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DEVELOPMENT OF INTELLIGENT DEVICES FOR COMMUNICATION AND DATA PRE-PROCESSING IN THE PROCESS OF ELECTRONIC METER TESTING

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ABSTRACT

The main problem of the intelligent devices for communication in the process of tests in production lines that evidences and justifies the development of the research, meets the lack of communication between the various electronic devices, the synchronization of information through a system that allows support for decision making and the need to have this set of data related to production, process and quality as a requirement for framing the pillars of maturity of Industry 4.0. Currently, the companies of this sector do not have an information or intelligent system that allows this data processing, neither the expert systems embedded in hardware to collect data from the manufacturing process of the electronic meter DOW1310L. Considering that the integration of cyber-physical Systems, Intelligent Systems and AI are requirements for the company to increase the maturity of its process according to Ordinance No. 2.091-SEI, of September 17, 2018, it is necessary to develop this project aiming at cost reduction and product quality. The objective of the article is to develop an Intelligent System of Lean Manufacturing capable of promoting the integration of communication to support decision making when using Production Control processes, to ensure product quality, reducing production cost. The materials resulted in the following forms: Cutting Sequence, Z-Safety, Material Thickness, Relief Dimension, Simulation Block Dimensions and Simulation Relief Resolution. Of the methods: Importance of CNC machining, Indication of the axes of the CNC. Keys of operation of the CNC, CNC Interface. Part Machining, DERD, Parameterization, - 3D Modeling of the Pima Verification System, 3D Modeling of the Pima Verification System (Rear View). The results found were: Firmware embedded in intelligent devices for data collection and transmission; Algorithm applied to demand forecast and production indicator in which generate knowledge and are available in Dashboard; Intelligent system with API integration and integration of stacks for optimization of computational processes using modern technologies and frameworks for web development with production engines.

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INTRODUCTION

The Industrial Pole of Manaus (PIM), concentrates a range of applications of raw materials for transformation into final products, because of this, the growing competitiveness in relation to competitors and the demand for new technologies that increase the production capacity and maturity of the company, it is necessary improvement projects, modernization and innovation in factory processes (DESPRES,1991; HOBDAY,1995;

FUNDERBURG, LALL, and YEPES, 2004). The Industry 4.0 is a reality that increasingly grows in the country, the investment in technologies such as Internet of Things (IoT), Big Data, AI, Blockchain, cyber-physical systems and others that aggregate and are part of the pillars of this Industrial Revolution becomes greater, due to a cost benefit of machines, skilled labor and better results (ABIKOYE *et al*., 2021; JAMWAL *et al*., 2021). With the advance of technologies in manufacturing processes aligned to methodologies that enable production efficiency, this project demonstrates a focus on the modernization of factories by using the pillars of Industry 4.0 to enable new perspectives of investment and framing of the company in the process maturity requirements (OZTEMEL and GURSEV, 2020; CUNHA *et al*., 2020). The research proposal occurred due to the preparation of a project in order to encourage the development of this new perspective of intelligent manufacturing and modernization of its process aimed at reducing costs and product quality (MISRA, N. N. *et al*., 2020). The research covers technologies such as: Internet of Things (IoT), Intelligent Manufacturing System and AI, characterizing a bounded project using devices and sensors that use communication technologies to exchange data intelligently on server, requirements aligned to the Lean Manufacturing to work the data processing reaching the expectation of the company and AI to optimize the results for decision making with Machine Learning Algorithms and Deep Learning (IUNG, 2003; WANG *et al*., 2020; SANCHEZ, EXPOSITO and AGUILAR, 2020; SOLDATOS *et al*. 2020). The research design adds innovative technologies through the pillars of Industry 4.0, however, the application potential becomes greater when analyzed by a macro view of the company's reality, where it is possible to add other technologies for optimization, process improvement, robotization and especially intelligent projections of previously programmed scenarios through Intelligent Systems (BRUNETTI, Federico *et al*., 2020; SEPASGOZAR *et al*., 2020; OZKAN-OZEN and KAZANCOGLU, 2021). A potential application case is the use of Big Data to analyse other means of process improvement aggregating different sectors of the plant such as: logistics and materials. Another potential application is the use of Cybersecurity when using Blockchain Algorithms to improve the integrity of the information and the Systems that come to be integrated via Cloud Computing or through local Servers.

LITERATURE REVIEW

Electronic meters: Electronic energy meters: According to NBR 14519 [NBR, 2020], electronic electricity meters are static meters in which current and voltage act on solid-state elements (electronic components) to produce an output information proportional to the amount of electricity measured. These meters are basically composed of transducers, multipliers, integrators and recorders (Valle, 2018; Caio Jodas *et al*., 2022), the following diagram illustrates, as shown in Figure 1.
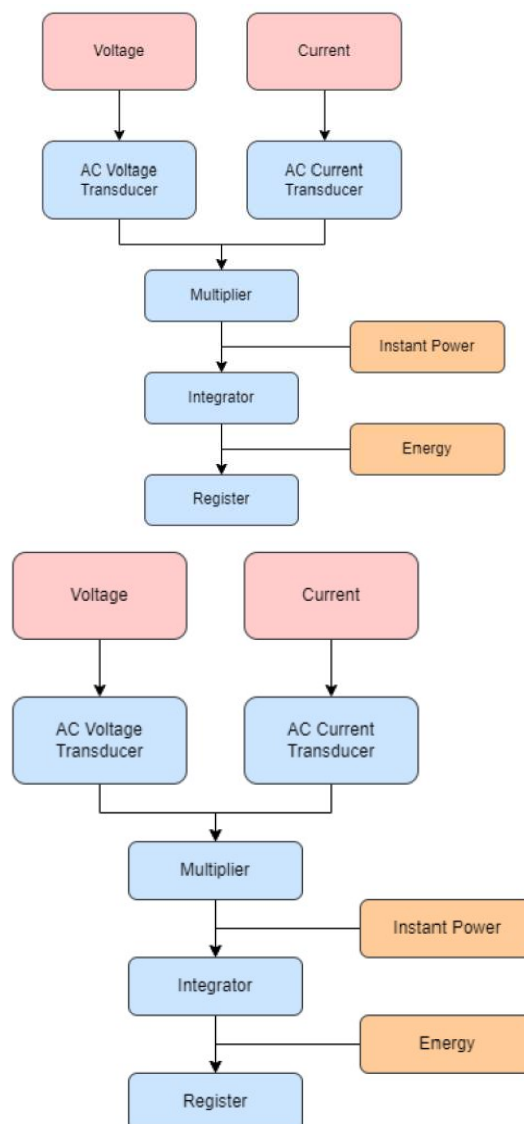
Fonte: CAIO JODASet. al., (2022).

Figure 1. Diagram of an electronic meter

Exemplified in Figure 1, voltage and current transducers do the acquisition and adjustment of the input signals to be multiplied. The multiplier in turn determines the instantaneous power by multiplying the voltage and current signals coming from the transducers. The power is obtained by integrating the instantaneous power which is performed by the integrator. Finally, the result is shown in the recorder (OLIVEIRA, 2017; GODOI, 2018). The power can be observed by means of equation (1) (CAIO JODAS *et al*., 2022).

$$p(t) = v(t) . i(t) \tag{1}$$

For analysis in alternating current (AC) circuits, equations (2) and (3) provide the instantaneous voltage (V) and current (A), respectively (CAIO JODAS *et al*., 2022):

$$v(t) = Vmsen(wt + \alpha) \tag{2}$$

$$i(t) = Imsen(wt + \beta) \tag{3}$$

Being:

Vm and *Im* the peak values of voltage (V) and current (A), respectively; *w* the angular velocity, measured in (rad/s); *α*and *β* are the angles (rad) of displacement of voltage and current, respectively.

Resulting in equation (4), the instantaneous power (W) (CAIO JODAS *et al*., 2022):

$$p(t) = VmImsen(wt + \alpha)sen(wt + \beta) \tag{4}$$

Then, according to (Linhares, 2017; Silva, Cordeiro and Medeiros, 2012) the integrator sums all the instantaneous powers, which is presented by the following equation, (5), providing the energy consumed and that will be presented by the recorder (CAIO JODAS *et al*., 2022):

$$e(t) = \int_0^t p(t)dt = \int_t^t v(t).i(t)dt \tag{5}$$

Electromechanical and electronic meters were designed to operate in linear systems, i.e., in pure sinusoidal conditions of the voltage and current signals (SUHETT, 2008]). Measurements made by an electromechanical meter and by an electronic one gave similar results, showing good functioning of both. However, according to (Ferreira, 2013; Nóbrega Sobrinho, 2015; Ribeiro, 2015) when in presence of non-linear loads, meters present higher errors in the measurement due, mainly, to the low power factor. This is due to the fact of increasingly having the use of non-linear loads connected to the network as air conditioners, computers, induction motors (lifts, pumps, compressors among others) that cause harmonic distortions in the voltage and current signals.

Operating principle of the electronic meter: The measuring principle is briefly described by means of a block diagram as shown in Figure 2, below. The main inputs to the meter are shown on the left, identified the phase (L1, L2, L3) and neutral (N) connections for energy measurement and for power supply to the meter, as well as, the control inputs (E1, E2) for switching the energy tariff (FRENZEL, 2012; SILVA, 2012).
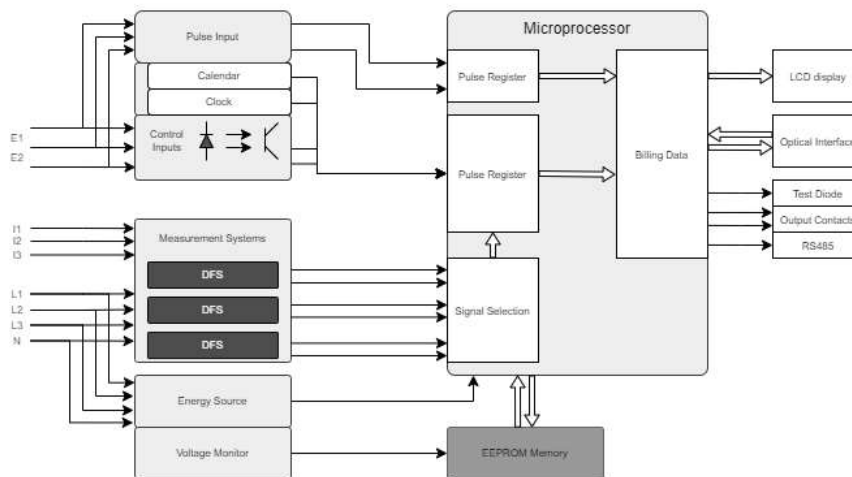
Source: CAIO JODAS *et al*, (2022).

Figure 2. Three-phase meter block diagram.

The main output of the meter is shown on the right (as well as the optical interface input), in Figure 2, the identification display (LCD - display) is used to read the measured energy value (usually with 8 digits, additional information is used for energy direction, phase presence, phase sequence, applied energy and current tariffs), test diodes, optical interface constants read automatically in the field via reader (portable terminal) and PC's with optical port and output contacts for pulse constant transmission selection (CAIO JODAS, 2022). The power supply of the electronic instrument comes from a three-phase voltage circuit. The voltage monitoring circuit ensures efficient operation and data storage in case of power failure, as well as a proper restart when power is restored. The measurement system is based on the integrated DFS technology (Direct Field Sensor, based on the "Hall" effect) and generates a signal proportional to the power per phase based on the applied voltage and the circulating current. This signal is converted into a digital signal for further processing by the microprocessor. The current is usually detected by a "Hall" effect sensor and the voltage is detected by a resistive voltage divider (HANNAH and POLLOCK, 1990). The signal processing is performed by a microcontroller that sums the digital signals of the various phases and forms fixed energy pulses. It divides these pulses into positive and negative ones based on the direction of the energy flow (WU, 2017).

It then processes them according to the measurement constants and provides information to the corresponding registers according to the tariffs determined by the tariff controller. The microcontroller also controls the data communication with the display, the optical interface and also ensures safe operation even in the event of a power failure. A non-volatile memory (EEPROM) contains the parameters set in the meter and secures the billing data - energy data - against loss in the event of a power outage.

Meter calibration: The calibration is the determination of the meter's errors, through comparison with service standard meters, and its compliance with the operation conditions established in the metrological legislation.Meter calibration can be performed by the Network of Accredited Laboratories, according to NBR ISO/IEC 17025 INMETRO. The tests are carried out through the use of meter calibration benches. The benches have a standard meter, which is calibrated by an accredited laboratory and periodically tracked by INMETRO. The Figure 3 shows an example of a bench, observing that this model has 24 positions for accommodation of the meters and beside it there are amplifiers, devices simulating the standard meters.

Source: Authors, (2022).

Figure 3. Benchmarking/adjustment of electronic meters

Besides the physical structure, shown in Figure 3, inside the adjustment and gauging bench, there are battery banks, hardware for serial communication via RS485 bus and other elements. During the meter manufacturing process, it is necessary to verify and adjust meter errors. The electronic electric energy meters in use, have the accuracy classes as presented in Table 1, regulated through the Metrological Technical Regulation (RTM) according to Inmetro Ordinance No. 587, from 05 January 2012.

Table 1. Percentage error limits for active power measurement.

% In	Cos φ	Percentage error limits for meters with class index			
		D	C	B	A
10	1	+/- 0,2	+/- 0,5	+/- 1,0	+/- 2,0
100	1				
100	0,5 ind	+/- 0,3	+/- 0,6		
100	0,8 cap				

Source: Authors, (2022).

As shown in Table 1, the accuracy test (Current variation) for active energy meters should be carried out at nominal current for cos = 1, cos = 0.5 inductive, cos = 0.8 capacitive and 0.1 In current with cos = 1, using the nominal or supply voltage, as appropriate. Polyphase meters must be polyphase checked. When meters have the function of reactive energy measurement, the error limits shall be followed as presented in Table 2.

Table 2. Percentage error limits for reactive energy measurement

% In	Cos φ	Limites de erro percentuais para medidores com índice de classe			
		D	C	B	A
10	1	+/- 0,4	+/- 1,0	+/- 2,0	+/- 4,0
100	1				
100	0,5 ind	+/- 0,6	+/- 1,2		
100	0,8 cap				

Source: Authors, (2022).

The accuracy test for reactive energy meters shall be performed at rated current as presented in Table 2, for sen = 1 inductive, sen = 0.5 inductive, sen = 0.8 capacitive (if applicable) and 0.1 In current with sen = 1 inductive, using the rated or supply voltage, as applicable.

Parts of the electronic meter: According to (Do Carmo Miranda,2011), the electronic electric energy meters, in general, are made up by the following modules:

- ***Connection module:*** It consists of the connection block of the measurement transformers, resistive splitters and auxiliary signals. The current transformers and the resistive divisors work as sensors for the quantities of interest and as protection for the meter's electronic circuits against external electrical disturbances.
- ***Measuring module:*** It comprises the measuring circuits and the power supply. The primary function of this module is to transform the input signals from analog or continuous form to digital or discrete form, through A/D (Analog/Digital) converters, as well as to process these signals. For this, an electronic microprocessor is used.

- **Recording module:** It is composed of the electronic circuit to record the quantities processed in the measurement module, mass memory, communication interfaces, user interfaces (display and operating and command keys and real time clock.
- **Housing:** It is a module designed to provide mechanical support and protection, both mechanically and against the weather, to the other components of the meter.

Data acquisition: In electronic meters, data collection is performed by sensors. The characteristics of a sensing element are: transfer function, saturation, output impedance, excitation and frequency response.The main characteristic of the sensing element is the transfer function, which establishes the relationship between the input signal and the output signal, always determining the optimal transfer function of the sensor. Saturation must also be considered, because all sensors have operating limits beyond which linearity can be lost (YANG, 2007). The output impedance of the sensor is important for designing and measuring the system interface circuitry. For voltage output, the output impedance should be low and the input impedance should be high. On the other hand, for current output, the output impedance should be high and the input impedance should be low. The excitation characteristic specifies the amount needed for the sensor to operate (SONG *et al.* 2015).The signal processing is performed by a microcontroller, which sums the digital signals from the individual phases and forms pulses of fixed energy. It divides these pulses into positive and negative ones based on the direction of the energy flow. It then processes them according to the measurement constants and feeds the corresponding registers with the tariffs determined by the tariff controller. The microcontroller also controls the data communication with the display (display), the optical interface, which ensures safe operation even in case of power failure (CANESIN *et al.*, 2008; SILVA, 2008).

Current sensor - shunt resistor: The most commonly used process of measuring electric current in a circuit is done by introducing a shunt resistor in series with it. When a low ohm resistor is connected in series with a circuit, current flows through the shunt resistor-R- and generates a voltage drop. Figure 4, shows the example of typical shunt measurement connection in a simple circuit.
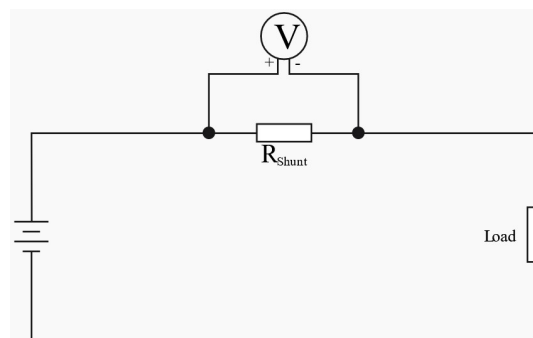
Source: Authors, (2022).

Figure 4. Measurement connection via shunt

The voltage drop can be measured by applying Ohm's law to calculate the current, as follows from equations (6), (7) and (8).

$$I = V/R \tag{6}$$

$$V = IxR \tag{7}$$

$$R = V/I \tag{8}$$

Where:

V: Voltage
*I: Current*
R: Resistance

Ohm's law describes the relationship between voltage (V), current (I) and resistance (R). If two of these three are known, one can easily calculate the third by simple arithmetic. Therefore, if data of the voltage (dropout) and the resistance is available, the current can be calculated using equation (6).The shunt resistor must be chosen for the appropriate voltage and current range, because too high a resistance will affect the measurement and waste energy and distort the measurement as the resistor heats up.

Technological advances: For Pontes, (2017), the evolution of the analog meter brought to the national market the electronic meters, with considerable improvements for the utilities, ease of installation, operation, readings being able to incorporate new features, such as reactive electric power measurement, bidirectional measurement, hourly-seasonal pricing, communication via peripheral outputs etc. The Smart Grid is a technological innovation, an alternative to meet the needs of electricity distribution. It has acquired space in other countries as well as in Brazil, in view of events in the electricity sector with constant failures and surges. The term Smart Grid (from English) refers to an electric power system that uses information technology to make the system more efficient (economically and energetically) reliable and sustainable (SANTOS, 2018).It can be considered that Smart Grid (SG) or Smart Energy Network (IER) is the application of information technology to the power electric system, integrated with communication systems and automated network infrastructure (RUIZ-ROMERO2014). As a goal of IER, it is sought the production, transport, distribution and final use of electric energy in an efficient, environmentally sustainable, economically viable, and reliable, safe and resilient way (SAFARI, AMIR *et al.* 2019).In Brazil, many utilities tend to adhere to the SmartGrid, because it is a system that automates not only the monitoring, but also the entiremanagement of electricity use. This internal implementation requires the adoption of a systemthat integrates the operation of Operational Technology (OT) with IT (GALO, *et al.* 2014).The Smart Grid is a new model, interactive both for energy generation sourcesas for the loads. The old central and vertical model is replaced by a distributed anddisaggregated in which different customers emphasize different aspects of the new electric grid according toaccording to their perspective (SANTOS, 2018).
Figure 5, shows the power grid model adopted in Brazil. It is a central and vertical system
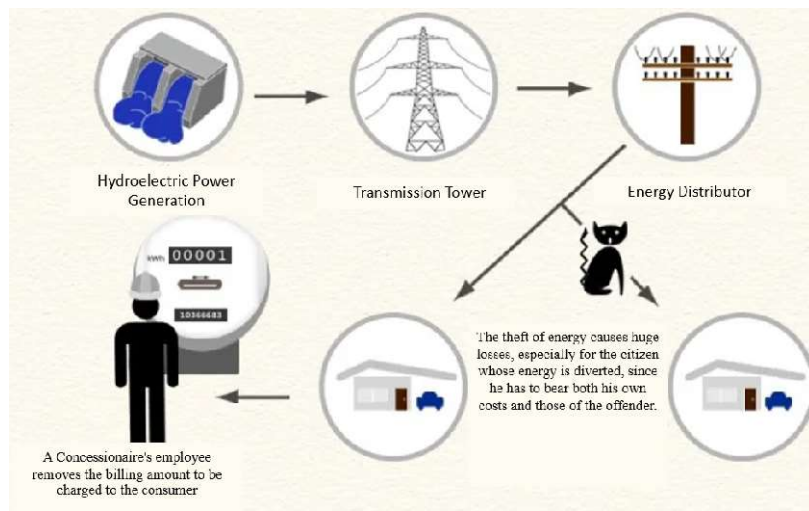
Source: Authors, (2022).

Figure 5. Model of the electric grid in use in Brazil

According to Figure 5, initially energy is generated by means of hydroelectric power plants and is transmitted by distribution towers to the distributor. On the way between the distributor and the customer, there are often energy deviations, causing irreparable losses. Finally, an employee of the concessionaire measures the consumption for billing directly at the consumer unit. SG has the potential to modernize the RE, with the use of IoT. Figure 6, shows the Smart Grid system diagram in Brazil. In this system, it involves the application of processors, with the purpose of performing tasks on the microsecond scale, intelligent applications, demand management, to optimize generation costs and energy use, sensors, to identify abnormalities in the system. In short, it is a modernandinterconnected system.
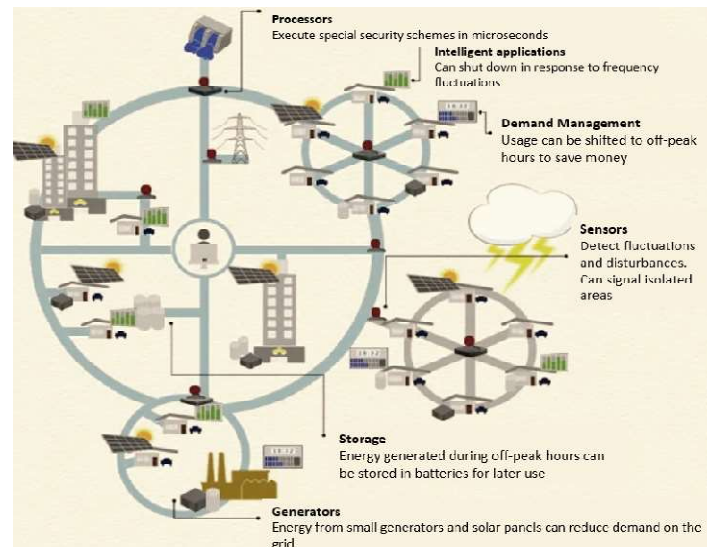
Source: Authors, (2022).

Figure 6. Diagram of the Smart Grid system

In this new model, there is high speed with advanced measurement and control technologies, a bidirectional communication infrastructure supports the networks. Through interconnection between the transmission and distribution structure, consumers and generators become interconnected with new network components of intermittent nature - energy storage units and renewable sources.With smart meters, data is provided to the utility through remote, real-timeremote collection in real time, at pre-determined time intervals, without the need for andisplacement of an employee to the residences (RIBEIRO, 2015).

Architecture of communication networks: According to (SONG, 2015), an IoT communication network architecture can be divisible into three stages: perception, network and application. In the perception stage, are the devices such as sensors and actuators. In the network stage, where the data and information obtained in the perception stage are transmitted throughout the system. In turn, in the application stage is where the data obtained by the whole system. In turn, in the application stage is where the data obtained in the previous stages are processed and treated by computational intelligence algorithms. This is a relevant point, since the stages based on the IoT concept can also be applied to IoT and Industry 4.0, given that the stages of obtaining and communicating data are carried out in a similar way, as can be understood in the following examples:

- Smart distribution grid: The energy utility can install a smart meter in a distribution substation to realize the perception of information about the electrical energy consumed at that connection point and send it through the connected communication network so that more efficient operations and controls can be performed.
- Smart home/industry: The consumer can install a smart meter to perform the perception of information about their consumption (In real time, daily, monthly, peak times, different environments and devices etc.) and send the information over the connected communication network to apply energy efficiency methods through computational intelligence and control and automation systems, or send it to the RDI itself and

make this information available to the utility, becoming part of the RDI as an active component, i.e. that starts to communicate directly with the REI.
- The perception, network and application stages of these IoT networks can be divided into function layers. This segregation is also used by the model in IoT technologies. Table 3, shows the main protocols used in the five layers of the TCP/IP model for IoT networks (SHARMA *et al*. 2020)**.**

Table 3. TCP/IP network models and IoT Protocols

Camadas	Protocolos
Aplicação	CoAP e MQTT
Transporte	TCP e UPD
Rede	IPv6 e 6LowPAN
Física e Enlace	IEEE 802.15.4, IEEE 802.11 e IEEE 802.15.1
Todas as camadas	Z-Wave, Zigbee, LoRaWAN, NB-IoT

Source: Authors, (2022).

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Source: Authors, (2022).

Communication Protocols applied in IoT: In Industrial Internet of Things (IIoT) Technologies, the communication bridge and data exchange between sensors, devices, gateways, servers and user applications is enabled by network protocols such as WiFi, Bluetooth, ZigBee and others. The end application requirements of range, data, security, power and battery life determine the choice of network protocol. This paper explores some of these technologies and communication protocols (NING, HUANSHENG; HU, SHA. 2012).The data layer is concerned with the data collected, processed, sent, stored, analyzed, presented and used in business contexts, that is, the Business Intelligence. The application layer is the component that allows humans to interact with IoT devices (VARSHNEY, TANISHQ *et al*., 2019). The inherent adaptive and reliable nature of the Internet Protocol (IP) makes it an acceptable medium for transmission between IoT modules. The system architecture (through which data must travel) determines the type of IoT protocol. The Open Systems Interconnection (OSI) model provides a map of the various layers that send and approve the receipt of data. Each protocol in the IoT system architecture enables device-to-device, device-to-gateway, gateway-to-data centre communication, gateway-to-cloud communication and communication between data centres (CHANAL, POORNIMA M.; KAKKASAGERI, MAHABALESHWAR S., 2020). Table 5 presents the IoT protocol stack.

Table 5. IoT protocol stack

ApplicationLayer	CoAP	AMQP	DDs		MQTT
TransportLayer	UDP		TCP		
Network Layer	IPv6	ICMPv6	RPL		
AdaptationLayer	BLE 6LowPAN				
Physicaland Link Layer	IPSP		SoftDevices BLE, LTE, NFC, RFID, WiFI		

Source: CHANAL, POORNIMA M.; KAKKASAGERI, MAHABALESHWAR S., (2020).

With the application of protocols the sending of data becomes encapsulated and safe which prevents possible malicious interceptions to capture data improperly, in addition, it is a way to manage devices remotely in environments where the communication processes are necessary and the use of these mechanisms ensure quality in the process (CHANAL, POORNIMA M.; KAKKASAGERI, MAHABALESHWAR S., 2020).Thus, a simple way to understand what the Internet of Things is is to think that now are the most varied objects of everyday life that generate and consume information on the Web and, through this, interact and offer services to people. The European Commission, meanwhile, defines it as being "single identity objects operating in smart spaces to connect and communicate in social, environmental and user contexts". The origin of these different definitions is the way the Internet of Things is seen and the abstraction used: oriented to things, Internet-oriented and knowledge-

oriented (SANTOS, 2018). With that, the interconnection of devices, sensors and actuators providing the ability to share information across platforms through a unified framework, develops a common operational scenario enabling innovative applications The advent of wireless technology brought mobility to the network in a way that opened precedents to explore the possibility of adding other devices to the network, which were not exclusively computers. Thus, in recent years, the Internet has started connecting other devices (such as smartphones and tablets), considerably increasing the population of nodes on the Internet (KUMAR, GULSHAN *et al*., 2021).It is in this scenario that the Internet of Things (IoT) paradigm emerges (Figure 7).
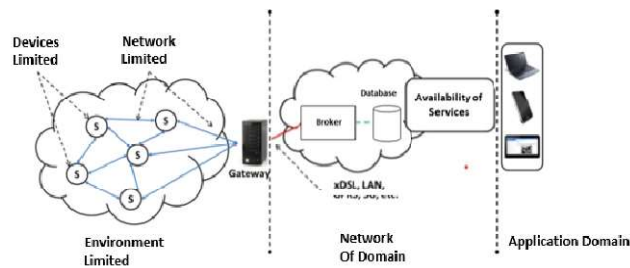
Source: (ALBERTI, ANTONIO MAZZZER*et al*., 2017).

Figure 7. Conceptual model of architecture limited to IoT applications.

Despite the efforts to standardize and unify communication protocols, with the development of IoT objects carried out by several manufacturers, using different protocols at the higher layers, as of application, interoperability has proved to be one of the biggest challenges for this new reality (ALBERTI, ANTONIO MAZZZER*et al*., 2017).

MATERIALS AND METHODS

Materials

The materials present the three parameters:

- Cutting Sequence
- Z-Safety
- Material Thickness

Cutting Sequence: This option is of utmost importance in case of several joints of vectors in the same path, because it is possible to select by which joint of vectors the machining will start. Knowing this, there are two options for cutting sequence: "Automatic" and "Manual". The "Automatic" is the sequence set by the software itself, the "Manual" is set by the user, thus indicating where to start. It is recommended to select the "Automatic" sequence.

Z-Safe: The Z-Safe is the height, after machining has been completed, at which the tool retracts. The "X-start", "Y-start" and "Z-start" indicate the starting positions at which the tool will start the machining process. Following in the context, the "Safe-Z" was 10 millimeters, in many cases, it is not convenient to use high values in this parameter, since after finishing the machining the tool will move up or down according to the determined value. The "Start Z" was 10 millimeters, this value is important when there is the creation of several paths, because after ending a path it is necessary to remove the tool from inside the material so that it then moves on to the next path, thus avoiding damage to the tool and the material. Therefore, the CNC tends to retract according to the value referenced in "Start Z" and then it moves on to the next stroke. The "Start X" and "Start Y" have been referenced with 0 millimeters, because there is no need to retract or advance these two parameters, since it will not affect the going to the next stroke.

Material Thickness: As the name implies, it is used to define the thickness of the material and the starting point for machining. This option can be modified in the "Options" tab or in the material configuration area.After setting the parameters correctly and according to need, the next step was to define a name for the toolpath and click "Calculate Now", this way the toolpath was created:

- After the creation of the route, it was necessary to simulate it, for this, in the area called "Route", there is an item called "Simulation", within this item there are two interesting options: "Simulate Route" and "Simulate All Routes". "Simulate Route" is the option where the simulation will occur for one route at a time. "Simulate All Routes" is the simulation of all the routes together.
- After clicking "Simulate Route", the window called "Route Simulation - Block Definition" will appear, where there is the following separation:- Dimensions of the Relief;- Dimensions of the Simulation Block;- Resolution of the Simulation Relief;

Relief Dimensions: Area where it contains the dimensions of the material to be used, minimum height, maximum height, width and height. In this case, minimum height is -12.7 millimeters and maximum height 0.0 millimeters, the minimum height is negative because the machining will start from the top (zero piece of material) with negative direction, ie, machining down. Material width is 1000 millimeters and height 500 millimeters.

Dimensions of the Simulation Block: There are two parameters to analyze and two to choose which one is best suited to the need. The parameters to analyze and confirm that it is in accordance with the pre-established are "Block top face at height" and "Block bottom face at height," these settings are related to the direction that the machining will have, i.e., if the machining will be from top to bottom, or the other way around, because depending on the choice, the sign of the values will invert and so will the order. In the context used, since the machining will be from top to bottom, the upper side of the block is indicated by 0.0 millimeters and the lower side of the block is indicated by -12.7 millimeters. The parameters for choosing which one is best are "Entire Model" and "Within Vector". They are related to the form of machining, ie, there is the option to machine all the vectors at once automatically, without the need to create several paths, this option is the "Whole Model", is widely used in the machining of custom images. The "Inside Vector" option is used to machine one path at a time. In the case of the figure below, as there is only one path created, both form meet the need*.*

Resolution of the Simulation Relief: This is the section where the resolution in which the final product of the simulation will appear is defined. Therefore, most of the times the option "Standard" is used.

- With the simulation done successfully, the next step is to save it, for this, still on the tab "Course", you must click on "Save Course As...". The "Save Courses" window will appear. Naturally all the courses created will be in the "Courses to Save" area, but it is not possible to save all the courses together and it is also not recommended, because at the time of machining, it is better to do it with one course at a time. Therefore, it is necessary to move the tool paths that will not be used at the moment to the "Calculated tool paths" area and save what you have in the "Tool paths to save" section, but to perform this procedure it is necessary to find a destination for these files and paste it in the "Save" option, indicated by the orange arrow, after that, indicate the name of the file in the "File Name" tab, it is interesting that it be the same name as the tool path created to avoid confusion, and then choose the format in the "File Format" tab, in most machines the "G-Code (mm) (*. tap)" format is used in most machines.
- The path in G-Code format will be created in the folder selected previously, this way the file is ready to be inserted in the CNC.

Methods

Importance of CNC machining: Within industry, new devices and parts go through several stages before reaching the manufacturing process, known as machining. Machining is the process directed towards the production of parts, tools and mechanisms using a raw material. These accessories are manufactured by machines and then delivered for use. Moreover, this process arose to improve and achieve a large demand for a particular product, being able to make it on a large scale while maintaining the quality or in smaller quantities, valuing the quality in the same way.One of the machining processes that contributed greatly to technological advances and continues to be a trend with applications increasingly wide is the CNC machining. CNC stands for Computer Numeric Control, which means that it is a system that after being installed on a machine tool, seeks to control it, such as lathes and machining centres. With the installation successfully done in a machine tool, it is possible to control the axes X, Y and Z simultaneously, based on a code called G-Code. The G-Code is responsible for communicating to the system which movements will be executed by the machine tool as shown in Figure 8.

Source: Authors, (2022).

Figure 8. Indication of the CNC axes

As shown in Figure 9, the Z axis is the axis related to the ascent and descent of the machine, the X axis indicates which way (left or right) the machine will act and the Y axis is the forward and reverse direction. It is important to note that the axis signals are not ignored, since in G-Code, the signals indicate which directions the machine must follow.The advantages that explain the importance of the use of CNC are several, such as: More flexibility, greater precision, greater quantity of operations, varieties of operations with the same fixture, greater productivity of the machines, short production time when compared to conventional systems, among others.As said before, the CNC system must be coupled to a machine tool, as lathes. There is also the possibility of coupling it to milling machines, which are machines that have several features such as: cutting, grinding and drilling. Knowing this, the CNC Milling Machine was the device used to manufacture the part, as shown in Figure 66, because it contains the primordial functionality for such manufacturing. Next it will be possible to observe and analyse the machining process on a CNC based on a logbook.

Source: Authors, (2022).

Figure 9 - CNC

- First step was to turn on the CPU at the back of the CNC, this is done by clicking the ON/OFF button as shown in Figure 10.
- There are some keys that are necessary for the perfect operation of the machine, as shown in Figure 11.

The first, indicated by the blue arrow is responsible for initializing the CNC system and screen, when this switch is activated, the blue light is on. The second, indicated by the black arrow, is the key that activates the electronics. The third, referenced by the orange arrow, is to control the spindle of the CNC milling machine axis, that is, to manually control the axis rotation speed. The fourth, referenced by the yellow arrow, is responsible for activating the Spindle operation and, the fifth, indicated by the green arrow, is the emergency button, which in case of something out of control, locks the entire system so as to completely stop the machine.
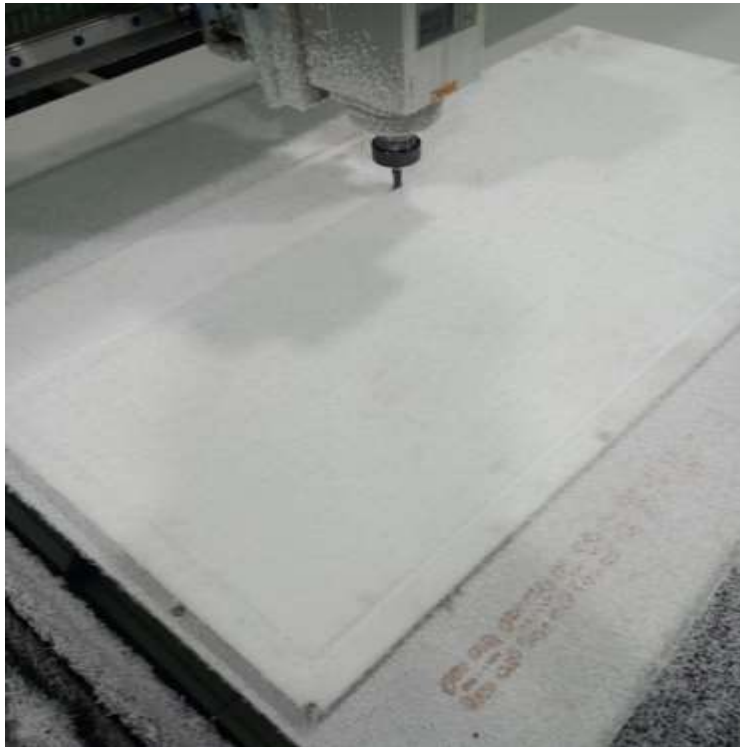

Source: Authors, (2022).

Figure 11. CNC operating keys.

- With the CNC turned on, the pen drive was inserted into the USB input of the CNC, this was important because the G-Code is on the pen drive and the same, as said before, is responsible for the instructions of movements, speeds, bridges, among other actions and settings.
- After the initial settings was necessary to enter the Mach3 CNC software. Then there are screens and buttons that are necessary to understand to machine correctly as shown in Figure 12.

- The next step was to clamp the workpiece on the table, so as not to allow it to move during machining and also to reduce the impact of possible unwanted bends in the material, leaving it as straight as possible.
- Then, to monitor the machining process of the CNC contains the codes in progress of the machining operation of the part, this code generated earlier and, as said, will control the movements to be performed, as shown in Figure 13.

Source: Authors, (2022).

Figure12. Interface CNC

Source: Authors, (2022).

Figure 13. Part machining.

As shown in Figure 14, it was possible to finish the machining operation successfully, given that the part was completed without damage to the material and the tool, and the dimensions also remained unchanged.
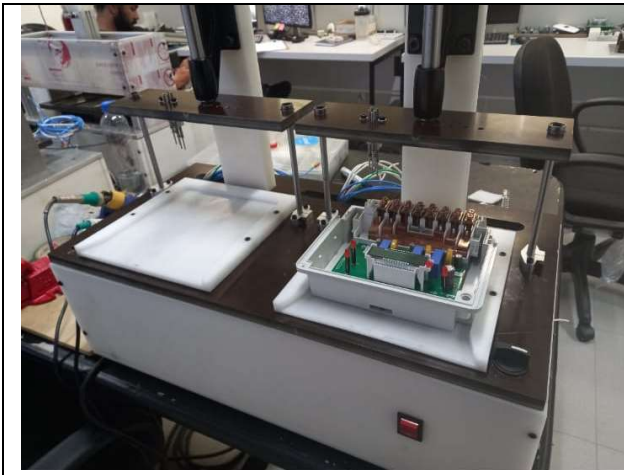

Source: Authors, (2022).

Figure 14. Machined part

The manufacture of the other parts were performed as described above, all went through the 3D modeling stage, technical drawings were created, exported to the ARTCam software, which were vectorized and finally machined.

RESULTS AND DISCUSSIONS

SIME Development/Mechanical Development: The mechanical development of the devices allowed to embark the data collection systems that communicate via Raspberry PI to send data in a programmed way considering the volume of accesses that each device will make. The creation of these devices allows the company to climb stages of maturity in the process, where these devices that have communication technology allow to take advantage of the resources of protocols and layers of the OSI model to transport data, raising the stages 1, 2 and 3 of maturity in the process as shown in Figures 15 and 16.In this case, the PIMA Verification System is a device that aims to monitor the meters in order to present on an LCD the data capture and the verification if the meter contains the correct data, this verification is done by the RJ 45 path PIMA protocol connector. Therefore, this is an equipment of paramount importance to ensure correct data delivery. To conclude successfully the prospection of the device, it became necessary to model a visual prototype, as shown in Figure 17 and Figure 18 to perfect the project and validate all the mechanical, electronic and pneumatic parts. Moreover, this prototype helps in the development of the manufacturing process of the parts, because it performs dimensional analysis of each modeled part.
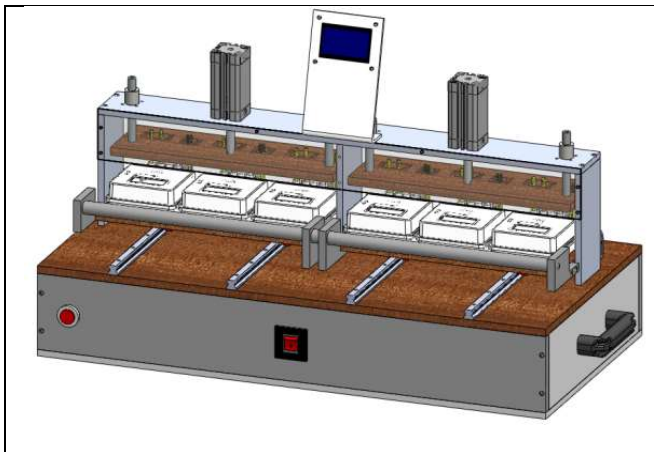

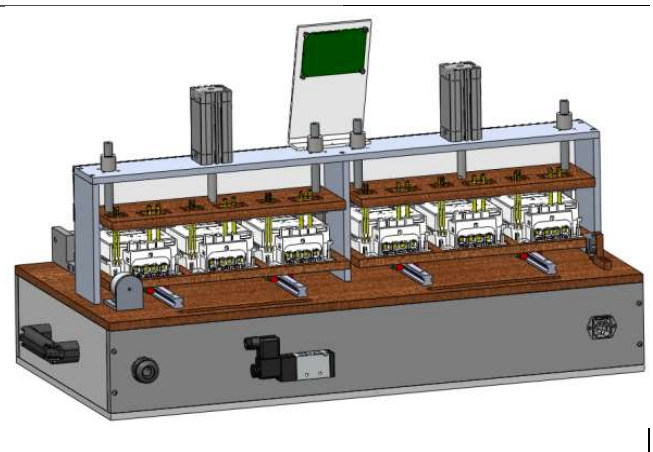Source: Authors, (2022).

Figure 15. DERD

Source: Authors, (2022).

Figure 16. Parameterization

Source: Authors, (2022).

Figure 17. 3D Modelling of the Pima Verification System.

Source: Authors, (2022).

**Figure 18. 3D Modelling of the Pima Verification System (Rear view).**

As shown in Figure 19, the SolidWorks software also helps in the calculation of mass properties, making it possible to verify the total mass of the device, its centre of mass and among other properties. The main parameters to be evaluated are the total mass and the centre of mass, because in the case of the equipment in question, there may be the need to move it to another location, so the mass of the device directly influences the ease of handling it, for example.

Aligned to the explanation of mass, the explanation of mass centre is also adequate, because in this case it directly affects the positioning of the handles on the equipment, because by being directly in the centre of mass, it facilitates the balance of the equipment in case of handling, thus avoiding possible tipping.

The equipment in question was planned based on three important parts, they are: Lower Base, Upper Base, Meter Cradle.

- Lower Base: It is the part that stores both the electronic and electrical devices, in addition, it receives four parts in its lower part that will serve to lift and sustain the equipment. The material used was Nitacetal.
- Upper Base: Piece that stores the entire upper structure of the equipment, from the rails to the base of the pneumatic cylinder. The material used was Phenolite.

- Cradles: Used to allocate the meters with the best possible dimension so as not to become narrow and cause interference at the time of allocation, as well as not to leave too many gaps, so as not to keep the meter completely fixed. The material used was Phenolite.
- In Figures 20 and 21 will be possible to observe moments of machining of the three pieces cited above, starting with the Lower Base.
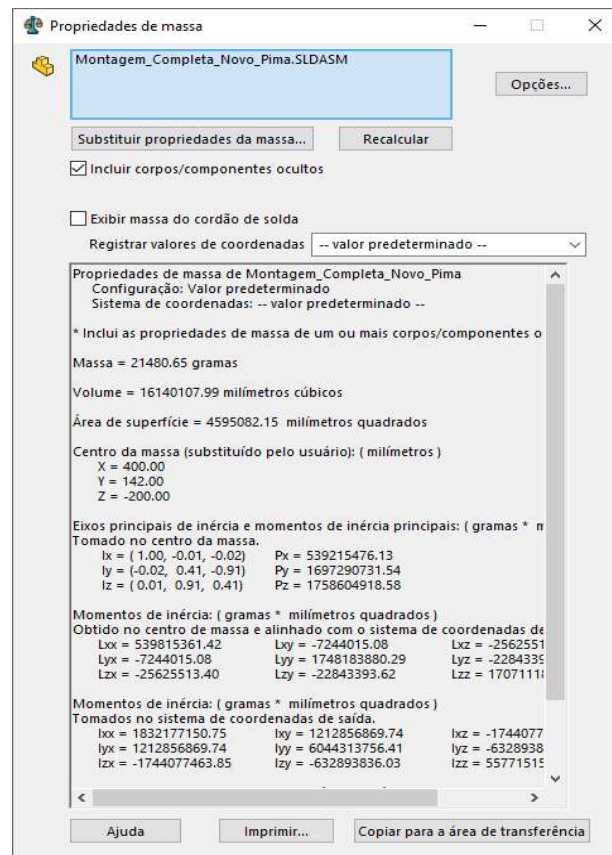
Source: Authors, (2022).

Figure 19. Mass Properties
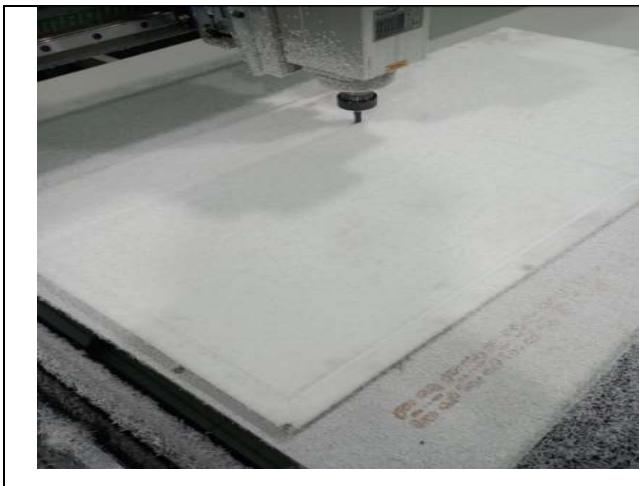
Source: Authors, (2022)

Figure 20. Machining Lower Base

Source: Authors, (2022).

Figure 21. Bottom Base

As shown in Figure 22, the machining process of the Lower Base was done in a sheet of polyacetal with the same thickness that was designed for the Lower Base, so there was no need to thin the material in order to reach a specific depth, so it was possible to optimize the machining time. Figure 23 illustrates the final result of the operations, as can be seen, the piece was successfully completed.

According to Figure 24, the machining process of the Upper Base was done on a sheet of Fenolite with the ideal thickness that was designed for the part, so there was no need to thin the material, thus optimizing the machining time. Figure 25 shows the final result, being possible to observe that the piece was successfully completed.

Como mostra a Figura 25 o processo de usinagem do Berço foi feito em uma folha de Fenolite com a mesma espessura que foi projetada para o Berço, porém houve a necessidade de desbastar as áreas indicadas pelas setas azuis, logo, a peça passou por um longo processo, tendo em vista que desbastar determinado local acarreta maior tempo de usinagem, importante salientar que estas áreas desbastadas servem para alocar os medidores do modelo DOW1310L

Source: Authors, (2022).

Figure 22. Machining the Upper Base

Source: Authors, (2022).

Figure 23. Upper Base

Development of the communication protocol

Mechanical Development: The development team created sketches of mechanical solutions for a device that could record and configure the information requested by the dealerships and that later, with the implementation of software, would make it possible to collect data and make them available to the database. The mechanical development stage followed with the mechanical modeling and later the creation of technical drawings in 2D format. With the modeling, it was possible to visualize how the device will be after its manufacture, in Figure 25, the following is presented this stage of development, according to Figure 26.

Source: Authors, (2022).

Figure 24. Cradle machining
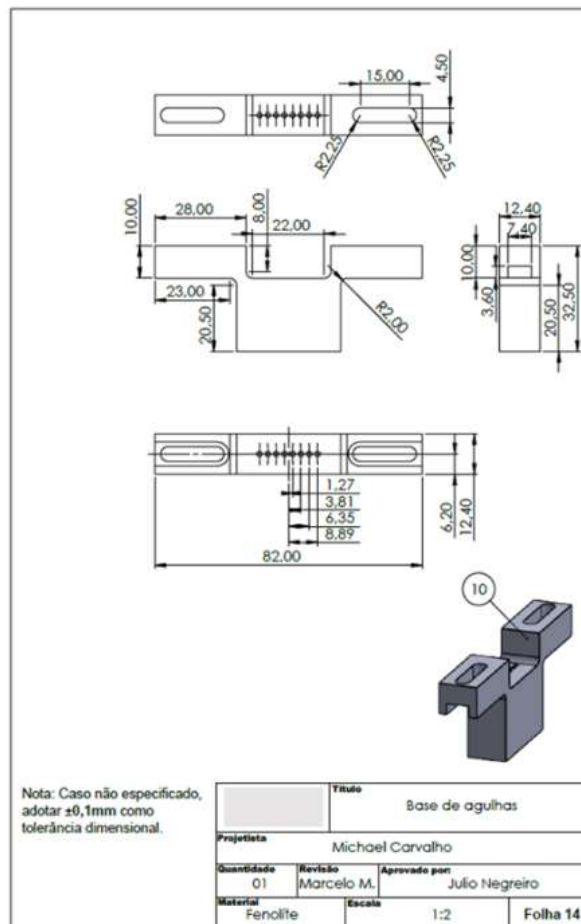

Source: Authors, (2022).

Figure 25. Meter cradle

Source: Authors, (2022).

Figure 26. 3D Modeling - Parameterization Device

As observed in Figure 27, above, with the aid of SolidWorks software it was possible to create the device using the available tools. The 2D technical drawing transmits all the necessary information so that the professional can make it, in each part of the device a file was generated, with dimensions and specifications such as type of material, size, tolerances among others, in Figure 66 is shown an example of a 2D part.

Source: Authors, (2022).

Figure 27. 2D technical drawing

As shown in Figure 27, in each 2D drawing the data for its design is specified. From that moment, it is possible to create the parts and assemble the device.

Communication Software Development: In parallel with this activity, code was developed so that the device could perform the parameterization and configuration on the meters. The software was developed using the Python language, it was associated with a hardware called Raspberry, besides other interconnected components. The code of this device was developed based on the NBR 14522 - Information Exchange for electric energy measurement systems, in which the standard of information in the electric energy measurement system is defined, in order to achieve compatibility among electric energy measurement systems and equipment. Figure 28 shows the algorithm's header, which enables observing the dates when each activity was developed. It is through the header information that it is also possible to observe if the deadlines of the activities were obeyed according to the planning schedule. In addition, it is presented the topics of the algorithm, thus giving an overview of what the source code is about.

```
# -*- coding: utf-8 -*-
__author__ = "Laís, Henrique, Gabryel"
__license__ = "Privado - distribuição não autorizada sem a licença dos autores"
__version__ = "2.1.0"
"""
Software de Configuração do medidor DOW1310L, com display LCD rodando via terminal (sem precisar do x11)

Config versão 1   - DOW1110LA
Config versão 2   - DOW1310L
Config versão 2.1 - DOW1310L OE2

Controle de Versão
03/01/2022 - 2.0.1 - Emissão inicial (baseado na versão 1.0.6 de 30/08/2021 do mesmo software para medidor DOW1110LA)
10/01/2022 - 2.0.2 - Ajuste do PIMA Energisa, detectando pelo código de configuração 167
13/01/2022 - 2.0.3 - Ajuste do Algoritmo do PIM A Energisa para detectar automaticamente, independentemente de ser 67 ou 167
17/01/2022 - 2.0.4 - Inserida rotina que salva os dados no Banco de Dados Horus (API)
20/01/2022 - 2.0.5 - Pulamos a versão 2.0.4 não testada, implementado algoritmo de PIMA
25/01/2022 - 2.0.8 - Acrescentado suporte ao novo Firmware OE1 RS232 (CEMIG)
02/02/2022 - 2.1.0 - Novo protocolo medidor OE2. Novo Display LCD 16x2 I2C.
Versão finalizada em 02/02/2022
Escrito para Python 3.7 (incluindo bibliotecas externas)
"""
```
Source: Authors, (2022).

Figure 28. Algorithm header

Variable Declaration: In this topic, shown below, it is about the declaration of variables, in this step all the key characters were inserted so that they could be called during the code in a faster and more practical way. Besides this facility, after declaring the variables, it was possible to perform interconnections with other codes, for example: the source code of the parameterization device needs other codes responsible for performing specific activities, such as the code OE2_Serial Protocol, this algorithm was responsible for sending all parameterization parameters for the product, parameterization that respects the protocols of NBR 14522 and ABNT. Figure 29 shows howthevariablesweredeclared.

```
global num_medidor
global script
global retorno_
retorno_ = ['','']
num_medidor = '0000000000'
script = {}    # inicializador do script do roteiro de configuracao do medidor
barramento = 1  # barramento I2C do Raspberry
endereco = 0x28 # endereço I2C do Display LCD

defenviarABNT(comm, tp, cmd, arg, tout=1800, verbose=False): # Rotina de envio de comando extendido no protocolo ABNT
    global retorno_
ifverbose: print('entrei no enviaABNT')
if verbose: print(comm, tp, cmd, arg)
   if (tp == 'W'):
       if verbose: print('enviarABNT')
ifverbose: print(comm)
       retorno_ = comm.enviaComando(cmd, arg, True)
elif (tp == 'R'):
print(' Função não implementada no protocolo ABNT ')
       retorno_ = ['Função de Leitura não implementada no protocolo ABNT', '99']
   return retorno_
```
Source: Authors, (2022).

Figure 29. Declared variables of the Algorithm

As shown above, it was declared global variables and then started a routine to send extended commands in ABNT protocol, the code can only proceed with its parameterization routine if this first step is correctly obeyed, in cases of "Function not implemented in ABNT protocol" and "Reading function not implemented in ABNT protocol" the code automatically accuses an error in which stops the parameterization process.

Routine parameters and data sending: In the test routine, shown below, one can observe a software routine to identify if the sending was done correctly, a routine binary architected in which 0 represents that the sending was successful and 1 informs that the algorithm could not complete

the sending of the parameters. In addition, this step was responsible for organizing the most different details that each meter contains, such as for example the number of numbers that each ID can contain. The Figure 69 can observe the commented steps and their due parameters.

Parameters of routines and data sending: In the test routine, shown below, one can observe a software routine to identify whether the submissions were done correctly, a routine architected binary in which 0 represents that the submission was successful and 1 informs that the algorithm could not complete the submission of the parameters. In addition, this step was responsible for organizing the most different details that each meter contains, such as for example the number of numbers that each ID can contain. The Figure 69 can observe the commented steps and their due parameters.

Script Update: The first one is done automatically, as some fixed parameters of each customer have been established, in which, by reading the barcode, the device is able to identify which customer the meter must be parameterized for. Besides updating the script, this step has all the parameters according to the NBR 14522 protocol, to carry out the parameterisation correctly. It is possible to observe that there are special cases for each customer, i.e., the algorithm was created so that the proper parameters are automatically recognised, but there are situations in which it will not be possible, so the update must be carried out manually as previously mentioned, as shown in Figure 30. The second one could be done manually by an ADM Master that has authorization to mess with the source code, this manual way requires a USB-TTL module shown in Figure 71. This module transmits the new client directly to the database that is in constant communication with the embedded system, after performing the above mentioned communication, it is necessary to disconnect the USB-TTL module from the device so that the program can compile normally.

Source: Authors, (2022).

Figure 30. USB-TTL module

ArtCAM Journal Development

Artcam is a multifunctional CAD/CAM software designed for product design and part manufacturing using CNC machines, Laser engraving machines and/or 3D printer. The software's feature set combines varieties of modelling tools and machining technologies into one complete solution. The 3D design was created using relief import, which is a tool used to import files made in specific software. For example, design part in SolidWorks software, which specializes in 3D modeling, and then import into Artcam.After importing the file, it was necessary to transform the relief in gray scale, because in gray scale it is possible to observe areas in which it is necessary to add textures, as soon as the relief is imported, the same is seen in a standard colour of the software. Following the procedure, after performing the transformation to grayscale, and manipulate all the necessary paths aiming a successful machining, it was necessary to generate the G-Code file, because it is the language used by most CNC machines. Below you can analyze an example with all the procedures from the import of the piece to the generation of the G-Code file:

- This is the first and most important step in making the part in the CNC, because it is in this part that the part is modeled with the proper length, width and thickness. A poorly modeled part can generate serious problems in 2D design in Artcam and manufacturing of the same. In addition, knowing the thickness of the piece is of utmost importance, because this defines the depth of material to be machined, which paths will be required to perform the machining and what is the minimum height to create borders in ArtCam.
- After modeling, it was necessary to save the file, with the option "Save as", so that the file format could be chosen.
- By default, SolidWorks offers the option "sldprt", because it is the format that is automatically saved the parts, but to use the file in ArtCam and make the appropriate changes, it was necessary to use the format ".igs", it transforms the part into composite relief, thus making the part usable.
- To start the 2D design in ArtCam, it was necessary to open a new model;
- When opening a new model, a window appears containing information related to the dimensions of the model, it is important that they are aligned with the measurements of the material to be machined, so that you have a better view of how the part will be machined. After this definition, the choice of unit was also of utmost importance, because the unit used in the model is related to the one used in the choice of material.
- The design screen of ArtCAM, contains several tools for modeling, both 2D and 3D. But before entering the modeling, it was necessary to configure the size of the model sheet and from which point will start machining.
- In the window "Model Size" there are some parameters to be configured. The first is the "Method", most often the "Image Size" is used, because this is the size that was initially configured in the "New Model..." tab. As the part will be imported, there is no need to use the "Scanned D.p.i" and scan the part to know which sheet size best fits, because, the sheet has already been pre-set (size of the material used) and the part has already been modeled externally, so many times there is no need to modify this parameter.
- After setting the size, it was necessary to import the model, when clicking on this option, a window for selecting the composite relief will appear, the relief was chosen and then necessary to click "Open".
- With the window open, it was necessary to make configurations referring to the position of the relief, aiming better positioning of the part in the model sheet.

- To center the part, it was necessary to observe the configuration of the origin and align it with the origin of the part. The two origins have to be starting from the same point so that there is no conflict, after setting the machining origin, it was necessary to click "Center" to centre the part on the sheet.
- There was the need to adjust the angle of the piece in relation to the sheet, because the piece in the vertical position would cause more difficulty when choosing a material with the desired thickness. Soon, there was the need to place it horizontally, for this the option "Relate model on an axis" was used, this tool shows the option to rotate the piece on a desired axis, in this opportunity, the desired axis was the X and the required angle is 90º, because rotating on this axis and with the angle indicated, the piece will be horizontal as desired.
- After the changes, the shortcut "Alt+G" was used, the composite relief is started at bitmap level and to add texture to 2D shape, the first step is to transform it to grayscale level.
- Next, the option "Create Border from Relief" was opened. When opening the window, some parameters needed to be configured, the most important was the "Height Range", marked the option "Use Height Range" and then set minimum height of texture and/or a maximum height, this defined from what height should add texture to the piece. Done this, was created the border that the piece will receive, in their borders, vectors united, forming lines or curves.
- To start the process of defining the path to be machined, needed to click on the tab "Path".
- It was essential to define the thickness of the model according to the part to be machined, for this, on the tab "Configure Material", there are the following characteristics: "Material Thickness" and "Position in the 16. Material". The first option refers to the thickness of the imported relief, ie the depth of the part that was modeled in SolidWorks, it is important to note that for a successful machining, it is essential that the data entered in this field, is in accordance with the modeling. The second option is about which position the zero part will start, ie whether the machining will start from the top of the part or bottom. It is recommended, for safety's sake, that part zero always starts at the top, because starting from the bottom increases the chance of damaging the tool. The information "Top Offset" and "Bottom Offset" are necessary when there is a change in the thickness of the material in relation to that inserted in the 3D modeling, when there is this change, depending on the location where the zero part will start, the offset is no longer "0.0" and appears with the difference between the original thickness and the modified thickness. This is to understand that in case of decrease or increase of thickness, the zero part will start below or above the expected. In the machined parts, the thickness of the materials was 12.7 millimeters and the position in the material selected was the upper one because it is the most suitable way as explained previously.

The moment of defining the path requires attention, because there are several options of paths for machining. The most commonly used for machining parts are: Profiling, Roughing and Drilling, which are located on the 2D Path tab. Since the part has no holes and also no areas with thicknesses less than the original thickness of the material, then there is no need to use Roughing and / or Drilling. Therefore, the path used to machine the relief is Profiling, which will cut along the sides of the part, thus highlighting it. On selecting the path, the "Profiling" window will appear, in this window there are configuration parameters, which are necessary to indicate the correct way to machine the part. The first parameter to be set is the "Profile", there are three options: "Outside", "Inside" and "Along", this refers to how the cutter will cut the material. The machining by "Outside" indicates that the cutter will profile the part by the outside of the lines or vectors, this way is indicated when there is the need to machine the part and remove it for use, because the diameter of the tool will not influence the dimensions of the part.

The "Along" option is the profiling passing over the lines, that is, the tool will cut material both inside and outside the workpiece, because the radius of the cutter will act on both sides. For example, the cutter used was 9mm, when you select "Long" profile, 4.5mm will be taken from the outside of the part and 4.5mm will be taken from the inside of the part.

CONCLUSION

With the objective of elucidating the development of intelligent devices capable of performing communication and pre-processing, were achieved by means of the electronic meter test process tested in the production line of a factory in the Industrial Pole of Manaus (PIM), aiming to establish with a lean manufacturing system (SIME) to support decision making. The requirements of the production process of the electronic meter DOW131L were mapped, using the parameters of the production control process based on the adaptation of SIME, identifying the bottlenecks and making improvements/automation in the manufacturing process of this electronic meter DOW1310L using Computational Intelligence and Lean Manufacturing to obtain the increase of the productive capacity, the reduction of the cost, efficiency of the process and quality of the product. It was developed the communication models that guaranteed using the Programmed Application Interface - API for data capture via mechanical devices and information transformation by SIME, with real time use.

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