Monitoring System for Biomedical Refrigeration Equipment

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Abstract

The temperature monitoring of medical products for human use is an internationally debated issue. Given the importance of ensuring the safety in distribution and storage, there are regulations that mandate the control of these substances during their life cycle, that is, from manufacture to administration. By means of electronic equipment, the control of these conditions can be done without human intervention, allowing the triggering of alerting mechanisms on abnormal situations. The economic viability of this electronic equipment has a great impact on the facilities that need it. The current master's thesis intends to study a solution that is economically viable for small and large facilities, enabling a mechanism that offers scalability at a low monetary cost with alarm mechanisms and system configuration. As well as the use of smartphones and the integration of a web platform to view and control the system. Using a mobile app for the Android operating system, one can view the current settings of the sensors that are in the system, in addition to configure each sensor in order to reach the desired criteria. Through SMS exchanges, it is possible to carry out these configuration operations without the need to be present on the site or the latest generation mobile network. The use of a web server, and in the presence of Internet access, it is possible to view the data collected and the system configuration in any part of the world, and it is also within reach to create reports if requested by the competent entities. The solution proposed in this master's thesis shows that it is feasible to develop a scalable system in an economical way with the intrinsically necessary functionalities.
Keywords: Temperature Monitoring, Alert Mechanisms, Scalability, Configuration, Mobile App, Sensor, SMS, Web Server

1. Introduction

Paraphrasing the Center of Disease Control and Prevention (CDC) governmental website, proper vaccine storage play a major role in protecting individuals and communities from vaccine-preventable diseases. The proper storage of vaccines and the endurance of their quality is a shared responsibility of everyone, from the moment of manufacture until its administration[14]. A vaccine is a biological substance that looses its properties if exposed to improper temperature. Once those properties are lost, they can not be restored. In order to provide protection against disease, vaccines must be distributed, stored and administered at recommended temperatures[6]. Blood and blood products are another critical example of a biological substance that must stored in adequate conditions. The deviation from specified temperature ranges during storage can seriously affect the viability of the constituents of blood[31].

Recognizing the problem leads to the conclusion that there must be monitoring devices that monitor regularly the temperature of biomedical refrigeration equipment. The devices that are available in the market, tackle this problem with different approaches, nevertheless there are some setbacks in these systems that can be exploited. This can drive to a new and better solution that can come up against some of the gaps.

There are countries with mandatory monitoring and, for that reason, there are companies selling monitoring equipment. Some companies target the food industry, where temperature and humidity must be controlled, other target industrial facilities or server rooms and finally, a minority targets the biomedical industry. By identifying their strengths and weaknesses, the scope of the thesis can be deepened.

1.1. Existing devices

Accsense

Accsense brands their product has "Monitor Vaccine Temperature in Hospitals & Clinics"[12]. From all of the solutions they offer, all of them require a Ethernet connection for the monitoring devices. This feature can be a disadvantage in an facility that does not have access to a network at a given location. This also leads to a reduced autonomy of only 4 hours, with a periodicity between readings of 1 minute[3][4].

Monnit

With a wide collection of products, Monnit stands out of the competition with a large variety of monitoring devices at the disposal of the consumer. Their system consists on having temperature sensors that communicate with radio frequency (sub 1 GHz) to a gateway, with the latter having the ability to connect to a mobile network or the Internet. It offers some level of scalability at relatively high sensor costs and enforces the user to a subscription plan[18][19][17][16].

Phase IV Engineering

Phase IV Engineering develops custom sensors to a wide variety of applications, being one of them, the monitoring of freezers and refrigerators[22]. They do not target their product with a biomedical enviroment in mind. The system is quite simple, having only a sensoring device, a cellular or Ethernet gateway and a "Internet User Interface", where the user can receive emails and SMS/text messages alerts, configure sensors and visualize data[21].

Vaisala

Claiming to be the global leader in environmental and industrial measurement, Vaisala focus their business in Industrial Measurement as well as Weather and Environment[29]. In the Industrial Measurement area they specifically have a category for "Life Science" applications, with emphasis to "Refrigerator and Freezer Temperature Monitoring"[30]. From what it was found, Vaisala system can be quite complex, having different options to choose from. Vaisala is the only one that offers some kind of scalable solution, but with the disadvantage of its products being designed for industrial applications and not having an integrated solution for use with a mobile application.

Sensaphone

Sensaphone allows the monitoring of several parameters, such as lack of energy, humidity, water and temperature. With a focus on temperature monitoring, Sensaphone offers a solution that allows the end user to connect up to 30 wireless sensors[24], while also giving the possibility to view data and manage configurations through a web interface. It has the disadvantage of having temperature sensor with such dimensions that difficult the placement inside a refrigeration unit, while still practicing high costs per sensor[25].

1.2. Wireless communication technologies

Addressing existing technologies, there a will be divided into communication technologies wireless and temperature sensors. Only the most common technologies in the industry are approached by exploring their characteristics, followed by a summary with the advantages and disadvantages that each one offers.

Bluetooth

Bluetooth is a specification for short distances radio frequency-based connectivity[27]. The Institute of Electrical and Electronics Engineers (IEEE) as the standard 802.15.1 that serves has the basis for the Bluetooth communication technology. According with "Article 5 - Frequency allocations" of the International Telecommunication Union (ITU) Radio Regulations edition of 2012, Portugal, among other European countries, can use the 433.05 - 434.79 MHz band (center frequency 433.92 MHz), as well as common Bluetooth of 2.4 GHz, for industrial, scientific and medical (ISM) application[9]. A common usage of this techology is when there is a device playing the role of "master" and communicates with a device that is playing the role of "slave" (a master can communicate up to seven "slaves") - this structure forms a *piconet*. The technology has restricted performance characteristics by design, therefore its applicability is limited for wireless sensors networks[27].

ANT

In "Comparisons between Low Power Wireless Technologies" by Phill Smith (2011), says that ANT is a low power proprietary wireless technology that operates in the 2.4 GHz spectrum. Typically, the ANT transceiver device is treated as a black box and shouldn't require much design effort to implement a network. He also refers that similar to Bluetooth Low Energy, ANT devices may operate for years on a coin cell battery[26].

Zigbee

Zigbee is the most popular industry wireless mesh networking standard for connecting sensors, instrumentation and control systems[28]. Zigbee and IEEE 802.15.4 are a wireless networking standards that offer low power consumption, low duty cycle and low data rate requirement devices[28]. The IEEE 802.15.4 physical layer adopted by Zigbee has been designed for the 868 MHz band in Europe; 915 MHz in North America and 2.4 GHz as the global band accepted in almost all countries[28].

Wi-Fi

Wi-Fi is a technology that allows numerous devices to exchange data or wirelessly connect to the internet using radio waves[2]. The Wi-Fi Alliance states that Wi-Fi devices are any Wireless Local Area Network (WLAN) products that are based on the IEEE 802.11 standards[2]. The 802.11 standard is a set of medium access control and physical layer specifications for implementing WLAN communications.

Overview

Staring with Bluetooth, it has the limitation of only being able to communicate with a reduced number of devices, 7, with the aggravation of traditional Bluetooth having a transmission current of 60 mA[28]. Wi-Fi has the highest transmission current, reaching 400 mA[28], as well as an equally high current in standby mode[28]. Zigbee has appealing features, with its long communication range, 70 to 300 meters [23], and relatively low transmission and standby current, 9.3 mA and 4.18 μA[15], respectively. ANT has the lowest transmission current, 2.9 mA[15], but at the cost of a shorter communication distance, 30 meters[23].

Temperature sensors

Quoting the renowned company National Instruments, there is a "variety of sensors to translate temperature phenomena into a measurable signal. Three common sensor varieties are the thermocouple, RTD, and thermistor." [20]. A summary of the characteristics of these sensors is additionally provided, Table 1. Analysing this table, it is seen that the thermocouple has a great need for signal conditioning and a reduced sensitivity, whilst offering the advantages of not having the phenomenon of self-heating and the lowest cost of them all. RTD has the disadvantage of requiring an adjustment to its primary resistance as well as having the highest cost of the three types of sensor. Finally, the thermistor has a very high self-heating component, a high sensitivity to temperature differences with medium accuracy, a low cost and fewest requirements for signal conditioning.

Table 1: Overview of different sensors types.

Parameter	Thermocouple	Thermistor	RTD
Temperature range	-210 ºC to 1760 ºC	-40 ºC to 250 ºC	-240 ºC to 650 ºC
Linearity	Fair	Poor	Good
Sensitivity	Low	Very High	Medium
Response Time	Medium to Fast	Medium to Fast	Medium
Stability	Fair	Poor	Good
Accuracy	Medium	Medium	High
Self-Heating	No	Yes, Highly	Yes, Minimal
Durability	Excellent	Poor	Good
Cost	Lowest	Low	High
Signal Conditioning Requirements	Cold-Junction Compensation; Amplification; Open Thermocouple Detection; Scaling	Excitation; Scaling	Excitation; Lead Resistance Correction; Scaling

2. Architecture

The proposed system aims towards the conception of a system that allows the monitor of medical refrigeration equipment, in order to alert a user when the temperature inside it exceeds certain values. For this purpose it is necessary to have a sensor to collect the temperature and a processing unit that sends alarm notifications. Subsequently, there is a need for a user interface that allows the configuration of the system whenever seems necessary. The system is then divided into three main subsystems, the "Sensor Unit", "Hub" and "User Interface".

Sensor Unit

The Sensor Unit has a simple operating mechanism. With the function of periodically read the temperature of the environment where it's located and to send the collected data to the Hub with the established wireless communication. The temperature readings can be configured within the User Interface, at intervals of 15 minutes up to a maximum of 24 hours. The temperature range can be set between -30 and 20 ºC with a precision of ±1 ºC.

The architecture of the Sensor Unit, bases on a temperature transducer, a microcontroller, a radio frequency (RF) module and a power supply. The logic flow of the Sensor Unit does not require a lot of complexity, Figure 1. It will have an initialization process where a radio module is properly configured, followed by a periodic loop in which temperature readings take place and are sent to the Hub. Given the importance of the data that is being carried, in order to ensure that Hub actually received the information, it will wait for an acknowledge feedback.

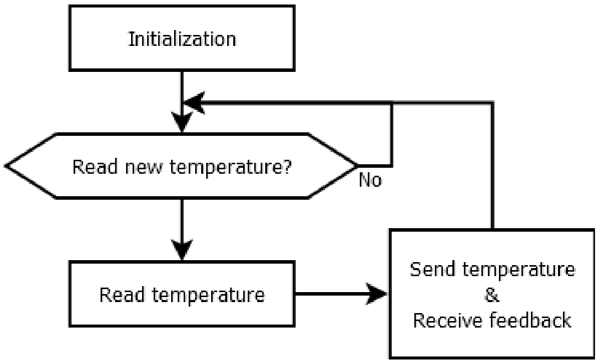

Figure 1: Sensor Unit functional diagram.

Hub

The Hub is the center of operations, as it controls the sensors and determines what the User Interface will be like. The main feature of the Hub is its modularity, having a modular architecture allows for different operating modes. Naming these modes of operations, we have "Repeater Hub", "Cellular Hub", "Wi-Fi Hub" and "Cellular & Wi-Fi Hub". It establishes a communication route with the sensors and, depending on the operating mode, sends the proper information to the user interface.

In the unique presence of a "Wi-Fi Module", a "Repeater Hub" emerges. It aims to prevent the situation where two refrigeration equipment stand apart from each other at a great distance, making the RF communication infeasible. Through a Wi-Fi network, using the 802.11n protocol, communication with the main Hub is assured. The main Hub in this situation would be a "Cellular Hub" or "Wi-Fi Hub".

The "Cellular Hub" requires the presence of a "Cellular Module". It allows a cellular connectivity to 3G mobile network, enabling the user to exchange text messages. These ones can be alarm notifications or a reconfiguration of a sensor in the network. In the absence of "Webserver Module" in regards to the "Cellular Module", the a user interface will be carried out by the mobile application. The information exchange between the mobile application and the Hub will be achieved by text messages.

In the presence of a "Webserver Module", the Hub earns the characteristic of "Wi-Fi Hub", functioning as a web server on which a website is hosted. This website can be accessed through a conventional web browser. The user accesses the website, logs in and proceeds to configure or view system parameters. Whenever new temperature data arrives, they are to be sent to the module in order to be stored in a local database. This local database is the support needed for viewing data in the web pages that comprises the User Interface. If said module is present, the system configuration must be taken place in the web based interface

User Interface

Regarding the User Interface, it comes down to a web page where the user can view the collected data related to the temperature readings and alarms, as well as the configuration of the sensors as desired. This web interface is entirely related to the "Wi-Fi Hub". There is yet another type of interface, linked to the "Cellular Hub", that is achieved through a mobile application for Android OS based smartphones. This mobile app allows the user to view the configuration status of a given sensor and reconfigure it when needed. In parallel, the default SMS app that comes with the Android OS, will handle the received alarm notifications.

3. Implementation

This section aims to document and justify the implementation decisions made during the development phase, while maintaining separation between Sensor Unit, Hub and User Interface. The selected hardware in this chapter targets the implementation of a "proof of concept", since there is a need to evaluate and validate what was selected, resulting in possible changes in certain components that will only be justified with a performance analysis and real characterization of the select hardware, during the testing phase seen the chapter 4 - Results.

Sensor Unit

The Sensor Unit is the critical component of this project, it will have to work under non-ideal conditions of temperature, humidity and RF communications, so it is critical to test its feasibility. As mentioned above, the Sensor Unit is composed of a transducer, microcontroller, RF module and a power supply. Starting with the microcontroller, "MSP430G2452"[8] from Texas Instruments was selected due to its low consumption, several I/O ports and communication interfaces, namely a USART (Universal Synchronous/Asynchronous Receiver-Transmitter). The RF module is the "RFM69HCW"[1] manufactured by HopeRF with a Adafruit Industries breakout[13]. A 1 kΩ (at 25 ºC) thermistor named "B57164K" by TDK Epcos[10] was chosen due to its low cost and few signal conditioning requirements. As for the power supply, four AA alkaline batteries (MN1500) from Duracell[11] as a result of a wide commercial availability alongside with characteristics capable of fulfilling the criteria of the tests latter performed.

The selected transducer varies its resistivity linearly with the temperature, and the relationship between resistivity and temperature is calculated based on simplified the Steinhart-Hart equation, taking into consideration that β parameter is specific to each thermistor (1).

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{\beta} \times ln(\frac{R}{R_0}) \quad (1)$$

By means of a voltage divider and using the microcontroller analog-to-digital converter (ADC), we have the relationship between voltage and temperature. Since V_{Ref+} is the voltage that powers the voltage divider, the output of the voltage divider, V_O, is given by the equation (2).

$$V_O = \frac{R}{R + 1K} \times V_{Ref+} \quad (2)$$

With V_{ARef} being the positive reference of the ADC, the value given by the conversion, ADC_{Value}, having the same 10 bits, is seen in (3).

$$ADC_{Value} = V_{ADCInput} * (2^{10} - 1)/V_{ARef} \quad (3)$$

Replacing V_O of equation (2) with $V_{ADCInput}$ of equation (3) we get the relationship between the binary value of the conversion and the voltage in the voltage divider. If the positive analog reference, V_{Ref}, is equal to the voltage that powers the voltage divider, V_{ARef}, we get a conversion value that is independent of the supply voltage on the voltage divider, (4).

$$ADC_{Value} = \frac{R}{R + 1K} \times 1023 \quad (4)$$

Hub

Due to the modular approach, with different modes of operation, this chapter comprises the greatest effort in the project development. For the same reason as in the Sensor Unit, the Texas Instruments Inc "MSP430G2553"[7] was select. Once again, the "RFM69HCW" for the RF module to ensure compatibility. The "Wi-Fi Module" ended with a "NodeMCU v1.0", with the SoC (System-on-Chip) "ESP826", that allows 802.11n connectivity and it has a supporting IDE that aids the use of the Lua programming language. Regarding the "Cellular Module", the breakout "Fona 3G/GSM+GPS" from Adafruit Industries was selected. It uses a "SIM5320E" SoC from SIMCom, an external antenna (850/900/1800/1900/2100 bands) and a 3.7 V with 1350 mAh lithium battery. This breakout allows a connection to a third generation mobile network and is controlled, through a UART, with AT commands. Finally, a "Raspberry Pi 1 B+" accomplishes "Webserver Module". It is responsible for hosting a web server, with a LAMP implementation (Linux Apache MySQL PHP), which houses the web User Interface. Once again, via a UART connection, the module and the MCU communicate, with the latter sending the default configurations of new sensors, to be stored in a data base, and receiving the user configurations for those sensors.

The Hub needs to know what context it's in, that is, what other modules are available in the system, since this determines its behaviour. In the presence of the "Wi-Fi Module" and absence of the "Cellular Module", this Hub becomes a "Hub Repeater". Otherwise, in the presence of both, it is a secondary Hub that only sends the received temperature data to the primary Hub. On Figure 2, it is shown the configuration page of the NodeMCU. This is a mandatory step in the configuration of the "Wi-Fi Module" since it has to connect to a network. A small web page was developed where the user can specify the name and password of the network, as well as the desired IP of the current "Wi-Fi Module" and the other one on the network.

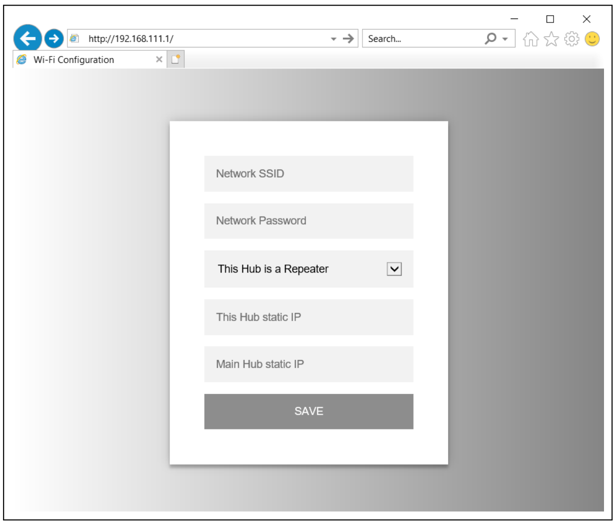

Figure 2: NodeMCU configuration page.

The "Cellular Hub" needs the presence of the "Celular Module", with or without the presence of the "Wi-Fi Module". To properly function, the "Celular Module" requires a SIM card with the ability to send and receive text messages. As mentioned earlier, the access to this module is accomplished by means of AT commands, allowing the MCU to read and sent text messages. Through the User Interface, the "Cellular Module" will receive text messages with the request to change the configuration of a particular sensor or with the request gather the current settings of the sensors and send it back as a text message. It will be through this module that the user will receive the text message that a certain sensor is reading temperatures out of the desired range. Seen bellow is an example of a alarm SMS, where the sensor with ID '2' read a temperature of -5 ºC, with a maximum allowed temperature of -7ºC. It's also shown one major aspect of this mechanism. The importance of the warning is to prevent losses in property, therefore, upon receiving this SMS, the user must reply to that phone number saying "Stop alarm sensor 2", in this instance. Otherwise, every five minutes, the Hub will send a new SMS with the same information until a reply is given.

Temperature alarm!
Sensor ID: 2
Max temperature: -7 C
Current temperature: -5 C
Reply "Stop alarm sensor 2" to disable this alarm.

Finally there's the "Wi-Fi Hub" with the "Webserver Module". This module is achieved with the mentioned Raspberry Pi. Since it is necessary to establish a communication bridge between the Raspberry Pi's UART and the web server itself, a "Python" script was developed, using libraries that allow the use of UART peripheral and the HTTP protocol. The MCU sends messages with a specific format to the UART that are captured in this script. With the GET type method of the HTTP protocol, the parameters are defined to be interpreted by the web server. The client and the server are on the same machine, that is, the Raspberry Pi itself, so to address the file on the web server responsible for handling those parameters, the web server's own IP, localhost, is used. The messages sent by the MCU to the web server relates to the registration of the default information of a new sensor, temperature readings and alarm situations. On the other hand, the MCU receives messages with a new configurations for any given sensor.

User Interface

The web User Interface allows the user to perform several actions. All users go through a authentication process. If the user already has an account it can just log on, otherwise it has to register first. This interface gives the end user the possibility to visualizing his data, such as the telephone number, the ability to view temperature charts for a given sensor, view past alarms that have occurred, generate and download a report, in the ".xlsx" format, with the recorded temperatures, and verify the changes in maximum temperatures that took place. Mainly, it can configure the periodicity, the maximum temperature and the responsible user associated to a sensor.

Another User Interface at the disposal of the user is the mobile app. It starts by asking for the Celular Hub's phone number, followed by the options to view the current configuration scene or change the configuration of a sensor. When choosen the visualization of the current scene of the sensors, an SMS will be automatically sent to the Hub, which, moments later, will respond with an SMS containing that information. Within the app, the user has at his disposal an option that allows the search, in the SMS inbox, for that information in order to properly view it. As mentioned, the other major capability of the app is to change the configuration of a sensor. Firstly, the user has to specify which sensor is to be reconfigured and then, it is presented with the options of change the maximum temperature and associated mobile phone, as well as the period between readings.

4. Results

The carried out tests within the scope of the thesis, where divided once again by the three subsystems that compose it.

The Sensor Unit, was tested in an environment that aims to approach a real scenario. It was placed inside a domestic refrigerator and freezer. In each of these, the thermistor was exposed to air and soaked in propylene glycol. This comparison is important since it is intended to ensure that the temperature readings are correct and reliable. The freezer was set to -17 ºC and it was expected that the recorded temperature to reach that value. The result suggests a circulating air without a homogeneous temperature, which is quite visible on the graph, Figure 3.

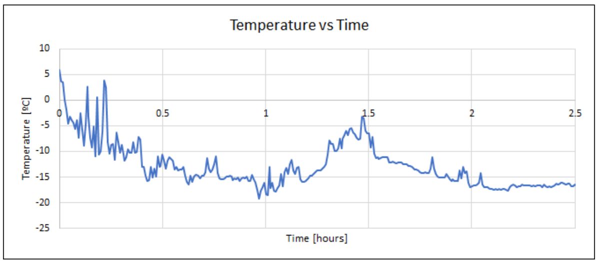

Figure 3: Freezer - Thermistor exposed to air.

On the second run, the thermistor was soaked in glycol. It was expected smoother fluctuations in the apparent temperature, bringing it closer to the expected value of -17 ºC, Figure 4. Both results propose an unforeseen conclusion of a thermal conductivity difference between the glycol and the thermostat that regulates the start and stop of the refrigeration system. This difference adds up to 3 ºC between the value after temperature stabilization and the programmed one in the freezer.

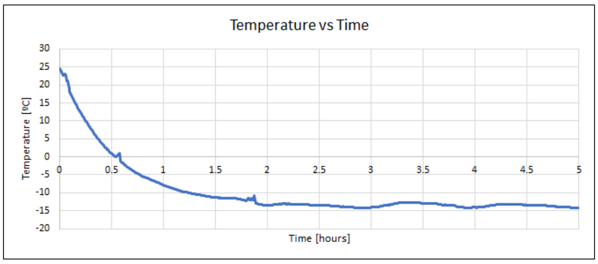

Figure 4: Freezer - Thermistor exposed to glycol.

In an early stage of development, the antenna placed on the "Radio Module" was compressed of a 20 centimetres cooper wire, corresponding to 1/4 of the wavelength. This led to a communication distance of only 50 centimetres. In order to improve this distance, a 433 MHz calibrated antenna was installed. With this change, the communication distance had risen to just 1 meter. Various modes of operation were tested in order to justify such short distances but without meaningful results. Unfortunately, it was not possible to change the "Radio Module" to check if one of these was defective, leading to the conclusion that these were not reliable.

The tests carried out at the Hub level summarize in the validation that all the different modules are communicating properly. By capturing the messages that passed through the MCU's UART, it was possible to validate the correct supply of information to the "Webserver Module" as well as the reconfigurations given by the web User Interface, the received and sent of text messages by the "Cellular Module" and the proper reception of temperatures by the "Radio Module" and "Wi-Fi Module". The test with the most impact was in the context of an alarm situation, where the sensor was configured with a maximum temperature of -16 ºC and Sensor Unit read a temperature of 22.7 ºC, leading to the reception of the text message with this information. The reply message was not immediately given, leading to the reinforcement, 5 minutes later, of the text message previously received, Figure 5.

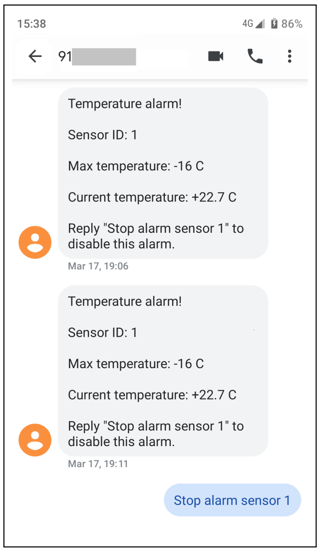

Figure 5: Received alarm SMS.

The results of the tests led to the conclusion that there are points to be improved in the selected hardware. Starting with the Sensor Unit and Hub MCU, an integrated solution of a "Radio Module" in the MCU's SoC, would be the "CC1310 SimpleLink" from Texas Instruments. This solution reduces the points of failure of the system and allows a reduction in energy consumption by 60%[11].

Based on the energy consumptions provided by the "CC1310 SimpleLink" datasheet[11] and, assuming that between the start of the temperature read until the acknowledge reception, there are 5 seconds, in which the MCU is not in low power mode, there is an estimate of the average current, for the minimum period of 15 minutes betweens reads, of 0.0409 mA. For a desired two years of run time, the battery capacity should be around 720 mAH. The previously selected batteries had an operating temperature range starting at -20 ºC, making them insufficient for the sensor operating temperature of -30 ºC. Battery wise, a valid option would be the ANSMANN's Manganese Dioxide Lithium Battery, "5020022"[5], with a nominal voltage of 3 V, a rated capacity of 850 mAH and a operating temperature starting at -40 ºC.

An alternative to the "Webserver Module" would be the use of "Raspberry Pi Zero W". From the performance point of view, both the previously selected and this proposed one, have similar characteristics, and, since the "Raspberry Pi 1 B +" is no longer in fabrication, its use would not be possible. The "Raspberry Pi Zero W" would be potentially less costly when compared to the latest model that the Raspberry Pi Foundation has to offer.

5. Conclusions

Getting to this point of the dissertation, it is time to look at all the work developed so far and not only remember what was done, but also analyse, critically, the solution performed. Thus, the first aspect to refer is the problem that was imposed in the realization of this master's thesis, which consists in the development of a system whose function is to monitor the temperature inside medical refrigeration equipment, in a more economical and scalable way compared to the solutions found on the market today. While also offering the possibility to choose different system configurations, remotely monitor equipment, receive alarms in specific situations and configure the system through a mobile application or web page.

This master's thesis was introduced to the thesis advocate during the professional internship, under the IEFP, carried out after graduating in Biomedical Engineering Degree, at the "Serviço de Utilização Comum dos Hospitais" (SUCH). The problem can be summed up at too high of a cost in the generalized implementation of temperature measuring sensors in Portuguese hospitals. Thus having an opportunity in the market to present a product capable of competing with the competition, not only in the final solution itself, but also in the economic impact of the solution.

Functional and non-functional requirements were specified for a modular system that would collect temperature measurements from a medical refrigeration equipment, with the possibility to view the collected data and configure the system through a web interface and, alternatively, in a mobile application for the Android operating system. On top of that, it would be necessary to set up alert mechanisms that would notify a user that a certain sensor was outside the defined temperature range. The proposed and developed thesis challenged the thesis advocate to the extent that unfamiliar programming languages, other than the traditional "C" were used, passing through the languages such as "LUA", "PHP", "HTML" , "MySQL", "Python", and "Java". The design of a modular system and the way in which various components would be integrated into the proposed ecosystem, proved to be an interesting and attractive challenge.

It was then designed and developed a system that fulfilled these requirements based on a proof of concept implementation that would give depth to a final implementation necessary to the commercialization of the product. The main requirements were successfully achieved, and it was possible to test the system in a scenario that converges with a real case operation. The biggest factor that led to a slow implementation was the selected radio transmission device. The "RFM69HCW" proved to be unreliable due to inconsistencies found in its functionality. With a minimal communication distance of 1 meter, tested in laboratory conditions, it proved itself ineffective. Putting the performance of the "Radio Module" aside and focusing on the successes, it was built a modular system, that can host thirty Sensor Units, that were configured by means of a central processing unit, the Hub. The Hub was tested under various operating modes, having been able to receive an SMS with the information that a certain sensor exceeded its maximum temperature, a backup SMS when the necessary feedback was not provided and, finally, the sensors were configured with the aid of a mobile application and web interface. The system is scalable due to some factors, one being the fact that the Sensor Unit is built with low cost components, based on the proposed final hardware, a "CC1313" microcontroller from Texas Intruments, a 433 MHz antenna, a thermistor and a 850 mAH battery. Having the possibility to send data within a local Wi-Fi network, it is possible to implement this solution in large facilities, despite the fact that for smaller facilities, the inherent modularity makes it a viable option. The User Interface proved to be quite functional since it allows the user to remotely monitor and configure the system. In the case of a Cellular Hub, with the need to perform SMS exchanges with the Hub, those SMS would have the added costs inherent to the mobile network provider. The graphic design, both of the mobile application and the web page, are considered basic since they are composed of non dynamic pages. The justification relies on development phase, the emphasis fell on the functionality of the pages and not on their graphic aspect. At the end of the entire project, we can look at it as a good platform for future developments in this area. The key point would be in the design of a functional prototype of the final hardware. Going through an initial implementation of a prototype of the Sensor Unit that would have all the conditions to communicate with the conceptual Hub, followed by the implementation of a Hub prototype with the various modules that can be coupled. It would be necessary to ensure that all communication scenarios between devices where properly working, and ensure that the system deployment on a Wi-Fi network could be carried out without major obstacles. This system could evolve into a modular Sensor Unit as well, making it possible to associate new transducers and visualize new metrics on the User Interface. A clear objective would be the reading of humidity levels, with the need of improving the software so that this new parameter could be carried out throughout the pipeline.

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