Smart Shower System as a Cloud Service: A Low-Cost Proposal for Managing Water Consumption as a Service

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Abstract.

Water consumption is a major global concern. Despite the availability levels, the water resource is of paramount importance for countless activities. In order to optimize the management of water consumption of electric showers in commercial segments, such as clubs, gyms, in addition to public segments such as beaches and highways, which are widespread in the Brazilian scenario, this study aims at the development of a prototype of smart shower that is capable of being activated remotely through a mobile device. Besides allowing to inform the amount of water to be used. In this article, all the processes for projecting the solution are demonstrated, as well as the experiments to prove effectiveness, with calibration time analyzes, metered validation of expenses during their operation, efficiency of communication with remote accesses and validation of availability as a service. Based on market research, the feasibility of developing this technology has proven to be pioneering and national, using IoT (Internet of Things), Cloud Computing and messaging resources optimized for use in low-cost devices. Such tool, integrated with remote accesses, enables a management that can optimize up to the operating costs of the aforementioned commercial organizations.

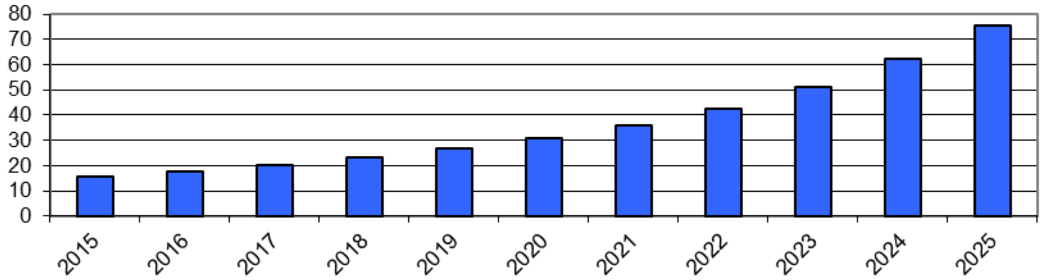
Keywords: Smart Showers, Walter Management, Cloud Computing, Mobile Solution, IoT.

1. Introduction

The constant evolution of devices connected to the internet defines a new way of interconnection allowing devices to operate in an intelligent way, thus building a different communication ecosystem within different contexts.According to Bassi and Horn (2020), this network of interconnected objects, based on communication protocols that allow them to collect, exchange and store data through a software application, is called the “Internet of Things”. It is noteworthy that this way of consuming the internet is current and expands the possibilities of creating products and services, which have their development oriented to help human beings.

Playing the role of assistants, virtual and/or physicists capable of automating homes, monitoring sleep, reading and answering emails, alerting on routes and removing intermediaries in bureaucratic services, the devices contribute to this expansion. According to the research published by IHS Technology, the number of connected Internet of Things devices worldwide from 2015 to 2025 (in billions) will be very impressive, as shown in the graph in Figure 1 (Lucero, 2006).

Figure 1: Growth of connected Internet of Things devices worldwide from 2015 to 2025 (in billions)



Source: Lucero, 2006.

In parallel to this technological scenario, there is a concern about not wasting a primordial resource for human existence, water. The great legacy of our planet is water, an essential element in the life of all living beings, and a common goal among all human beings is the reduction of waste of this element. On average, 135 liters of water are consumed in a 15-minute shower bath, and 45 liters of water on average with the use of an electric shower, also within the same period of time (DEMAE, 2019).

Based on the context described, this study aims to develop a prototype of a smart shower with remote activation capability through a mobile device, where it will be possible to previously inform the amount of water to be used, aiming at greater control over consumption and the quality of the bath. This improves the management of water consumption in commercial segments, such as clubs and gyms, in addition to public segments such as beaches and bus stations, which have public restrooms that offer baths. As specific objectives, this article aims to demonstrate: the resulting prototype; a modular assessment of the structure; a sequence of operating trials and a comparative market evaluation. To make this technology viable, it is intended to make it available as a cloud service, distributed in three main models. The choice was made based on research by Mell & Grance (2011) which lists advantages in the use of cloud computing such as:

- Availability of the service anywhere, as long as there is an internet connection, thus bringing mobility and flexibility to users.
- Scalability, which allows the application to expand horizontally, increasing the consumption of its resources upon demand, which mitigates the costs of purchasing physical resources.

This study is therefore justified by thinking about the commercial and public sector, where in the latter the technology would be applied in compliance with municipal laws that aim to avoid wasting water in public showers as in Rio de Janeiro (Brazil) (Prefeitura Municipal Do Rio De Janeiro, 2002).

In the subsequent sections, this article is organized as follows: the second section addresses some proposals that have similar aspects to the proposed system; the third deals with system modeling, detailing theoretical foundations, technology, platform, objectives and features of each of its modules; the subsequent section shows results obtained from deploying the system at a pilot site; the fifth section covers the tests performed and the results obtained; and, finally, are the conclusion, future works, acknowledgments and references..

2. Related Works

Although many articles that address commercial and academic solutions may have similar proposals and objectives, two articles were chosen, based on their elaborated solution, for the study of their characteristics and their differentials, aiming to adapt these differentials to the proposed system.

The research by Dornelas and Oliveira (2017) is an important reference, which takes into account that water supply companies are not able to correctly measure and monitor what they deliver. Based on this, they thought of a system similar to what this study proposes, since there is a movement in the market to consume digital measurement applications, is the case of the American FLUID (2016). The technological proposal of the authors uses Knot technology, an open-source meta-platform for the Internet of Things, which also provides low-cost devices that can be customized according to the needs of the solution. However, the elaborated solution only addresses the issue of monitoring consumption, like a digital water meter.

In the research by Souza et al. (2017), it is defined that a residential electric shower is one of the items that consume the greatest amount of water and electricity, so its implementation focus is to monitor and control the consumption of water and light in homes. The authors presented in their work the implementation of a prototype that allows the electrical and hydraulic coupling with a common residential shower. This prototype uses an Arduino microcontroller having its programming written in C, as well as a mobile application developed with the sole purpose of monitoring consumption of the resources described previously. The proposal consisted of a prototype and no additional analysis about availability and scalability has been done.

3. Theoretical Foundations

Moon (2016) defines some principles and flow processes at the macro level, which must be followed for one thing, hereinafter called device, which fits into the Internet of Things ecosystem:

- Sensors: first, sensors capture the environment and collect data, e.g. Cell Phones, Beacons, Smart Watches etc.
- Data Centers (Cloud): the data captured from the sensors are analyzed and processed through cloud computing.
- Software: applications use processed information and provide the service to the end user.
- End User: the consumer (end user) makes use of the service provided and/or shares useful information with other services or people.

To make this process flow viable, a cloud service that is based on the model defined by Jamsa (2013) is needed, where the interaction of the cloud with a customer, be it a user or an application, is done in various ways through capabilities called services, which are classified into three major models – SaaS, PaaS and IaaS.

Jamsa (2013) still defines some characteristics of these models:

- SaaS (Software as a service): A complete software application with a user interface.
- PaaS (Platform as a service): A platform on which developers can deploy their applications. A PaaS solution includes development tools and administrative tools.
- IaaS (Infrastructure as a Service): Provision machines, storage and network resources so that developers can manage, install their own operating systems, applications and support resources.

With these premises, the fundamental references of this article were researched.

3.1 Technology Focused on Water Consumption

Waste of water should be a latent concern. According to SABESP (2020), a shower bath for 15 minutes, with a half-open valve, consumes 135 liters of water. When closing this valve to soap and reducing the bath time to 5 minutes, this consumption drops to 45 liters, which corresponds to a saving of 90 liters of water. In the case of the electric shower in the same scenario the numbers are 45 liters and 15 liters, respectively, generating a reduction of 30 liters of water. A reduction of around 33% in both cases.

To assist the development of the proposed study, the technology focused on water consumption should allow the use of sensors to capture data related to this consumption (e.g. Internet of Things). It is also important to process this data on a distributed manner in an easily scalable environment that allows the interconnection of external consumers (e.g. Cloud Computing), such as being able to manage a network of electric showers at a distance, through a low-cost computing device (e.g. Raspberry PI).

3.2 Internet of Things

Internet of Things is defined by Lago et al. (2021) in general, as a ubiquitous ecosystem where, through small sensors, objects interconnected to the Internet create an environment aimed at facilitating the daily life of people. It is understood that this is much more than turning on light bulbs by smartphone. In other words, it is not just about controlling "things" over the internet, but making them smart to be able to collect data from the environment to which they are connected and process these data generating information.

3.3 Cloud Computing

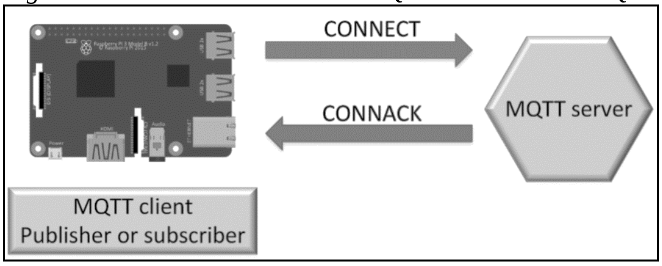
According to Mell & Grance (2011) Cloud Computing is defined as a pool of computing resources that is ubiquitously shared on demand. Nayyar (2019) analyzes this definition and presents the term as not only a model, but also a platform or style.

This model is widely scalable and accessible to a growing number of external consumers that dynamically provides access to configuration, reconfiguration and release of computing resources, in the form of infrastructure services such as servers, platform services such as hosting services and applications and software services that guarantee the availability of specific software. This way of provisioning, managing and using computing resources generates savings directly related to costs and time.

3.4 Protocol MQTT

MQTT (Message Queuing Telemetry Transport) is a lightweight messaging protocol, designed to be used by devices with limited memory and processing, which makes it ideal for communication in the pub-sub pattern (Publisher-Subscribe Pattern) in IoT devices (Figure 2) (HILLAR, 2017).

Figure 2: Interaction between an MQTT client and an MQTT server



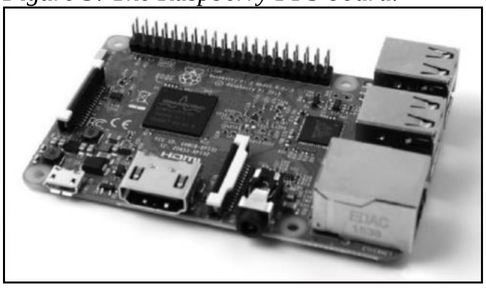
Source: Hillar, 2017.

It is important to understand that the entire communication structure of the devices takes place through a hub called the IoT Hub, which uses the MQTT protocol, in addition to enabling highly secure and reliable communication between the IoT client and server (Microsoft, 2020). This IoT Hub (with MQTT protocol) besides managing the devices connected to it providing a twin logical device (Twin Device) is hosted in the cloud.

3.5 Raspberry PI Platform

The idea of this platform was based on the concept of having a small and cheap mobile computer, programmable and that would allow access to the internet (Upton & Halfacree, 2017). Also according to Upton & Halfacree (2017), the Raspberry PI (Figure 3) is a card designed in an area of the size of a credit card with considerable computing power through resources such as ports, connectors, processor, RAM memory and storage unit. It also has a GPIO (general-purpose input/output) interface that can be used to connect the Raspberry PI to any other hardware, which considerably expands its applicability.

Figure 3: The Raspberry PI 3 board.



Source: Upton e Halfacree, 2017.

4. Methods

This work consists of an experimental study methodology, which according to Lazar et al. (2017), is defined as an instrument that aims to test hypotheses that concern the researcher's conviction and is characterized by directly manipulating the variables related to the object of study. Therefore, during the development process of this study, the first stage was focused on the prototyping of a system that could be smart enough to remotely carry out the control action of an electric shower. In this work, it was understood the need to use IoT together with

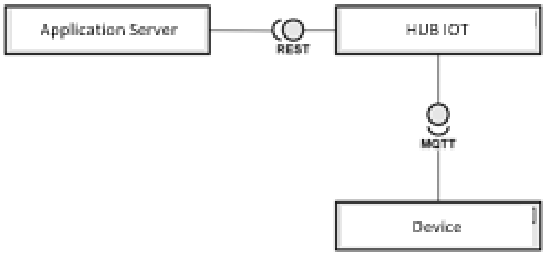
a hardware controller application and a mobile application. Then, a hardware system modulated in the following parts was built: Central device and controller of in-place actions (Raspberry PI) coupled to an LCD Display; Water Flow Sensor; Water Flow Switch
The hardware controller application consists of a program written in Python to interpret the data from the Water Flow Sensor and subsequent activation of the Water Flow Switch, while the mobile application is responsible for remotely activating the controller application, finally releasing the flow of water. The hardware system described previously, together with a controller and a mobile software, as well as a cloud infrastructure to ensure the interconnection between the parties, perfectly meets the research proposed in this methodology. The main idea is to create a flow of activation and shutdown of an electric shower, where this activation takes place through the software on a mobile device and its subsequent shutdown through this same device or through an algorithm that accounts for the intended flow. Based on that, after a flow is defined in the activation, the shower is turned off when it is achieved such definition.

5. Results

5.1 Resulting Structure

For a better visualization of the proposed study, some diagrams and flowcharts are presented to illustrate its structural design and functional schemes for the calibration processes of the water flow controller algorithm and data collection. The component structure (Figure 4) is a simple chain of components, composed of an application server, an IoT Hub, and the devices.

Figure 4: Component Diagram



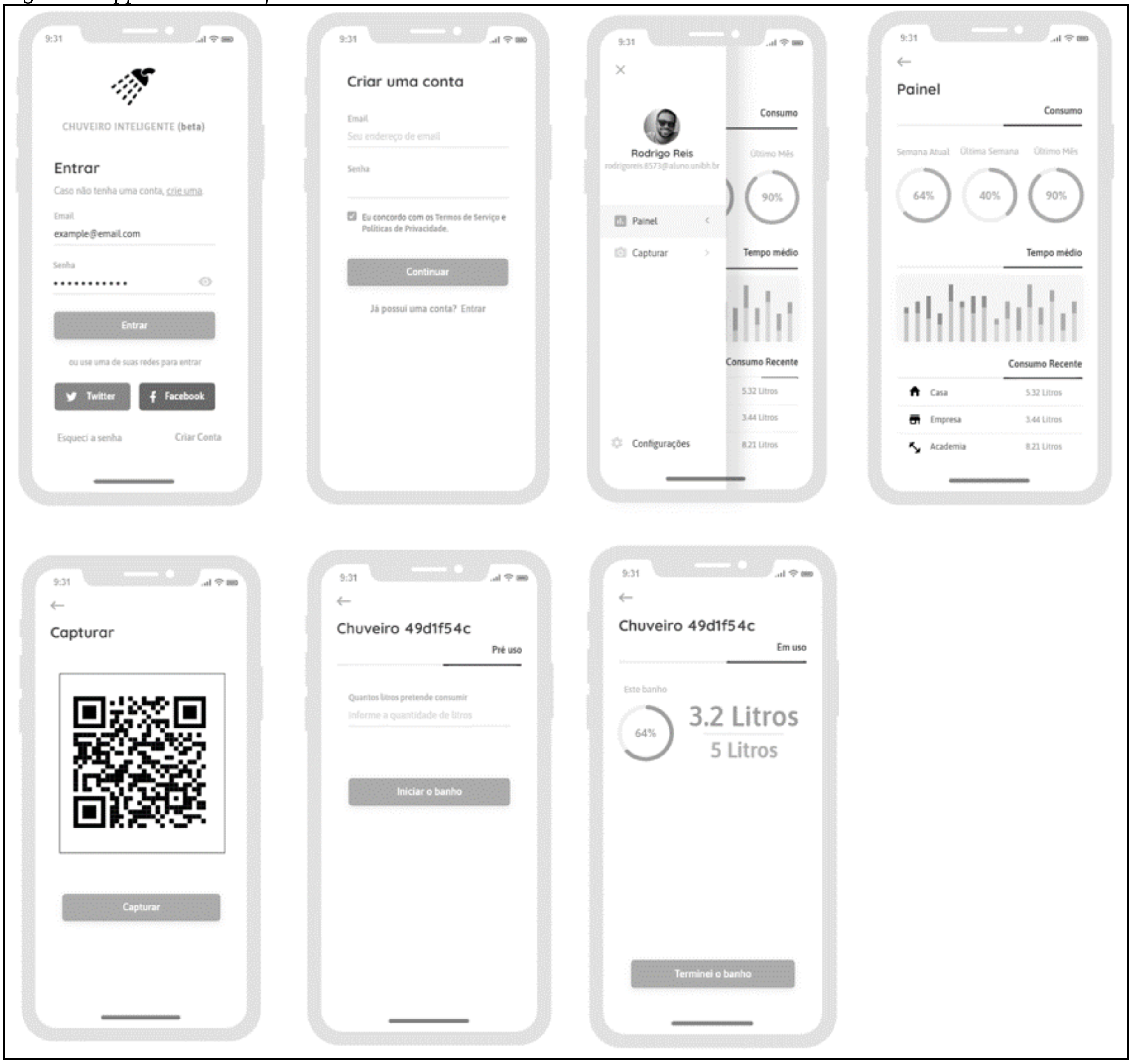
Source: Auhtors,2021

- Application Server: Component that contains the implemented business rules.
- IoT Hub: Cloud computing component that abstracts the communication infrastructure with devices, that is, it creates a logical device for each physical device connected to this Hub. Any command or query sent to this logical device is relayed via MQTT, a protocol of lightweight publish-subscribe model messages for IoT M2M (Machine-to-Machine) connection between sensors and small mobile devices, optimized for TCP/IP (Transfer Control Protocol/ Internet Protocol - Ethernet for example) networks.
- Device: Raspberry PI with solenoid module connected to an electric shower.

The operation of the system is designed to be simple and the process consists of, after being installed, the registration of the deviceon the network (IoT Hub in the cloud, of which it is part). After the registration the system is already operational. The next step is triggered by the user, who has a cell phone, and with the device application previously installed (shown in

Figure 5), by reading the device identification QR code (this QR code must be affixed visually).

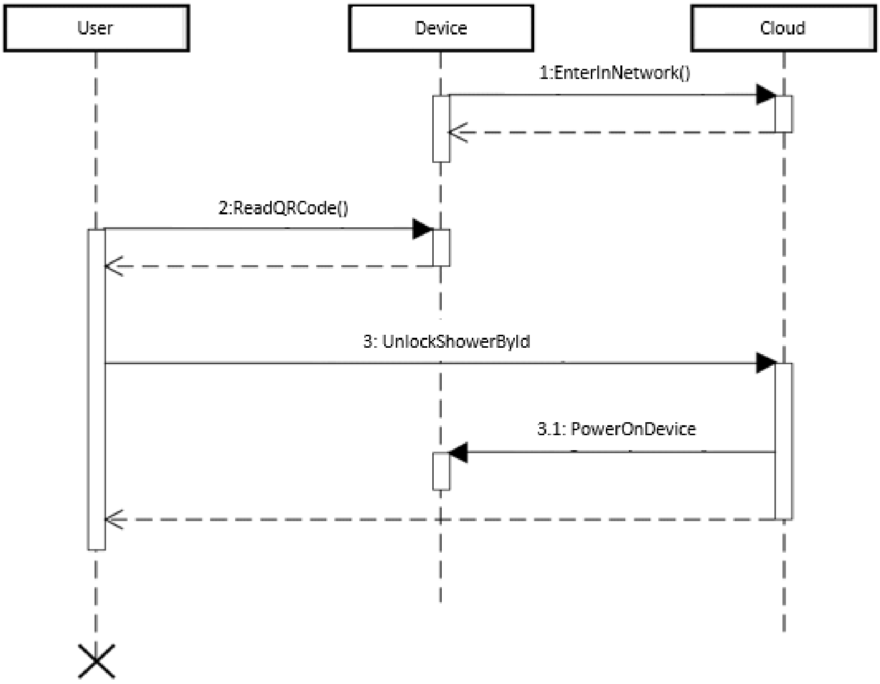
Figure 5: Application Interfaces



Source: Auhtors,2021.

Once the reading is done, the application triggers a request containing metadata of the usage action to the cloud server that simultaneously sends the command to the MQTT queue of the device. When the message with the command is intercepted by the device, it executes the command. Given the technology used (MQTT) the latency time is considered low according to Aichernig and Schumi (2018) and it was about 110.82 ms for connection and 32.72ms for message publication. The operating sequence diagram in Figure 6 shows the process step-by-step.

Figure 6: Sequence of Operation Diagram



Source: Auhtors,2021

5.2 Modular Structure

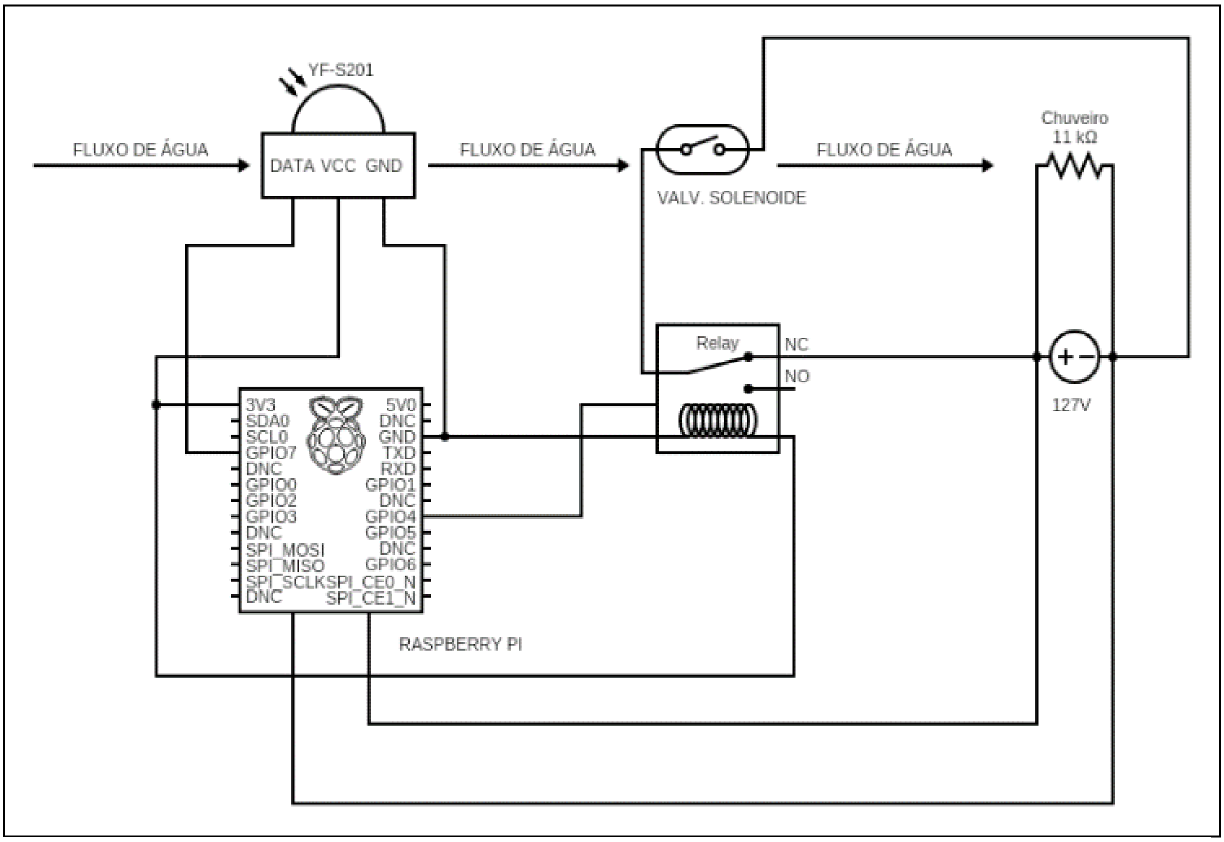
In order to demonstrate the modular structure, a schematic diagram of the connections was created (Figures 7 and 8) where it is possible to observe the entire electronic circuit that is proposed as a hardware system and includes all the electronic components described below:

- Central device and controller of on-site actions: for this purpose, the Raspberry Pi hardware was used, which has the necessary computational power and adequate size.
- LCD Display: user interface where a QR Code will be displayed in order to generate the interaction with the hardware when requesting the release of the water flow.
- Water flow sensor: using the YF-S201 sensor a liquid flow measurement sensor that contains a magnetic wind vane that is rotated by the incoming water and integrates seamlessly with the Raspberry Pi technology through the GPIO communication interface (General Purpose Input/Output).
- Water flow switch: for this purpose, it is understood that any solenoid valve would be ideal, therefore, a common solenoid valve of 127V – 60Hz was used;

- Waterflow switch trigger: the GPIO interface of the central device and controller of the in-place actions works with an output of 5V or 3V, which is not enough to trigger the waterflow switch (127V). Based on that, it is required a Relay apparatus that works with the voltage necessary for the switch operation.

The details of the LCD Display required for activation.

Figure 7: Schematic Diagram



Source: Auhtors,2021

Then, the software functionalities proposed by the study are presented, where first the hardware controller application is detailed, which was modularized as follows:

- QR Code reading screen: screen where the user reads the code of the device in question through the mobile application (detailed later).
- Consumption monitoring screen: screen where the user follows all the consumption of the flow released by it.

Given the description of the controller software components, the mobile application modules are presented:

- Login screen: screen in which the users identifie themselves to the system.
- QR Code reading screen: screen that presents the camera functionality, in order to capture the QR Code displayed on the QR Code reading screen of the controller application. After that, further decoding of information is performed regarding to the device on which the user wants to run the action of releasing the flow of water.
- Consumption monitoring screen: screen that allows the user to monitor consumption, in addition to allowing to the user the possibility of ending the flow.

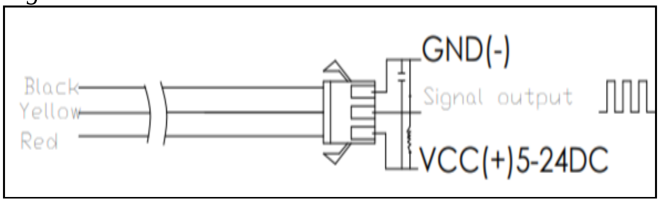
In possession of this structure, functional validation experiments were carried out.

5.3 Experiments

The study identified two possibilities that could make the project unfeasible: the first was the possibility of the YF-s201 sensor (a flow measurement sensor as explained in this study in section 5.2 Modular Structure) not establishing a communication with the Raspberry Pi through the GPIO (GeneralPurpose Input/Output) interface and the second was the accuracy of the sensor on measuring the water flow.

Experiments were then carried out in order to validate these premises. For this, some proofs of concept were conducted in the previous-mentioned requirements, which in theory behave as impeding facts.
The experiment consisted of creating a PoC (Proof of Concept/Proof of Concept) to validate the communication of the sensor with the Raspberry PI and at the same time measure the accuracy of the water flow.
The sensor has 3 pins in its connection: ground, current and signal (as shown in Figure 8). Its operation consists of the following premise, the more water passes through the sensor, the faster the vane blades are moved in rotation.

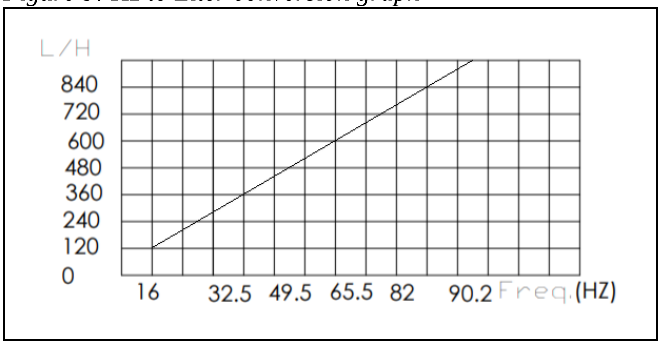
Figure 8: YF-s201 sensor connection



Source: Electronics H, 2020

The spin translated into Hertz (Hz) signal is used to calculate how many liters passed through the sensor per minute. A conversion graph is provided by the distributor as shown in Figure 9. Given the observation of the graph, it is possible to understand that at a frequency of 16Hz corresponds to a flow of 120 liters per hour.

Figure 9: Hz to Liter conversion graph



Source: Electronics H, 2020

Therefore, an algorithm was designed as follows:

- An event is linked to the GPIO pin that receives the sensor signal; the sensor sends a signal for each turn performed.

- The Event has a function that calculates the time difference between the initial and the final signal received, from there it is possible to calculate the frequency and later the flow, using the flow calculation formula, specified by the manufacturer according to Electronics (2020), by equation 1.

(*Pulse Frequency* (Hz))/7.5 = *flow rate* (L/min) (1)

In the experiment carried out using the algorithm, the communication of the sensor with the Raspberry PI GPIO interface worked correctly and the data related to the measurement were also obtained, with an interval of 0.0666 seconds per spin, that is, + /- 15Hz, which provides a flow rate of approximately 2.0020 Liters per minute or 120,1201 Liters per hour, validating the specifications of the manufacturer.

5.4 Market Comparison

In addition to the two related works found and reported in this study, in section 2 – Related Works, a market research was carried out in order to find similar products. A product was chosen for comparison and it was exhibited at the 2019 International CES. It is the Smart Shower from the company Moen (2019), which consists of a shower with a temperature controller and, in addition to this, the user can also turn the shower on or off remotely.
It was seen that it is also possible to set the desired temperature before the bath starts. When the water is good, an alert is sent by the mobile device through the app of the company. The product that is available on the market does not have a flow control function, which is the main proposal of this study, and as the manufacturer does not have national representatives, the maintenance cost is high, compared to the cost of the product itself. Thus, the inexistence of a direct competitor is verified, which counts as a positive point for the development of the technology presented in this work.

6. Conclusion

The present study aimed to demonstrate a new proposal for the use of an electric shower, detailing the steps for its construction and execution schemes of a functional prototype of this product.
Based on the results obtained, it was found that it is possible to implement the elucidated ideas, in addition to creating a viable business model for some market sectors, such as gyms and for the public sector in the field of leisure, where electronic showers are related to use on the Brazilian coast, where it is very common to have showers for public use where a fee is charged. Differentiating itself from other services analyzed in the related to work section and in the literature, this work imposes itself as a relevant solution in the market, and serves as the basis for an important national technology focused on intelligent consumption of natural resources.

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