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AURORA: An Intelligent Plant Monitoring System for Greenhouse Deployment

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ABSTRACT

This article presents a low-cost plant monitoring technology to assist in plants irrigation according to physiological demands. The project was conceived as a smart greenhouse capable of reporting on soil humidity, light and ambient temperature and presents principles of data-based agriculture. The methodology was based on engineering methods combined with design notions to adapt the technology to specific target audiences in a future stage of the project. Designed for small properties, the low-cost technological solution is an open technology that seeks to solve small farmers' pain regarding wasted resources in the field. The results are from isolated stages of the project, and point to correct data collection, processing using a microcontroller and sending the data for visualization on a dashboard. Future possibilities include a mathematical model based on the application of a differential equation to optimize the system, as well as building an application and carrying out integrative tests with tablets and other devices in a real production context.

Palavras-chave: Technology. Monitoring. Agriculture. Data.

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AURORA: Um Sistema Inteligente de Monitoramento de Planta para Implantação de Estufa

RESUMO

Este artigo apresenta uma tecnologia de monitoramento de plantas de baixo custo para auxiliar na irrigação conforme demandas fisiológicas. O projeto foi concebido como uma estufa inteligente com condições de informar sobre a umidade do solo, a luminosidade e a temperatura do ambiente e apresenta princípios da agricultura baseada em dados. A metodologia se baseou em métodos da engenharia aliados com noções de design para a adaptação da tecnologia a públicos-alvo específicos em uma etapa futura do projeto. Projetada para pequenas propriedades, a solução tecnológica de baixo custo é uma tecnologia aberta que procura resolver as dores dos pequenos agricultores relativas aos desperdícios de recursos no campo. Os resultados são de etapas isoladas do projeto, e apontam para a correta coleta de dados, processamento utilizando um microcontrolador e envio dos dados para visualização em um dashboard. Possibilidades futuras incluem um modelo matemático baseado na aplicação de uma equação diferencial para a otimização do sistema, bem como na construção de um aplicativo e a realização de testes integrativos com tablets e outros dispositivos em um contexto produtivo real.

Keywords: *Tecnologia. Monitoramento. Agricultura. Dados.*

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1. INTRODUCTION

The agricultural sector is the main engine of the Brazilian economy today, since it corresponds to a significant portion of the Gross Domestic Product (GDP). The incorporation of new technologies in the agricultural sector has been a reality in the most different countries, interested in modernizing agricultural cultivation and reducing waste and production residues. According to data from the Center for Advanced Studies in Applied Economics (CEPEA), agribusiness accounts for more than 20% of the Brazilian GDP, being essential for the slow process of complexification of the country's industrial activity and for supporting it. The use of technologies in the agricultural sector is more commonly found in large-scale production, but can also be observed in small-scale agriculture, as presented in this work.[4]

Well-being of human societies is associated with climate and is influenced by climate variability, so that severe climate changes are harmful to many species. The correlation between well-being and climate is especially strong in regions where the economy is based on rainfed agriculture, such as sub-Saharan Africa or where there is a strong dependence on river flow for electricity generation, and also in the case of Brazilian with hydroelectric production (Jank et al, 2004). In the economic field, on the other hand, the optimization of processes reduce wastes and generates productivity.

There are different methods to determine the water requirement of a plant, they can be direct, through measurement equipment, or indirect, obtained by simulations. Portable systems that provide information about the situation in the field have become options for improving agriculture and can be observed not only in smart greenhouses, but in applications that monitor the progress of biological pest control and other factors associated with agricultural production. In the Brazilian case, technologies are a way to optimize the production of this important sector and mitigate the natural damage to the environment that is intrinsic to the constructive activity.

This study aimed to build an algorithm to control a small greenhouse for food crops, focusing on computational aspects. Some articles were found to support the project. The study performed by Sampaio (2018) was dedicated to the construction of a small greenhouse

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[4]While a science-based methodology aims to produce new knowledge and expand the frontier of knowledge, and design-based engineering methodology may seek to improve an existing system, targeting an application or a different way of carrying out a task. Considering the needs for improvements and innovations within the industry's production systems, projects that consider the demands of the stakeholders involved have social relevance.

for testing, however, we did not reproduce such a sophisticated physical structure. In this sense, although in the literature there are projects with the physical development of greenhouses, this article has a central axis of information technology.

Despite the growth of the agro-export model in Brazil in the 1970s and 1980s, the development of agricultural technologies is still incipient, especially on small agricultural properties (Jank et al, 2004). The incorporation of technologies to reduce waste in the agribusiness sector can lead to the development of the area considering objectives in view of the circular economy and possibilities of greater productive efficiency with reduced waste considering the theory of restrictions (Goldratt, 1997), in which companies must eliminate restrictions that avoid profit.

Farmers need information during different stages of cultivation growth and this demand has drived technological projects during last decades (Mohanraj et al, 2016, p. 939). IoT has been used in agriculture to improve crop yields, quality and reduce costs. At same time, drones have been used to colaborate with human work in field, as in biological control of pests in plantations (Parra, 2012). Recent studies of data mining in agriculture have been responsible for the discovery of knowledge about complex biological processes (Nillaor et al, 2019).[5] Guo et al (2021) performed a review study of the progress of IoT research in agriculture and plant phenotyping, including the prediction of plant phenotypic traits (Guo et al, 2021). In this article, the use of information technology in agriculture does not involve big amount of data, but a free open-source project to support small farmers.

[5]Obtaining detailed information about the formation of specific biological characteristics can promote the process of functional genomics, molecular plant breeding and efficient cultivation.

2. METHODOLOGY

The main objective of the project is to create a plant monitoring system. In this monitoring system, three sensors must respectively capture soil humidity, temperature and ambient light, and these data must be shown on a dashboard in Grafana. The temperature sensor used is the BMP280 and the brightness sensor is the BH1750. In the case of local power supply of a microcontrolled system, a simple power supply consisting of a transformer, rectifier diode bridge, filtering capacitor and voltage regulators can be used. It was implemented so that a direct current signal can be provided in the case of a microcontroller placed in a box or sealed in another system within a planting space. The source was developed using a component calculation, phenolite plate corrosion, component allocation and soldering. Then, a transformer was placed at the input and the output signal was measured to verify if it had a regulated output, which was verified.

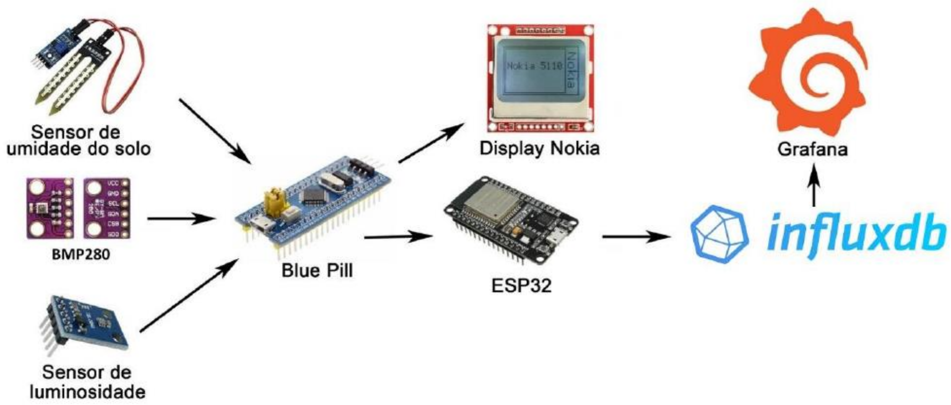
Figure 1: Simple power supply to microcontrolled system

Source: The authors (2023).

The use of the STM32F103C8T6 microcontroller (Blue Pill board) and the use of timer interruption and RTOS to read the sensors were defined as project requirements. The soil humidity sensor has an analogue output and is connected to an analogue input of the microcontroller. The BH1750 sensor can only be interfaced via an I2C bus. For the BMP280 sensor, which supports I2C and SPI interfaces, the I2C interface was chosen to take advantage of the same bus. To carry out communication with the internet and send data to a database, the ESP32 was chosen, which has integrated Wi-Fi. For the communication between the Blue Pill and the ESP32, the Blue Pill was defined as the master because it determines the reading frequency of the sensors and consequently the frequency of sending data, and so the I2C protocol was chosen to take advantage of the bus that is already being used.

The database chosen was InfluxDB, which will interface with Grafana to display information from the monitoring system on a dashboard. As an alternative for direct visualization of the data, a Nokia 5110 display connected to the ST microcontroller was used, which can only be interfaced through an SPI bus. A period of 10 seconds was chosen for reading the sensors and sending the data. As the BMP280 sensor allows configuring a waiting time of up to 4 seconds in its continuous measurement mode, this feature was used, whereas the BH1750 sensor, which does not have this feature, was read through single measurement commands.

Figure 2: Project Diagram



Source: The authors (2023).

To program the Blue Pill, the STM32CubeIDE software was used. Initially, an I2C interface, an SPI interface, the AD converter with an analog input, the digital outputs that control the RST, CE and DC pins of the display and two timers were enabled, one for 10 seconds to activate the reading of the sensors and another for 180 milliseconds to wait for the brightness sensor measurement to be ready. FREERTOS was also enabled through the CMSIS V2 abstraction layer, with a mutex to manage the use of the I2C bus and 4 tasks, one for reading humidity, one for reading temperature, one for reading luminosity and another for sending data. Timer 1 was enabled as the timebase source for the microcontroller because the STM32CubeIde recommends not using SysTick when an RTOS is used.

In the code, 2 libraries were included to control the Nokia 5110 display and the BMP280 sensor [2]. The ADC reading was performed based on an example seen in ASHISH (2023) using the HAL library and the I2C communication with the BH1750 sensor and the ESP32 was also performed through the HAL library, based on the sensor datasheet and defining an address arbitrary for the ESP32 different from the I2C addresses of the used sensors. In the code, 2 libraries were included to control the Nokia 5110 display and the BMP280 sensor. The ADC reading was carried out using the HAL library and the I2C communication with the BH1750 sensor and the ESP32, having also been carried out using the HAL library, based on the sensor datasheet and defining an arbitrary address for the ESP32 different from the addresses I2C of the sensors used.

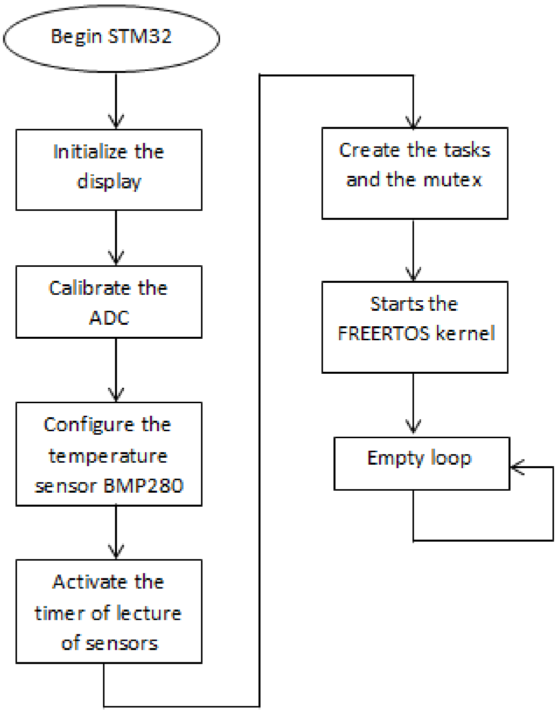
In the main part of the code (main), before starting the tasks, the display was initialized, the calibration of the analog-digital converter (ADC) took place, the BMP280 sensor was configured for continuous reading only with the temperature with rest time of 4 seconds and the resolution of 0.005 degrees. The sensors reading timer (timer 2) was activated and it was programmed to activate the sensors reading through their reading flags every 10 seconds. In all the tasks used, a small delay (waiting time) was maintained within the infinite loop in the code generated by the STM32Cubelde so that a task would not occupy the entire execution time of the microcontroller.

In the humidity reading task, a signaling variable (flag) of humidity reading was being checked by the code. When the flag was active, it was deactivated, and the conversion from analog to digital started. The task waited until the conversion was complete and then read the value from the analog to digital converter. The 12-bit value is mapped to a scale of 0 to 100, which is inverted so that higher values represent higher humidity, and the humidity flag is read and activated. After programming the humidity reading task, the data sending test was programmed to check if the humidity was read and show the humidity value on the display in order to test the operation of the code until then. In the temperature reading task, the temperature reading flag was checked. When this flag is active, it is deactivated, the mutex of the I2C bus is blocked to reserve the I2C bus for the task, the BMP280 sensor is read, the mutex of the I2C bus is released to release the I2C bus for the other tasks, and the flag that indicates that the temperature was read is activated.

In the read luminosity task, the read luminosity flag is checked. When this flag is active, it is disabled, the I2C bus mutex is blocked to reserve the I2C bus for the task, a measurement command is sent to the BH1750 sensor in 1 lx precision mode, the I2C bus mutex is released to release the I2C bus for the other tasks and the timer responsible for waiting for the sensor measurement to be ready (timer 3) is activated. In light sensor measurement standby timer return function (timer 3), it is disabled to function as a one-shot timer, I2C bus mutex is locked to reserve the I2C bus, sensor reading is performed of luminosity, the mutex of the I2C bus is released to release the I2C bus for the tasks, the bytes read are grouped in the variable that stores the luminosity value and its value is divided by 1.2 as indicated in the datasheet, and the flag that indicates that the luminosity has been read is activated.

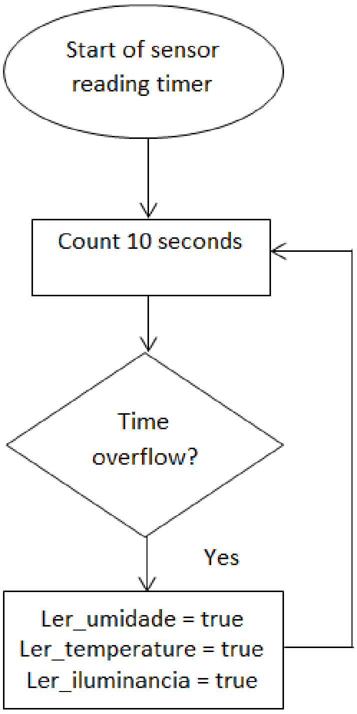
Before sending the sensor data to the ESP32, a test was carried out by sending a string for printing on the serial monitor of the computer connected to the ESP32 to verify the functioning of the I2C communication between the two boards. In the task of sending data, the flags that indicate whether the sensors were read are checked. When all of them are active, they are deactivated, the display screen is cleared and the sensor data read is written to it, the sensor data is grouped into a 7-byte vector for sending, the mutex of the I2C bus is blocked to reserve the I2C bus for the task, the data array is sent to the ESP32 and the I2C bus mutex is released to release the I2C bus for the other tasks. The STM32F103C8T6 microcontroller code flowchart demonstrates the code in a nutshell. When programming the Aurora technology code, the definition of the variable names took place in Portuguese, while the logical structure of the programming code took place in English, as is natural in free commercial languages in general.

Figure 3: STM32 initialization flowchart



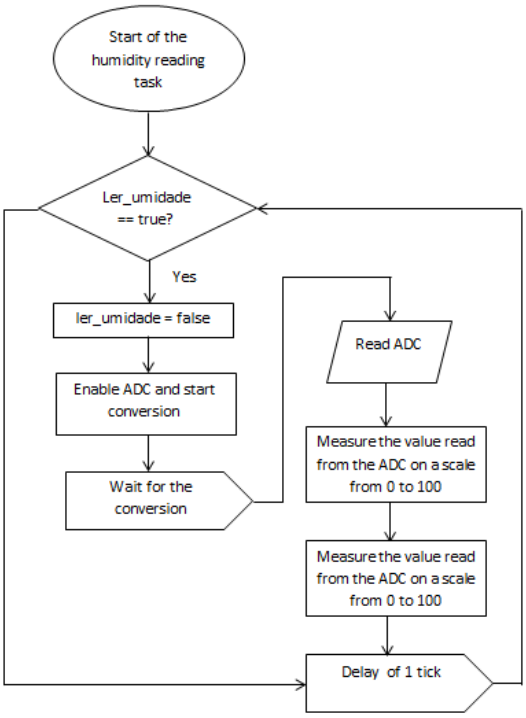
Source: The authors (2023).

Figure 4: Sensor reading timer flowchart



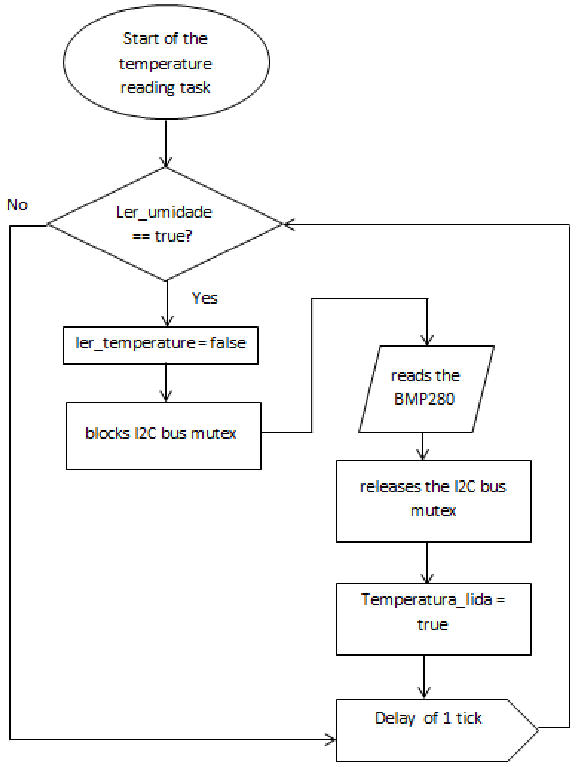
Source: The authors (2023).

Figure 5: Humidity reading task flowchart



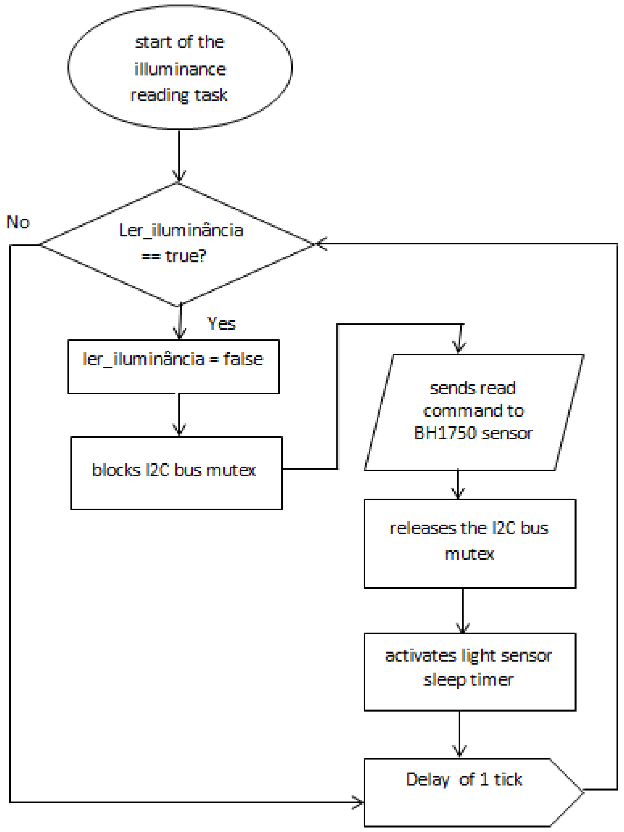
Source: The authors (2023).

Figure 6: Temperature reading task flowchart



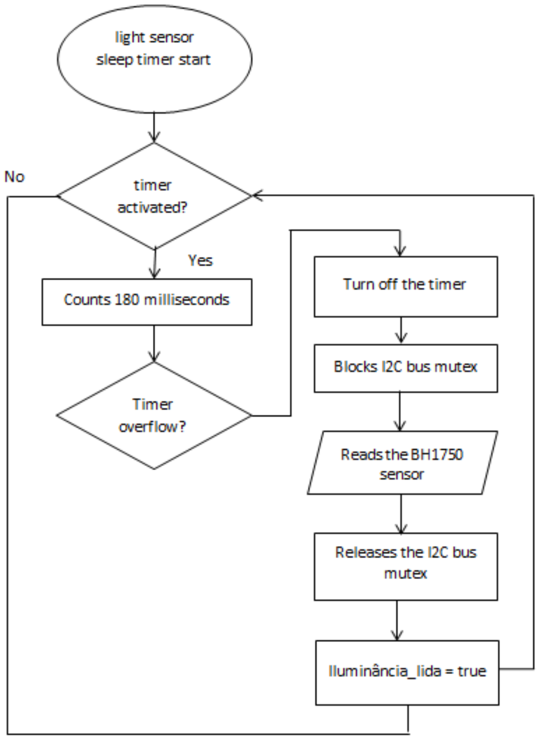
Source: The authors (2023).

Figure 7: Flowchart of the luminosity reading task



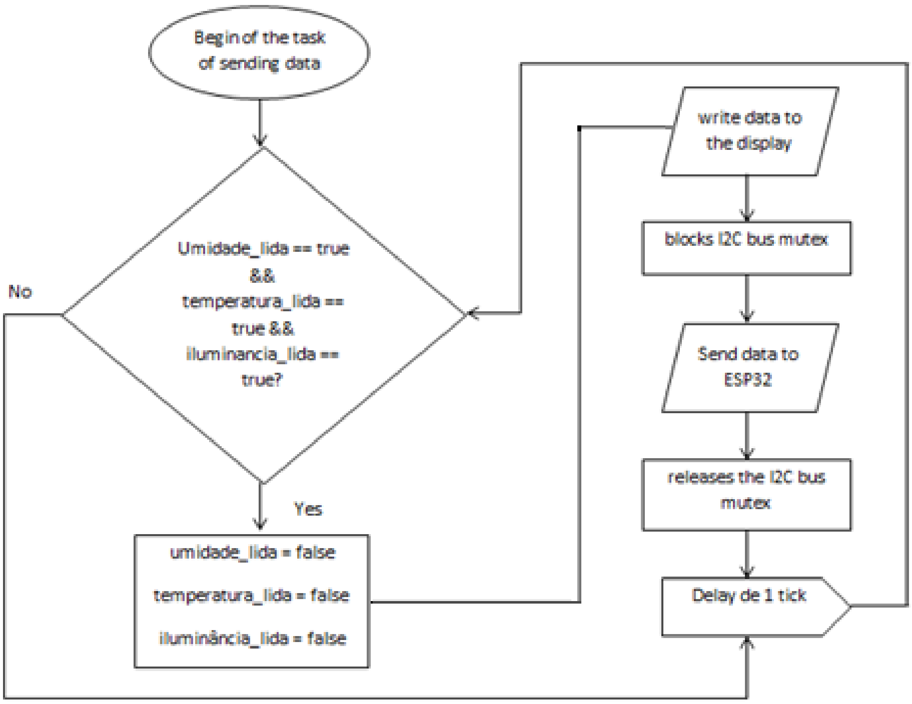
Source: The authors (2023).

Figure 8: Light sensor measurement wait timer flowchart



Source: The authors (2023).

Figure 9: Data submission task flowchart

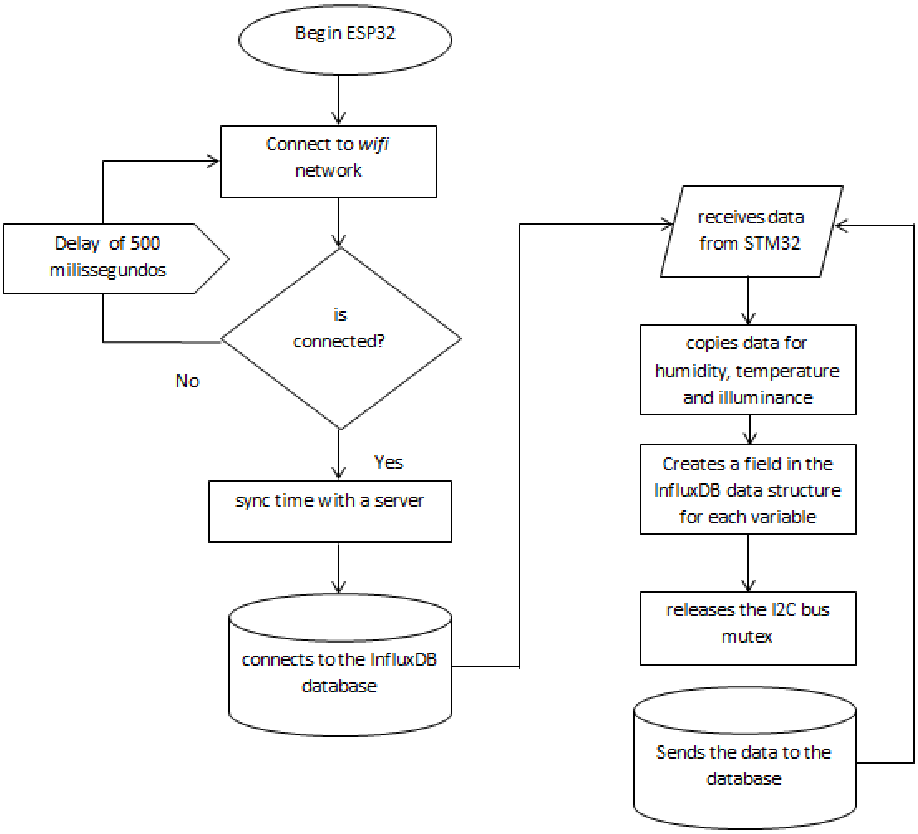


Source: The authors (2023).

To program the ESP32, the Arduino IDE software was used. ESP32 support was installed in the Arduino IDE according to the Espressif tutorial listed in the references, the Arduino Wire.h library was included, whose API and usage examples for the ESP32 are shown on the Espressif website cited in the references, and it was installed and included a library for ESP32 to communicate with the InfluxDB database, following the tutorial. The first part of the ESP32 programming was to use the Wire.h library to read the received data and print it on the serial monitor, to test the I2C communication step. Next, an example of secure writing from the InfluxDB library was used to send Wi-Fi signal strength data, testing the communication step with the database. Then the two codes were merged to send the sensor data to the InfluxDB database. In the setup, the Wi-Fi connection is made, the connection is checked every 500 milliseconds, tags are added to the Data Point of the measurements, time synchronization is performed with an NTP server using the local time zone, necessary for certificate validation and writing in batches to the InfluxDB database, the connection to the database is performed and the I2C bus is initialized in slave mode. If the connection is unsuccessful, a new connection attempt is made every 500ms.

In the data reception function via I2C, the received bytes are placed in a vector and then separated into the variables of humidity, temperature and luminosity. The temperature data is transformed into a float and divided by 100 to indicate the temperature in units of degrees Celsius. Finally, the data transfer flag for the database is activated. In the loop, the data transfer flag for the database is checked. When this flag is active, it is deactivated, the Data Point fields of the measurements are cleared, fields with the current humidity, temperature and luminosity measurements are added, and the Data Point is sent to the InfluxDB database. The flowchart that summarizes the ESP32 programming is described below.

Figure 10: Code flowchart in the ESP32 microcontroller



Source: The authors (2023).

Powering the system with the ESP32 was done using a micro-USB cable connected to the ESP32, which was replaced by a 18650 battery and a Shield V3 Battery Charger 18650, which is a board that regulates the 3.7 V voltage of the battery for 3 and 5 V outputs and allows battery charging via a USB cable. Figure 11 depicts the battery used:

Figure 11: 18650 Battery in Shield V3 18650 Battery Charger

Source: The authors (2023).

The database used to place the values read by the sensor was InfluxDB, an open-source high-performance time series database (TSDB) that can store large amounts of data per second. Each data point sent to the database is associated with a specific timestamp.

Therefore, it is ideal for IoT data logging projects such as storing data from weather station sensors. To create an InfluxDB database, the tutorial available on the “Servendo.in” portal was followed. An InfluxDB Cloud account was created to be able to create a database in the cloud and the server closest to Brazil was chosen, whose provider is Amazon Web Services and is located in the east of the United States. A bucket named “Aurora” was created by selecting the Arduino as a data source, which is the database that will store the sensor data. When creating the bucket, a code appears on the screen that shows the server URL, the email of the organization responsible for the database and the name of the bucket, used by ESP32 to connect to the database. To allow access to the database, an access token was created, used by ESP32 and Grafana.

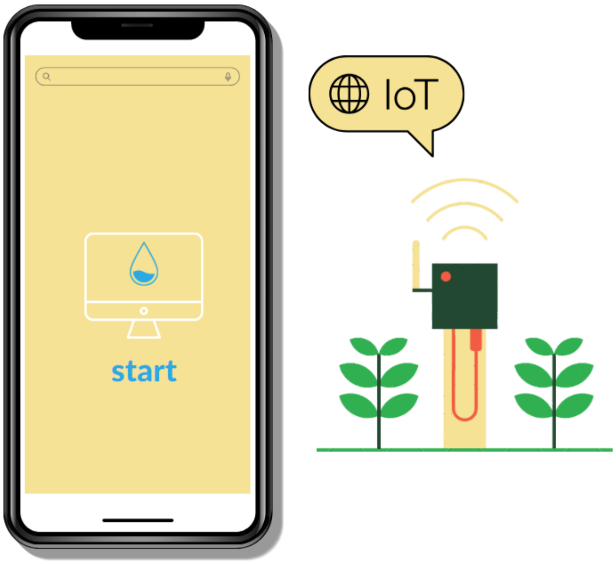
Figure 12: Data Explorer

Source: The authors (2023).

The technological project must be based on design so that it is usable for users. Design thinking is a methodology that allows the identification of the target persona and their pain points, and through qualitative research with users it is possible to identify the real needs of people who work with plantations. The use of cell phone applications becomes essential in a technology project. Design thinking considers that products must have a use, be pleasant and also fulfill a social function. Economic and technical feasibility is also relevant, as a project that is unrealistic cannot be proposed. Combining design with engineering research, one can think: who will use it? What is the viability of the project?

Does it apply to the characteristics of the local reality? Is it accessible? Figure 13 shows an initial mockup of the cell phone application that can be integrated into the solution.

Figure 13: Mockup of Agriculture Monitor App



Source: The authors (2023).

The development of an application would involve testing it with users to evaluate the technology in its context of use. Technologies need to be accessible and inclusive, they must take into account that users are diverse and may, in some cases, have low vision, little manual mobility, difficulty differentiating certain colors, hand tremors, difficulty identifying small letters or hearing sound signals from an application, as well as reading in general. In this sense, cell phone applications must be simple, safe and easy to use.

Although the constructed project was entirely based on algorithms and, therefore, representations of states and causal systems with variables that behave in a binary way, the project can be improved in future versions with the use of deep mathematics in an interface approach with physics. Chen, Mattdon e You presented a novel nonlinear model predictive control (NMPC) framework for greenhouse climate control to minimize the total costa mainly coming from energy use. Continuous-time greenhouse temperature model was represented by authors in terms of a differential equation that can be broken down into several equations (Chen, Mattdon, You, 2022, p. 5). This model has the addition of a terminal constraint to add and guarantee its stability. Chen, Mattdon and You model (2022) simultaneously control the temperature, humidity, CO_2 level and light intensity of the semi-closed greenhouse indoor climate. Energy and mass balance equations followed by system identification were utilized to generate nonlinear of dynamic models for greenhuse climate, including temperature, relative humidity, $C0_2$ concentration level and light intensity (Chen, Mattdon, You, 2022, p. 15).

The discrete-time nonlinear time-invariant system presented by the authors consists in a expression of $x_k + 1 = f(x_k, u_k, v_k)$. F is a nonlinear function in the dynamic greenhouse climate model expressed as: $x = f(x_0, u, v)$, where x, u and v are the system state, control input and disturbance sequence vectores (Chen, Mattdon, You, 2022, p. 5). Part of the energy consumed by lamps is converted into waste heat. The light intensity model is expressed by: $I = I_0 . K_a(1 - T_s . u_{blind}) + T_c . u_{light,max} . . u_{light}$. The authors presented some graphical results of the model response from real data in a real simulation at Cornell University. The results indicate that the use of the NMPC framework proposed in the study can reduce total energy and CO_2 costs (Chen, Mattdon, You, 2022, p. 14). Nabokov, Beznosov, Semin, Nekrasov and Zablitckaia developed a mathematical model for precision agriculture adapting a model of optimization proposed by Kantorovich in 1960's and including aspects as control of waste of resources (Nabokov, Zablitckaia, Nekrasov, Semin, Skvortsow, Beznosov, 2019).

Bolandnazar, Rohani and Taki (2019) presented a differential equation for estimating the energy required to extract water in a potato crop in Iran. The equation aims to determine the direct energy in the unit of Joules, considering the total direct energy dynamics , gravity, water density, electric pump efficiency, and total energy conversion efficiency (Bolandnazar, Rohani, Taki, 2019). Authors used the Cobb-Douglas (CD) model to evaluate the effects of energy inputs on potato crops. The model involved the farm's output energy, the inputs used for potato production, the regression model coefficients and indicators of change in the process. A sensitivity method was used to evaluate the sensitivity of the product based on the level of inputs, verifying the effect on the evaluated product when the unit of an input was increased or decreased. A Multilayer Perception Neural Network (MLP) with a backpropagation algorithm was used to predict solar radiation. This method is composed of at least three layers. In each of the layers (input layer, hidden layer and output layer), it is necessary to set a specific weight.

Bolandnazar, Rohani and Taki (2019) used a greater number of neurons in the hidden layer, while in the output layer, one neuron was used. The network was trained to predict future scenarios strictly associated with the output energy of potato production, based on a transfer function, in the output layer, of the sigmoid type (Bolandnazar, Rohani, Taki, 2019, p. 5). Authors also used a radial basis function neural network (RBFNN) due to its superiority over the MLP model, since it has high speed, does not present local minima problems and has a simple and fixed three-layer architecture. The authors used a Gaussian activation function in the hidden layer, to be able to transform the input vector. Bolandnazar, Rohani and Taki used a multiple linear regression model for predicting the output energy of potato production. Also, authors used a support vector machine model to convert quadratic optimization difficulties to linear content, starting from a dataset.

Bolandnazar, Rohani and Taki used a support vector machine model to convert quadratic optimization difficulties to linear content, starting from a dataset, and developed a computational integration of each part of the larger model (Bolandnazar, Rohani, Taki, 2019, p. 6). This work developed in Iran can serve as a basis for how a mathematical model can be built, part by part, for an agricultural system. On the other hand, the development of a model applied to the Aurora project involves collecting discrete data and adjusting the model using the computer. With the mathematical model implemented in the algorithm and with connections to the physical world, data can be collected from empirical experience and the coefficients in the model can be adjusted based on numerical analysis.

Numerical methods such as the interpolation of a function allow adjustments and advances to be made to the model based on local production contexts. In the same way, the validity of certain expressions can be tested based on real data from one vegetable crop compared to another, understanding the differences in coefficients that must be selected in the case of a tomato crop compared to a of potatoes, strawberries, lettuce, beans or other crops. As the sensors are already included in the project and certain parameters are already visualized, existing automation can be improved for the construction of the mathematical stage of the project, as long as losses and noise in signal processing are also measured and adequate filtering takes place. of the signals.

After defining a model that involves equations, interpolation is used to estimate intermediate values between known points or data, using interpolating polynomials such as the Lagrange or Newton polynomials for this purpose (Andrews, 1992). Optimization methods, such as the least squares method, are subsequently used to adjust parameters and coefficients. This specific method minimizes the sum of squares of the differences between the values predicted by the model and the actual observed values. Gradient descent can also be used as an optimization algorithm, with a view to minimizing or maximizing a cost function associated with the model (Friedman, Hastie, Tibshirani, 2008).

To validate a model, the results are compared with data not used during the adjustment, in order to ensure that the model generalizes well to the new data. Linear regression is useful for data that fits linear models. Nonlinear regression algorithms, such as polynomial regression, logistic regression, or methods that rely on nonlinear functions, can be used in situations that depend on nonlinear models, whic needs to be evaluated according to function and parameters. Cubed splines, smooth polynomial functions that pass through a set of data points, are useful for modeling complex curves and can ensure smoother transitions between different segments. Other methods can be used in engineering modeling, such as the aforementioned neural networks, for modeling complex relationships between data and identifying patterns (Friedman, Hastie, Tibshirani, 2008).

Bayesian methods are used to optimize the hyperparameters of a model, as they model the probability distribution of the hyperparameters, based on observed results. When the search space is large, the Bayesian approach can be relevant for exploring promising regions with a view to obtaining greater model stability. With this and other combined methods, it is possible to find a more suitable configuration for a mathematical model in a specific project, incorporating uncertainties in the scope.

3. RESULTS AND DISCUSSION

According to Silva, Costa, Crovato and Righi (2020), the industrial revolution began in the world in the XVIII century and occured through stages. The first industrial revolution was characterized by changes in the manufacturing process by the introduction of the steam engine. The second revolution consisted of the use of electrical energy, while the third industrial revolution was characterized by the integration of information technology and computers in factories. In the current context, the fourth industrial revolution is being consolidated, based on new digital and integrated technologies that have expanded the industry's possibilities. The use of the Internet of Things, Big Data Analytics and Cyber-Physical Systems (CPS) can be considered techniques and methods that describes some aspects of the productive reality in the fourth industrial revolution (Costa, Crovato, Righi, 2020). In the Aurora technology research article, low-cost methods based on certain concepts associated to Fourth Industrial Revolution are presented, such as the Internet of Things, but without the integration of actors as is typical of real productive activities.

Based on these considerations, some aspects of the project can be discussed. The minimum light intensity that a plant needs varies between 700 and 1000 lux. However, many plants do not have their metabolism active while the luminosity does not reach 10000 lux. Plants thrive best in a home if they are in a situation close to that experienced in nature in which they changed evolutionarily over thousands of years. By the type of leaf, organ that seeks light, it is possible to know which luminosity is needed, as shown in Table 1:

Table 1: Relation between necessary luminosity and type of leaf

Sheet Type	Necessary luminosity	Examples
Fleshy or spiny leaves	full sun	Cacti, succulents, sanseveria sp, mayflower and euphorbiaceae
leathery leaf	A lot of light	wax flower
large leaves	Sun	Asparagus sp
Variegated leaves	half shade and shade	Monstera sp, philodendron and anthurium
Colorful leaves	half shade and shade	Marantas (calathea) and begonias

Source: The authors (2023).

The luminosity in relation to the situation of the environment can be of three forms. In the case of the Sun, its relationship is for the whole day with direct sunlight, with luminosity above 20,000 lux. In partial shade, lighting varies from a few hours in the morning to a few hours of lighting in the afternoon, with brightness varying from 5000 to 20000 lux. In the shade, indirect lighting is from 2500 to 5000 lux. Another important aspect that must be considered is the temperature which influences most plant processes including photosynthesis, transpiration, respiration, germination and flowering. As temperature increases (up to a point), photosynthesis, transpiration, and respiration increase. When combined with day length, temperature also affects the change from vegetative (leafy) to reproductive (flowering) growth. Depending on the situation and the specific plant, the effect of temperature can speed up or slow down this transition.

In most plants, the ideal temperature for their good development ranges from 18 to 20 ºC. For testing purposes, a plant seedling of the botanical genus *Impatiens* was purchased.

This species is characterized by needing a lot of water, partial shade and ideal temperature between 16 and 20 degrees Celsius.

Figure 14: *Acquired Impatiens*

Source: Taiz, L.; Zeiger, E.;Møller, I.; Murphy, A. (2017).

In order to be able to quickly visualize and interpret the data, Grafana was used. In it, a dashboard was created using InfluxDB as a data source to interpret the data in different panels. Table 2 relates temperature data with colors and conditions for the *Impatiens* plant.

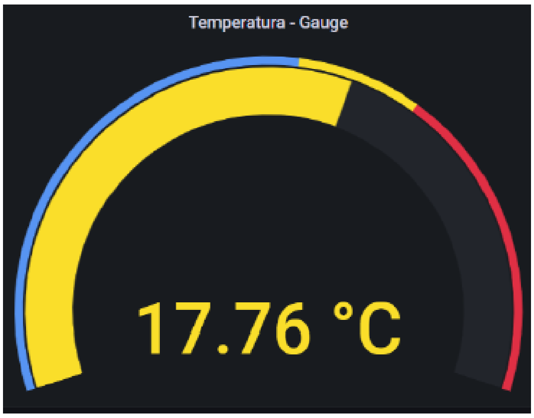
Table 2: Relationship between color, temperature and condition

Color	Temperature (ºC)	Condition
Blue	$T \leq 16$	Not ideal
Yellow	$16 < T \leq 20$	Ideal
Red	$T > 20$	Not Ideal

Source: The authors (2023).

In Figure 15, you can see an image of the temperature dashboard in Grafana.

Figure 15: Temperature panel in Grafana



Source: The authors (2023).

Table 3 relates the luminosity data with colors and conditions for the *Impatiens* plant and Figure 16 shows an image of the luminosity panel in Grafana.

Table 3: Relationship between color, luminosity and condition

Color	Luminosity (lux)	Condition
Strong orange	$L > 20000$	Sun
Faint orange	$5000 < L \leq 20000$	Half shade
Strong yellow	$2500 < L \leq 5000$	Shadow
Faint yellow	$750 < L \leq 2500$	Minimum
Weak blue	$L \leq 700$	Not ideal

Source: The authors (2023).

Figure 16: Lighting panel in Grafana

Source: The authors (2023).

Table 4 relates the humidity data to colors and conditions for the *Impatiens* plant, and Figure 17 shows an image of the humidity panel in Grafana:

Table 4: Relationship between color, luminosity and condition

Color	Luminosity (lux)	Condition
Strong orange	$L > 20000$	Sun
Faint orange	$5000 < L \leq 20000$	Half shade
Strong yellow	$2500 < L \leq 5000$	Shadow
Faint yellow	$750 < L \leq 2500$	Minimum
Weak blue	$L \leq 700$	Not ideal

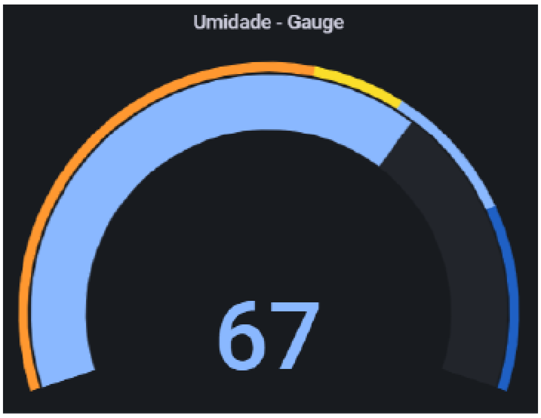
Source: The authors (2023).

Table 5: Relationship between color, humidity and condition

Color	Soil humidity	Condition
Dark blue	$U > 80$	Flooded soil
Weak blue	$65 < U \leq 80$	Medium humidity
Yellow	$55 < U \leq 65$	Minimum humidity
Orange	$U \leq 55$	Dry soil

Source: The authors (2023).

Figure 17: Humidity Panel in Grafana



Source: The authors (2023).

Finally, 3 more panels were built to visualize the variation of data in relation to time, as shown in Figure 18. The interface below is an example of how the data visualization can be adapted to visualize data from different instances in one possibility of project improvement using the internet.

Figure 18: Time series dashboards in Grafana

Source: The authors (2023).

The Internet of Things (IoT) has encompassed several fields and requires that technology data be sent to the internet and different stages of design are interconnected, such as machines, sensors and the actual biological specimens cultivated. This type of work model ends up being an alternative for managing activities in scenarios with a large extension of crops. Possibilities for improvement would involve the inclusion, within the technology of the project, of inclusive design to adaptation of the project to certain users.

Tests with larger and smaller greenhouses could also be compared, and the prototype could also involve listing low-cost materials for making the greenhouses, also considering materials that are easier to degrade and obtain. Studies on the reliability of software and electronic resources, as well as their degradation over time, could also provide more realistic estimates for projects that have a life cycle extended over very long periods. Because it is an initial academic study, no application data was obtained in the southern region of Brazil where it was developed.

Decision support systems for precision agriculture involve devices, controlled water tanks, irrigation structures, system with sensors for water flow, equipment to measure humidity, light, air temperature. Technology companies have also participated by connecting data in the Cloud. By using Cloud Computing to process data at the edge of the network, IT projects can be included in a ecossystem of innovation and entrepreneurship (Brown, 2010).[6]

With the collection and gathering of data in friendly interfaces, farmers have greater security and understanding of natural phenomena to test changes in the medium and long term that can be beneficial to the local community in terms of quality and price, and also to the environment. environment. In precision agriculture, the exact amount of humidity is monitored in order to identify which part is the driest and which is the heaviest. If a part of the crop is drier, more water can be added and other agricultural inputs adjusted, such as pH, fertilizers, nitrogen and so on. By doing so, you can get better yields, reduce costs and ensure sustainability.

4. CONSIDERATIONS

The project fulfilled its initial objective of presenting a low-cost technology that can be used by small farmers to improve their production process in the case of small crops. The technologies used are accessible and there is a large amount of materials available free of charge on digital media associated with pre-ready codes for optimizing the algorithms. Furthermore, some comments can be made about technology in the aspect of technological education.

Considering that tests of the mathematical model proposed by Chen, Mattosn and You (2022) indicated that it can reduce total energy and CO2 costs, one possibility for improvement would be to include a mathematical model in the project algorithm. Based on the idea proposed by the authors, a mathematical model for resource optimization guided by empirical data can be included in the Aurora project microcontroller firmware. A control system guided by the differential equation can reduce costs in a local Brazilian context.

The project aimed to monitor variables associated with the development of a plant and present them in an interface for an individual. The monitoring system informed the person about soil humidity, luminosity and ambient temperature, in an open-source strategy made available along with the article. Educational projects with practical purposes and

[6]According to Collins (2001), technology is an accelerator of movements that can produce financial health, companies that go from good to great companies use technology in what they are experts in developing with quality, seeking to embed technology at its structuring core to increase your conditions for success in your endeavors (Collins, 2001, p. 118). According to Schmidt and Rosenberg (2014), three technological aspects converged to change most industries. Firstly, the internet, which made information free, abundant and present everywhere; mobile devices and networks, which have made global reach and connectivity available; and cloud computing, which provided almost infinite computing and storage power (Schmidt, Rosenberg, 2014, p. 23).

applications that take entrepreneurship into account have been encouraged in STEM courses in recent decades. In the United States, the K-12 curriculum guidelines indicate that the areas of science and technology will be priorities for the future of nations. The reform of STEM field to include more activities of Technology and Engineering is difficult because depends of complex foundations in the basis the students's knowledge and experience, what can be stimulated with integrated multidisciplinary projects like the presented in the article. Projects-based education can be also a driver to resilience and a growth mindset if applied with pertinent discussions (Dweck, 2012).[7]

Technologies are also a way to solve concrete problems. Problems related to the food production chain and its bottlenecks constitute one of the biggest engineering challenges for the XXI century. the development of applied design thinking can be relevant in engineering education. The more humanistic teaching tradition can lead to difficulties in creating projects applied to real contexts, and currently a humanistic teaching culture is being transformed by a culture of innovation that involves prototyping and is impacted by rapid transformations in the knowledge industry. According to Etzkowitz, a trend observed in countries with a more consolidated, complex and diversified industry is greater integration between universities and industry (Etzkowitz, 2017).

Considering the reality of the job market and the maturity of the industry in Brazil, there is an educational deficit in the field of entrepreneurship education in Brazil. Data of Sebrae (Brazilian Support Service for Micro and Small Businesses) inform that that 54% of entrepreneurs did not complete higher education in Brazil. This indicates that, from a cultural point of view, there are still gaps in technical instruction on the field, what justifies projects involving technology and engineering applied to concepts of business and startups in education, and the necessity of public strategies to support industry growth, such as debureaucratization and political decentralization, which must be combined with social policies to promote possibilities of access to education and citizenship (Sebrae, 2022). Reforms in education aimed at technological and scientific teaching allow countries with emerging or developing economies to increase their industrial activity. An education that is only centered in humanistic disciplines, but does not develop applications and prototyping,

[7]In general, students with a fixed mindset are focused on their skills, not looking away from them and other things they can learn. In contrast, students with a growth mindset are more focused on learning, overcoming obstacles and have more resilience (Dweck, 2015, p. 10). Students who learn that they can develop their brains become stronger at learning and achieving greater impact results. Furthermore, when the process is structured with challenges, the need for hard work, strategies, focus and persistence, it leads to the understanding that results are not the result of natural or innate talents or abilities, but of hard work and discipline over time. (Dweck, 2015).

leads to, statistically, lower rates of students graduating in STEM careers. Currently, there is a deflation in the rate of engineers trained in certain countries, indicating a gap in activities that concern the infrastructure that supports a society.

The public sharing of the Aurora project allows it to be freely criticized and adapted for testing, with a view to providing better conditions for the survival of a type of plant and, perhaps, for a study of the project's applications, same commercially. As limitations of the project, the implementation of the greenhouse could be deepened, as well as the insertion of equipment, pumps, other sensors and the attempt to change from a local measurement with a sensor fixed on the ground to a measurement via a controlled drone, which would be a technological advance in relation to the presented system. Finally, a possible improvement in the project considering continuous improvement could be associated with the introduction of deep learning in the technology using equations and mathematical approach. Statistical and computational knowledge to understand data may require the optimization of pre-made computational codes to visualize and interpret how a technology behaves in nature. With this, it is possible to compare prototype results based on repetitions of its operation with a view to obtaining evidence-based conclusions. This improvement could provide future planting scenarios for small producers to have more information on how to apply resources, also allowing for better organization of the activity.

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