the local environment. This second environment was implemented with the Node.JS program language and the MQTT communication protocol.

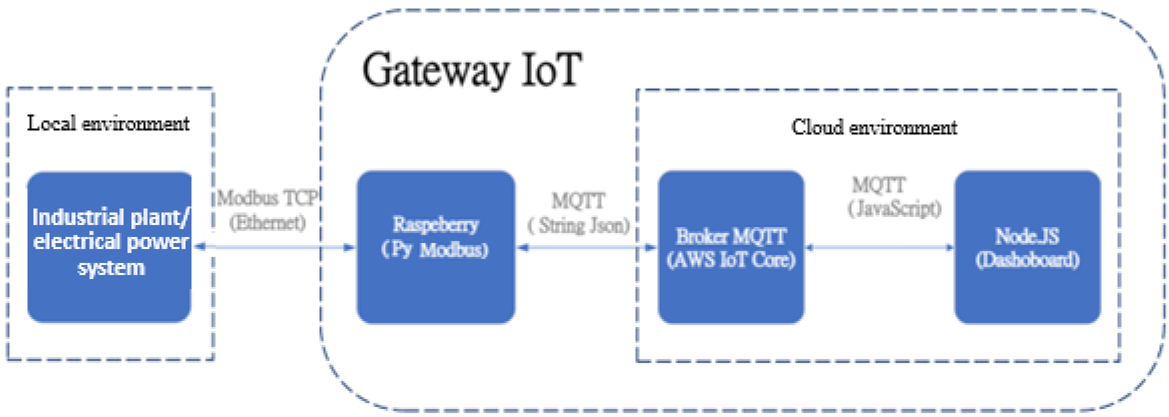

Figure 01. IoT Gateway architecture focusing on the interface between the various communication protocols and programming languages, as well as the integration of different environments.

Once the planning was consolidated, the first constructive step was to collect data from the environment to be monitored and controlled. One of the hardware used is a Raspberry Pi, which is an SBC (Single Board Computer), that means, it is a microcomputer built on a single and small board, thus associating processing, memory, inputs and outputs in order to obtain a similar performance to a computer, however, in a compact form.

The operating system is the foundation for running applications and software that make Raspberry hardware a practical implementation tool. For the work, the Raspbian operating system version was used, which is an open-source operating system based on the Debian Linux distribution of ARM architecture, optimized for the Raspberry PI hardware. The Raspbian operating system has Python 2 and Python 3 interpreters that will be used over the data extraction scripts.

The program for extracting the data from the PLC was in Python programming language, using the Py Modbus library, which is the complete version of the Modbus protocol implemented in the Python language and works in the TCP/UDP, Serial ASCII, Serial RTU, and Serial Binary in synchronous and asynchronous modes, operating with client and server classes.

The PLC used was the PLC300, which already works natively in the Modbus TCP server function, in this case, the IoT Gateway operates as a slave on the network, making the PLC300 not need additional configurations. In practice this means that any PLC with the specification of a Modbus server could provide data to the IoT Gateway without needing to intervene in its original

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

programming. In case of PLCs that do not have this characteristic as standard, it will be necessary to configure additional blocks to replicate the behavior of a Modbus TCP server.

The controller has a man-machine interface that is part of WEG's new generation of touchscreen color graphic man-machine interface. With the use of this man-machine interface, it will be possible to compare the parameters, data and variables recorded and displayed on the equipment with what will be remotely monitored through the IoT Gateway, simultaneously, having as main purpose a real and widely used application in the field, as well as the guarantee of reliability and for didactic purposes of the project.

For the project in question, we will use the Modbus protocol through the ethernet physical layer, as a result, the Raspberry PI ethernet port will be used to connect to the PLC300 through the network router that will also be responsible for providing a stable connection to the internet. The PLCs Ethernet interface can communicate using rates of 10 or 100 Mbps, in half or full duplex mode.

The most suitable network topology for using the IoT Gateway is the star, as shown in Figure 02:

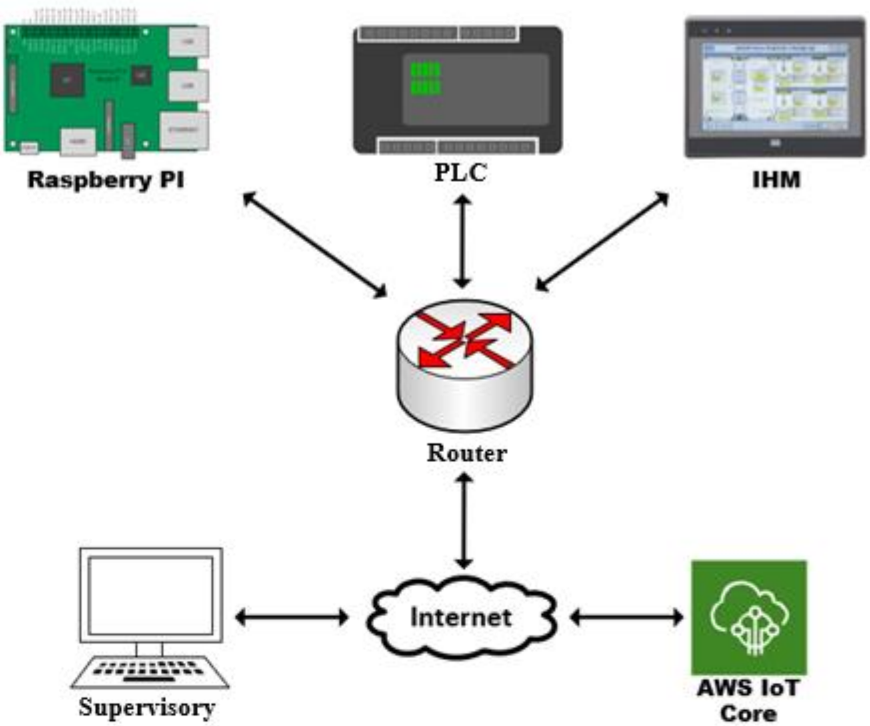

Figure 02. General diagram containing the connection and interface of the local peripherals with the remote environment through the router, showing the network topology.

From the data extracted from the plant, the Gateway needs to publish all this information to the AWS IoT Core broker.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

AWS IoT Core is a managed cloud service focused on IoT technologies and services. Its main function is to allow connected devices to securely interact with cloud applications and other devices.

Its main advantages are infrastructure scalability and flexibility, making it possible to create messaging systems. To this end, the M2M (Machine to machine) protocol called MQTT was chosen, it is a data transfer protocol between devices, it focuses on IoT with a light transmission rate and uses the Publish-Subscribe standard.

When clients are configured in the AWS service, authentication keys and certificates are generated. Authentication keys serve to identify the device, while authorization certificates determine what actions the device can perform within the platform.

Device connection is obtained through certificates and access keys, and topics are created from the first publication, that is, the client is responsible for generating topics within the broker.

For the Gateway developed in this project, two client-type instances will be created, the first being the "raspberry Pi", responsible for extracting and sending the data, and the second the "server" that will be responsible for collecting the information in the broker and generating the web browser user interface.

After the integration between PLC, Raspberry PI and MQTT broker, there must be a means of interaction that allows the user to access the devices, as well as the monitoring and control of the industrial plant or electrical power system. For this, a WEB page was developed, executed through Node.JS.

On the server side, another client instance was created with the aim of subscribing to the topic published by the Raspberry Pi, so within an MQTT network infrastructure we have the minimum necessary for the exchange of information, two clients and a Broker.

With both clients configured, there is an asynchronous information flow that provides the Gateway user with the data pre-configured in the Raspberry Pi data extraction script.

Case Study. In order to test the Gateway in a real scenario and obtain metrics of its operation, a supervisory implementation was carried out for a polyvinyl chloride (PVC) film extruder. A data extraction script was configured based on the variables of interest for monitoring. In this extraction process, the Py Modbus library was used, which is a complete version of the Modbus protocol implemented in the Python language, enabling high performance and reliability in data acquisition[7]. All variables were extracted from the memory map of the programmable logic controller used (PLC300 - WEG)[8].

The built-in supervisory consists of a scan of seven temperature zones containing setpoint and real temperature, together with graphs that follow the temperature variation as a function of time. Data were also extracted from 7 frequency inverters containing setpoint, real speed and percentage of current. The server address was also pointed to a specific domain “extrusora.com” in order to make it more intuitive to access the plant through the internet, with a web browser.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

For the supervisor in question, a reading cycle of 500ms was performed, in case of variation of more than 5% in the values of the variables, the data is sent to the broker, in parallel a fixed cycle of 30 seconds sends information constantly to the broker.

Figure 03 shows the PVC film extrusion machine:

Figure 03. Photo of an industrial plant, containing a PVC film extrusion machine.

Results and discussion. Taking into account that the Gateway project has communication stages with different specifications, tests were carried out in two stages. The first step aims to exclusively obtain the communication metrics between the Gateway and the MQTT broker. The second step aims to obtain the communication metrics between the Gateway and the PLC.

The connection between the Gateway and the broker is carried out through a router that fulfills the role of creating a local network and providing access to the internet and allowing connection with the MQTT broker.

To carry out the communication tests between the Gateway and the broker, a code was implemented with the timestamp functions, which records the exact time of an action within the program, and the callback function. The callback function is intended to pass a return after an action within the program. For the algorithm in question, the callback was used to inform the publisher of the message that it was successfully received by the broker.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

At the time of sending the message, a record of the exact time of the action is performed through the timestamp function, when this message is received by the broker, a callback function is used to return the status of the received message. The returned callback is also accompanied by a timestamp function in order to record the moment when the message was received by the broker previously.
Using time of information sent and time of information received, we extract the difference between the values, the result is the total value of the message sending time.

Table 01 presents a total of fifty tests performed for message exchanges between the Gateway and the broker:

Table 01. Communication test with the Broker

Parameters	**Time [ms]**
Nº of Samples	50
Minimum Time	186,699
Maximum Time	390,425
Amplitude	203,726
Average	218,471
Standard Deviation	44,471

Figure 04 shows a graph with the response time variations as a function of the number of samples between the Gateway and the broker:

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

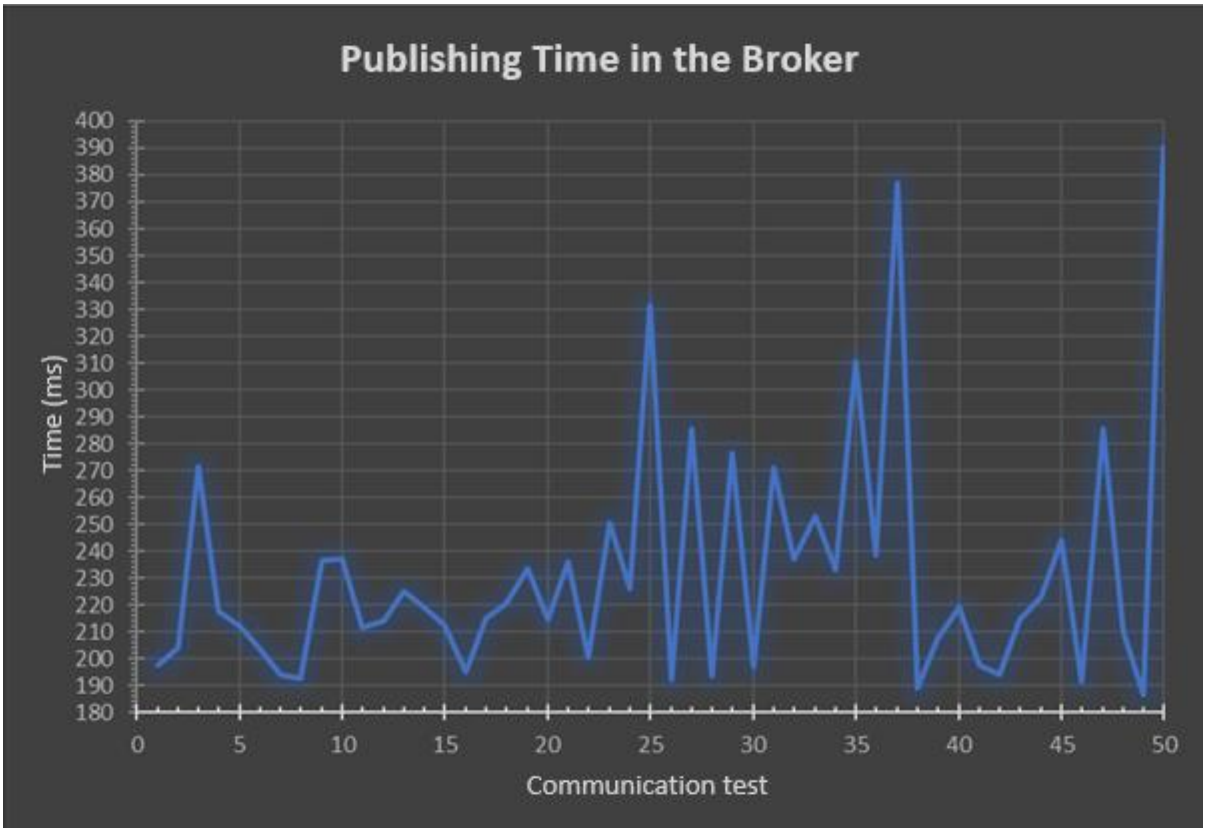

Figure 04. Gateway response time graph for posting to broker.

The time variations in the delivery of the message through the broker showed relatively stable results with standard deviation below the mean.

As for the response time for the local reading of PLC data, specific tests were carried out to monitor this variable. The PLC connection is made through the ethernet port and the communication is carried out through a router that fulfills the role of creating a local network and also providing access to the internet.

The algorithm used to perform the read tests between the Gateway and the PLC follows the same principles exemplified for the broker tests. Having the time stamp functions in sending the information, and the time stamp brought in through a callback function.

Table 02 presents a total of fifty tests performed for message exchanges between the PLC and the Gateway:

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

Table 02. PLC reading test.

Parameters	Time [ms]
Nº of Samples	50
Minimum Time	2,5955
Maximum Time	68,9411
Amplitude	66,3456
Average	13,9616
Standard Deviation	17,2922

Figure 05 shows a graph with the response time variations as a function of the number of samples between the Gateway and the PLC:

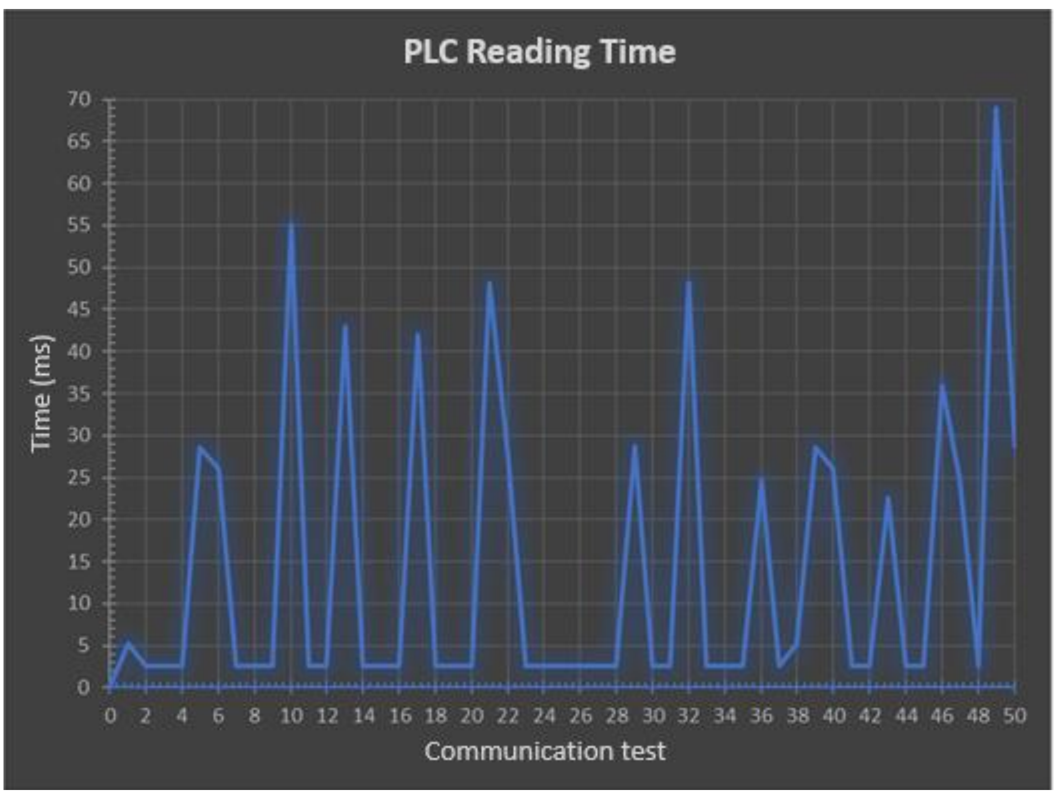

Figure 05. Gateway response time graph to read the PLC for data extraction.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

It is possible to see that at certain times the PLC presented a time variation in the delivery of the readings performed. The reason for the large time variation is inconclusive, but it was observed that the readings performed outside the PVC extruder's working regime showed more stable results.

Therefore, after the construction of the IoT Gateway, it was possible to integrate an industrial technology that did not have connectivity with industry 4.0 resources (PVC film extruder) that uses the Modbus TCP communication protocol (one of the most used protocols in industrial networks)[9], with a remote environment, using Internet of Things (IoT) tools and concepts, enabling control and monitoring from any authorized device with internet access, through the display of dashboard through the web, which is shown below, in the figure 06:

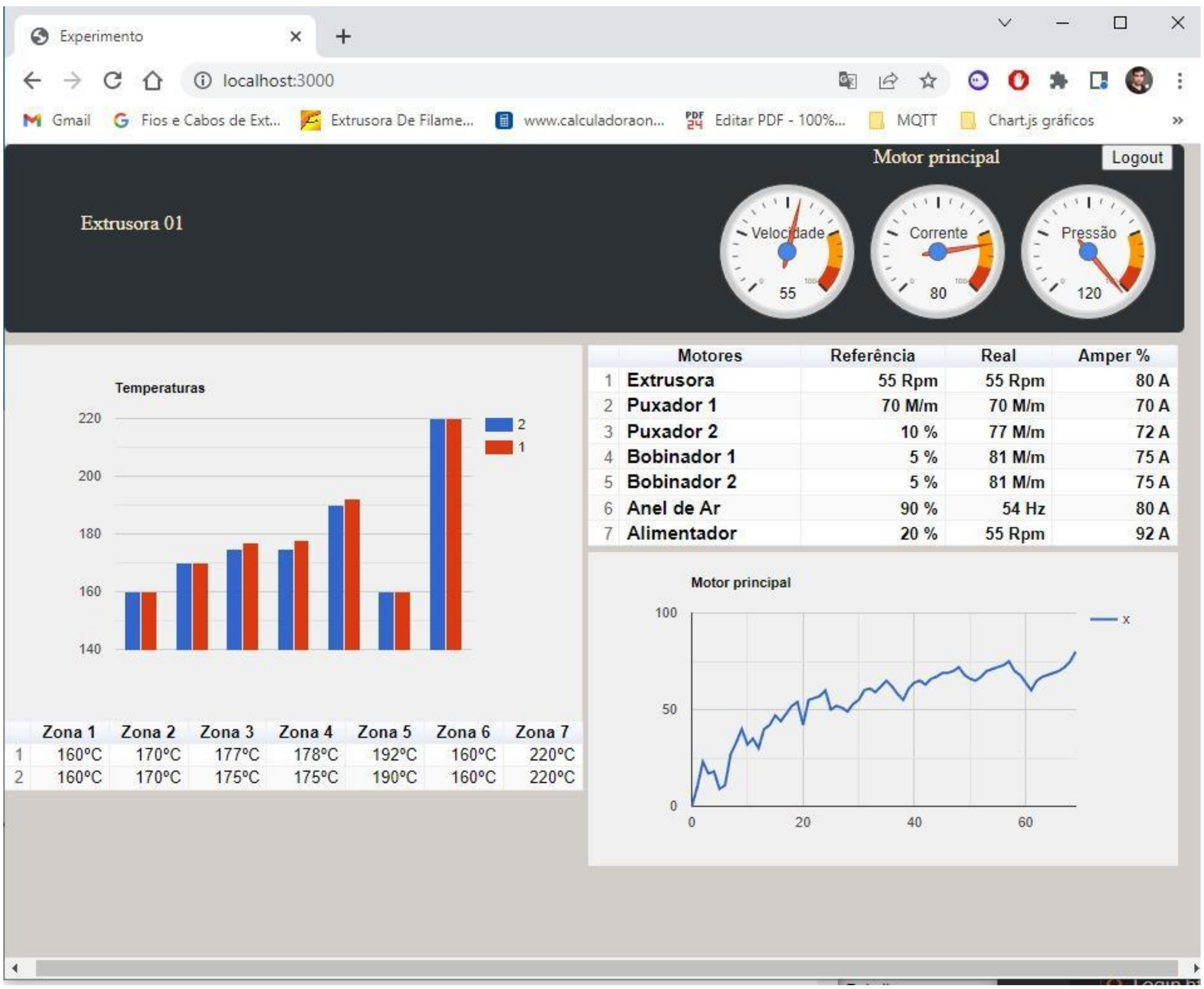

Figure 06. Screenshot containing the dashboard (supervisory) of the PVC film extrusion machine.

TAS Journal, vol. 6, n. 2, p. 128-140
ISSN 2595-1521
JUNE 2022
vgds12@gmail.com

Conclusion. This work was motivated to present a viable solution for the integration of industrial environments and traditional power plants, with new Internet of Things technologies, through research and development of a Gateway, proposing the insertion of machines, equipment and devices without IoT connectivity. within the scope of Industry 4.0.

The conceptual development of the project was carried out in a few main stages, the first being the elaboration of the hardware to be used to collect and receive all parameters, variables and control and/or monitoring points of an industrial plant or electrical power system, aiming at a set of robust, versatile, low-cost equipment, devices and components that are easily accessible in the market. For this reason, meeting the aforementioned requirements, the Raspberry Pi was used as the main hardware, which through this microcomputer and its Pymodbus library, it was possible to collect all the data and points previously required from a PLC responsible for controlling a PVC film extrusion machine.

For the design of a software solution, a server/client application was developed, with both the server and the web application being entirely implemented with open-source frameworks. Some crucial tools for the development of the Gateway were also used, such as MQTT, the protocol that governs the interface between the local environment, the AWS Broker (responsible for managing the exchange of messages and data in a secure, efficient and dynamic way) [10] and the dashboard, which will be used by the end user.

Through the applied case study, that is, the insertion of a traditional industrial environment, more specifically, a PVC film extrusion machine that does not have internet of things connection resources or similar technologies, it was possible to attest and verify the functionality of the Gateway IoT, since this device allowed access to all monitoring and control points of the extruder machine and the environment in which it is located, making this information available in a web application. It is worth mentioning that in addition to functionality, the response time and message exchanges between local and remote environments were also checked, with the AWS Broker, which were satisfactory, according to the graphs and considerations presented in the “Results” field.

It is also important to highlight that future works can take advantage and use the proposed Gateway as an instrument for research and alternative technologies, cooperating and collaborating for the study, advancement and improvement of knowledge, techniques and technological resources aimed at Industry 4.0, as well as the concept of Internet of Things.

References.

(1) Lenon – Opus *Software*. Node.js. [internet]; 2018 [quoted in 10/02/2022]. Available in: <https://www.opus-*software*.com.br/node-js/>

(2) Draft - O que é Indústria 4.0. [internet]; 2016 [quoted in 13/02/2022]. Available in: < https://www.projetodraft.com/verbete-draft-o-que-e-industria-4-0>

(3) GODOI, M. G. de; ARAÚJO, L. S. A INTERNET DAS COISAS: evolução, impactos e benefícios. Revista Interface Tecnológica, [internet]; S. l., v. 16, n. 1, p. 19–30, 2019 [quoted in: 09/04/2022]. Available in: <https://revista.fatectq.edu.br/index.php/interfacetecnologica/article/view/538>.

(4) SANTOS, I.B. Automatização de Processos Rurais. The Journal of Engineering and Exact Sciences [internet]; jCEC, Vol. 06 N. 01 (2020) [quoted in 01/03/2022]. Available in: https://periodicos.ufv.br/jcec/article/view/9356/5226

(5) CORTEZ, H. B. C.; Projeto de um dispositivo IoT para monitoramento do estado de um processo de produção de água purificada. Repositório UFRN, [internet]; 2021 [quoted in 01/03/2022]. Available in: <https://repositorio.ufrn.br/bitstream/123456789/45793/4/TCC_Hugo_Brian_revisado_com_ficha_catalografica.pdf>

(6) VICENTIN, A. Implementação de retrofit em máquinas industriais legadas para a inserção no contexto da indústria 4.0, [internet]; 2021 [quoted in 05/03/2022]. Available in: <https://repositorio.fei.edu.br/handle/FEI/3220>

(7) Núcleo de Pesquisa e Inovação - UniProjeção Centro Universitário [internet]; 2019 [quoted in 09/04/2022]. Available in: <http://revista.faculdadeprojecao.edu.br/index.php/Projecao4/article/view/1359>

(8) Service Drive - Modbus TCP - PLC 300 [internet]; 2013 [quoted in 01/03/2022]. Available in: <http://www.servicedrive.com.br/wp-content/uploads/Manual-do-Usu%C3%A1rio-Modbus-TCP-PLC300-Servicedrive-19-3012-6360.pdf>

(9) Freitas, CM. Embarcados - Protocolo Modbus: Fundamentos e Aplicações [internet]; 2014 [quoted in 20/12/2021]. Available in: <https://www.embarcados.com.br/protocolo-modbus/>

(10) Neri, R; Lomba, M; Bulhôes, G. Departamento de Eletronica - Escola Politecnica UFRJ – MQTT [internet]; 2019 [quoted in 10/04/2022]. Available in: <https://www.gta.ufrj.br/ensino/eel878/redes1-2019-1/vf/mqtt/

Authors ORCID (http://orcid.org/)
Abner Alves Vasconcelos
ORCID: https://orcid.org/0000-0001-8157-5794
João Victor Patrocínio Carneiro
ORCID: https://orcid.org/0000-0003-2062-0453
Vinicius Carvalho Gonçalves dos Santos
ORCID: https://orcid.org/0000-0002-7369-1071
Bruno de Jesus dos Santos (advisor professor)
ORCID: https://orcid.org/0000-0001-5176-4711