IoT Lab Box

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Abstract

Every day, new technologies emerge. New technologies are created and very often to make our lives simpler and easier. The possibility of having everything connected around us is something that generates interest in many because it allows having a single device where we can have control of all the other devices in a very easy-going way. New terms, related to technology keep on surging every day and the IoT one is currently a term that we are getting used to more and more and as the days go by it its popularity keeps on increasing.

IoT, Internet of Things, is the term used to describe a network composed of physical objects ("things"), that are embedded with sensors, software, and other technologies to connect everything around us, by exchanging data between services and systems over the internet. This project that is going to be developed, has its focus on this new world and focuses on exploring the Internet of Things by creating a system where multiple physical sensors are connected to one or more Arduinos and devices like the ESP32, giving us a more accurate and clearer perception on how we can perceive the environment surrounding us using these devices to our advantage.

To develop these kinds of projects, having a physical place to work is key. Since we are working with software and hardware, having a physical location allows for assembling sensors and actuators in a local and fixed place while at the same time can map the environment where these are located. A project involving hardware benefits from this, because moving around all the physical devices can be very time-consuming and increases the chances of damaging the materials. Nevertheless, also having the possibility of building a mobile project is important, since it allows us to map more environments and interact with different objects, enriching our experience.

The "IoT Lab Box" is a cyber-physical system where the software and hardware world are put together, creating a unified system working as one. By connecting multiple Arduinos devices and assembling sensors and actuators to it, the goal of perceiving the environment around us can be achieved. By providing wireless capabilities to this box, like Bluetooth and WIFI, this project becomes optimal for learning more about the IoT world, wherever we are. This "box" can be either imaginary or an actual physical box, where all the materials are concentrated in one place. By having a system designed like this, we can place a box in a fixed location, like a laboratory, creating a sort of intelligent room, or we can move the box to another place like a studying room, allowing multiple people to experience this project in a way that they desire. With the help of software to analyze all the data put out by the hardware, we will create an intelligent system, a system belonging to the Internet of Things.

Keywords: Technology; IoT; Internet of Things; physical objects; sensors; software; internet; Arduino; ESP32;

1. Introduction

Since the beginning of our time, technology has played a very important role in the development of civilizations and the development of people in general. Nowadays it is something so present in our lives that we don't even really think about it. Whether is a very simple thing or a very complicated one, technology is everywhere we go and, in many cases, contributes to a better and simpler life. New terms, related to this technology concept appear more and more often and the term IoT is one of the most important ones by being constantly around us. IoT means the Internet of Things. It is the term that describes the network composed of physical objects ("things"), that can be embedded with sensors, software, and other technologies to connect everything around us, by exchanging data between services and systems over the internet.

The initial idea of this term, a network of smart devices, was addressed as early as 1982, with an updated Coca-Cola vending machine at Carnegie Mellon University being the first Internet-connected appliance, able to report its inventory and whether recently loaded beverages were cold or not. The most common association of Internet of Things, and the interconnection between all the devices, many times is, for example, a smart home, where everything is connected to a single device, like a smartphone, and with that, we can control everything and see what is happening with all our devices. But it goes much deeper than this. Nowadays, self-driving vehicles are more and more popular and, all the bigger brands in the automotive industry are all competing to build the ultimate autonomous vehicle. This is a very good example of IoT. The possibility to connect all the infrastructure present, like roads, traffic signals, and lights to the vehicle is one of the most important challenges nowadays. But to have all of this, we must have a device or multiple devices capable of this connection and coordination between all of this.

The Arduino is an open-source hardware and software company that designs single-board microcontrollers and microcontroller kits for building digital devices. These boards, use a variety of microprocessors and controllers, and by connecting these devices to the internet, and the devices that we are trying to connect to it, we can use these boards to act as the brain of our entire operation. By acting as the brain of the system and processing data from the sensors and devices connected to it, it can control what we need. Since the Arduino board is an open-source tool, we can code it, using its specific language, C/C++, to create features suiting our needs. It has its IDE, and after the coding process, the upload process to the board is as simple as pressing a button. One of the great advantages of these boards is the fact that they can be programmed "n" number of times, allowing the creation of several IoT projects by simply changing the code and not having the need to have a completely different device to serve as our brain. Combining these two worlds, the physical sensors, and the software, allows us to gain control of devices in our home. A clear example of an application of the IoT. This concept simplifies our lives in a very good way. Whether is to turn ON/OFF a light present in another division, or to assure us that we turned OFF all of our electronic devices when we go on vacations or the ability to control the power consumption of our gadgets, giving us the possibility to see what are the most demanding electronic devices regarding power consumption and helping us, reduce the power bill at the end of the month, IoT is something that we all need and it's here to stay. Because of all this, a project called, IoT lab Box was purposed, aiming at integrating cyber-physical interfaces and by exploring wireless connectivity we can explore even further this world by connecting the box to the Internet or by using Bluetooth interfaces.

This project benefits greatly from a physical location to work with, like a laboratory but is not restricted to it. This box can be perceived as an actual box or an imaginary one, meaning that we do not need a box to put the devices inside. By having them in a workstation, like a laboratory, it is easier to assemble all the components to map the environment, knowing that they will always be there. By creating a room, where this possibility is explored, we can design a place with multiple sensors and actuators incorporated in this location, giving the possibility to students and others to have a place to develop this work with all the materials necessary always available. On the other side, by having all the components placed in a box, we now have the mobility to transport the components to where we want, making every location an intelligent one, if this project is present. From an educational point of view, this is a great advantage since the people who want to use this box are not limited to a specific location to interact with it. This "box", as said, by having Arduinos Uno/ESP32 connected will act as the brain of our IoT device, outputting values and information and with the help of software, these values can be seen and analyzed, making us aware of what is going on around us. In this project, we will explore them and pointing the advantages and disadvantages of both. The project will be executed on both devices, giving more information to the user on what device to use and why.

1.1. Objectives

The main goal of this project is the educational one and to accomplish that, we must integrate this box into courses that can use it to teach something to the students. The educational one is not complete only by making this project available and understandable to students who have a background in these subjects. It also involves those who want to learn more about these systems, even if they do not have a background this project must be open and understandable to everyone. At IST, Instituto Superior Técnico, we have different courses that focus on the IoT area. The ACIC course, Application and Computation for the Internet of Things; The Ambient Intelligence (AI); The Internet of Things Interaction Design (DIIC) course and The Mobile and Ubiquitous Computing (CMU) course.

However, as said, this box can be used by other people than just the students enrolled in this type of course. Since this box, is a combination of software interfaces and mobile hardware, this box can be used by students outside the typical courses that use these types of materials to increase their knowledge in these areas. The restrictions of the use of this box by only the students enrolled in the electronic/software courses doesn't make any sense and we must work to get everyone's interest, enriching their knowledge and presenting them a different opportunity and way of learning.

2. State of the Art

Since this project is going to be developed using the Arduino platform, it is important to explore how the Arduino is used in the educational context with similar or related applications to what we are trying to achieve with the construction of this project. This project has an educational goal, and the development of this project focuses on the IoT world and most importantly how can a project regarding this subject have a positive impact in the laboratory classes at IST and autonomously by the students. We start by considering IST courses where this platform can be used and where all the technologies present in the box can fit and be seen as an advantage. After that, other courses and universities were considered to have an overview of what projects are implemented and how they enrich the learning experience. The pandemic context we are now living in, begs even more for the implementation of technologies that require almost no contact for the safety of all users, specifically the wireless technology.

2.1. IST Context

In section 1.1 of the Introduction Chapter, we talked about courses at IST that could benefit from using this project. Developing this project and at the same time having the possibility to adapt it to serve the needs of several courses is a determinant factor for the evaluation of this work. Now we must understand why.

In the ACIC course [1], through laboratory guides, most of the students have first contact with the Arduino world. The students are prompted to assemble sensors and actuators and create features and implement code into the Arduino Uno, being evaluated by demonstrating their project/laboratory behavior. The opportunity to adapt this box, giving the students the possibility of using a project like this, the IoT Lab Box, to take advantage of it and improve their work, developing more complex and interesting laboratories and projects is a keen factor in deciding whether the project has value or not.

In Ambient Intelligence [2], by the end of the course, students must develop a project where they must monitor an environment and how it reacts to changes applied to him. Some students choose to use the Arduino platform to develop their project and this box might be something that provides them an advantage to the development of their project, whether by helping them or by motivating them to use this box to develop a more complex project. On the Internet of Things Interaction Design course [3], in their final project, students must develop interactive prototypes, combining hardware and software, using an IoT solution. There is a set of hardware that they can choose from, including the Arduino Starter Kit. This kit is also used during laboratory classes to do the exercises. Since this project is all about connectivity and IoT, having this project available will be something of their ultimate interest.

In the Mobile and Ubiquitous Computing course [4], students must develop a project where they create an android app. This type of box could be interesting for them, by having all these cyber-physical sensors available, if their project requires some and since this box will be possible to control via an android app, we put the two worlds together and if they wish, they have a system ready for them to use, to adapt and to interact. All the courses previously described, are courses where the students already have a background in software or hardware or both. By having this background, combining the IoT Lab box with their courses and knowledge is easier. But, what about the students who do not have such a specific background? While developing this project, this is something to look out for.

Nowadays, the interest in the IoT world keeps on increasing and many people who do not study these types of subjects have also grown an interest in this area. This belief is reflected in the construction of this IoT Lab box project. Whether is the use of simple the possibilities of the box or to explore, even more, this box is can be adapted and used by someone who has a background in software and hardware or simple for someone who wishes to learn more and use this box as an entrance to this new world.

This box is a collection of hardware devices in combination with software to create a seamless system. By having all the code and all the assembling processes documented, those who don't have a background can learn easily and understand what has been made and have the opportunity of working with a system already built, ready for action, and to explore how everything works. This project does not assume a background of any kind except the desire and the will to learn new subjects and the will to explore. The limit is the limitation of the hardware itself.

2.2. Related Work

In the field of education, Arduino technology has been used in many contexts, through various institutions and organizations. This segment introduces some of them with a view of getting a deeper understanding of how the platform is used and what functionalities are useful in this sense. Since this project is going to be used in courses and students attending IST, this organization was first approached in the previous section, providing us with some background, but it is also important to understand what has been made by other institutions regarding the Arduino technology. After searching, a few interesting projects came up:

- University de Trás os Montes e Alto Douro - In this university [5], specifically at the masters in electronic engineering, because of everything that it's happening in the world, the COVID situation, they developed a mobile laboratory to ensure that the students can keep working and learning at home with the Arduino platform, by using Arduino kits. The students conduct experiments, followed by the staff via the internet, and at the end of the semester, students will make a public presentation about the results and discoveries found throughout the semester remotely. The course responsible states that even doe these mobile experimental kits are mainly used by students of electronic engineering, this low-cost kit that allows students to make experiments at home and have a more hands-on approach, is an improvement and an add-on to their academic education.

- Stanford University, Stanford - In this university [6], a project called "Lab-in-a-box" was developed to act as a low-cost approach that combines hardware and software for teaching signal processing and analog electronics. It has the goal to improve the teaching of these concepts by providing a different type of platform that is more understandable to the students and by being a low-cost approach and breaking economic barriers to the students that study these types of courses. The Lab-In-A-Box makes the transition from a leisure student to a student easier with a cheap, robust, and accessible collection of tools that connect the system's students are using today with high-fidelity hardware and software interfaces.

- Columbia University - At this university [7], a lab kit was introduced, based on an Arduino microcontroller board and open hardware, to allow students to use low-cost, training-specific hardware to complete lab exercises at home. The selection of hardware was deliberately made to allow the adjustment and adaptation of current laboratory exercises to be used for this new platform and, by doing so, this new platform enables the development of new exercises that would not be feasible by using a conventional means of solving laboratory exercises. Since colleges are turning more and more to online courses, laboratory classes and exercises have become a challenge, and the adoption of distributed lab kits can be promoted using free hardware and software. These lab kits had to be available to students with little knowledge, but they had to be strong enough to solve laboratory exercises. New exercises were also introduced to take advantage of the lack of time constraints. These activities may be constrained by the availability and expense of hardware, but cost-effective and instructive exercises can be planned. Since the interface is accessible, students and teachers can continually change and develop the lab kits. This platform is highly promising for distance learning courses and can quickly be extended to other courses.

3. Architecture

The IoT lab box is a cyber-physical system where multiple interfaces, hardware, and software, work together creating a system that can be used to develop features and give information to the people using it about the environment surrounding them. This box has the objective of demonstrating to everyone using it, how can we perceive the environment surrounding us by using sensors and cyber-physical interfaces to show what is going on and at the same time, giving them a different approach on how to work with sensors and how can we develop code and create features, by having a more hands-on approach to this. This box will present itself as a new way of gathering information and displaying it to everyone, showing different types of applications and ways of making the best of this new thing called the Internet of Things (IoT). A simple box, where multiple physical interfaces work together with the help of software, will allow this idea to be implemented. Given the scope of the project, after developing the features and assembling all the components, tests must be run to ensure the correct behavior of the system. The ACIC course previously referenced, is a course where the first contact with the Arduino platform is presented to the students. This course has already laboratory guides built that do not use the system how it's built, but that limitation does not present itself since the IoT Lab box can be adapted for the purpose desired. This adaptation will serve as a test for our project in terms of performance and viability.

3.1. Requirements

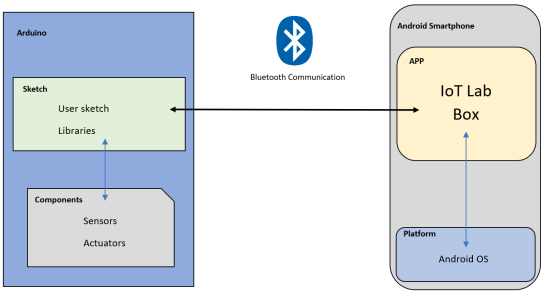
To develop this box and to use it, different materials are required. This box can be assembled using two main hardware devices. The first one is the Arduino Uno and the second one is the ESP32. The Arduinos Uno are provided by the teacher. It is necessary a computer, mainly the personal computer of the person using the system for them to be able to connect to the Arduinos present in the box and to design and interact with the features. To enable the possibility of having a wireless interaction, a Bluetooth and WIFI shield will be provided. The Bluetooth and the WIFI interface are provided by the teacher, and it will be a key component to develop a new type of connection, a wireless one. Although this Bluetooth shield provided by the teacher is the one present at the time, this author acquired a new Bluetooth device for reasons that will be explained later. To interact with the box via Bluetooth, we will use a smartphone. This communication will have as its “middleman”, an android app, to be developed, where all the features will be present and will allow the user to interact with the box and visualize all the outputted values from the sensors. The WIFI connection will be made using a WIFI shield provided to the students, allowing the connection to the Internet.

By saying all of this, we still need to tell the students what they must have and bring to be able to work with this box. Since the IoT lab box is provided as a system altogether, the Arduinos are not needed by the ones using it, unless they want to connect more Arduinos to the box to try to develop more features or to explore how the different types of communication between them work, which is highly encouraged. For the most basic, a computer is everything that all anyone may need. Taking a further step, if the students possess an android smartphone, they can install the app and work with the Arduino in that way, making this the easiest solution since it does not involve the transport of the computer, and all the computers they need, can be carried in their pocket. This android app is built using an online platform that allows to compile the project into an app and install It on the smartphone. This platform also allows the use of an emulator, where the students can install this emulator on the smartphone and load the project that they built onto it, enabling the possibility of visualizing the built app in the smartphone while at the same time if changes are made to the app via the online website, these changes are immediately updated in the smartphone.

Nevertheless, this project and all the software and hardware behind it must be compatible with the Arduino IDE to enable the possibility of developing more code and new features besides the ones that are already planned to be developed.

The ESP32 is a new approach. It will operate in the same way as the Arduino Uno, and the knowledge necessary to code it and to assemble sensors and actuators on it is the same as in the Arduino. If the ESP32 approach is the one chosen, the WIFI shield and Bluetooth shield will no longer be necessary, since this device already has these two pieces of hardware incorporated.

Figure 1: Functional Architecture Bluetooth

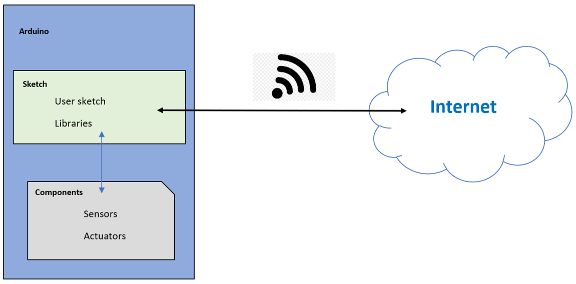


3.2. Functional Architecture

This section is an overview of our system regarding the implementation details of the IoT Lab Box using the materials described in the previous topic. To understand why we use the hardware devices that we used, we must have an overview of the Functional Architecture of our system. This overview is the fundamental plan to move on to the implementation of the IoT Lab Box (Figures 1 and 2). The assembling procedure of these devices and what are the advantages and disadvantages of these when compared to similar devices that we could have used and how do they work and perform will be explained in the following Implementation section.

Looking at Figure 1, we have an overview of the system regarding Bluetooth communications. To implement this communication, we need an Arduino and a Bluetooth module. As we can see in Figure 1, the Arduino has two main parts, the Sketch, and the components. The Components part of our system includes the sensors and actuators needed for the project. The sensors map the environment where the system is placed and send that information to Sketch. The Sketch is composed of two main features: the User sketch and the libraries. The User sketch is what we code. The user creates a program to be able to read the information sent by the sensors and can send information back to the actuators, that as the name suggest, act. When creating a sketch, several libraries can be used, depending on what we need for our system to work properly. For example, to enable the communication between the Arduino and the Bluetooth, a specific library, responsible for this communication must be added to our user sketch so that the system performs as expected. Having created the code needed for our program and imported and used the libraries to enable the Bluetooth communication, we send the information from the Arduino to the Android Smartphone. The smartphone, running the Android OS platform has

Figure 2: Functional Architecture WIFI



the App for our project, the IoT Lab Box App. The values sent by the Arduino are received in this App and displayed there. As seen in Figure 1, the arrow responsible for demonstrating this communication is bidirectional. This means that the communication between the Arduino and the smartphone can be made in both ways. Both can send and receive information. When sending information from the App in the smartphone to the Arduino, the Sketch part of the system, is the one responsible for filtering the data, showing the user the correct information.

Looking at Figure 2, the logic behind it is the same as in Figure 1. Our Arduino part of the system is divided into two main parts, the Sketch, and the Components. The way these communication works is the same as it was described in the previous paragraph. Here, the only changes that we encounter are the libraries used, since now we are using the WIFI as the communication method and not the Bluetooth. Nevertheless, the overview of the system whether we are using Bluetooth or WIFI is the same. This WIFI communication is also a bidirectional one since data can be sent and received from both devices.

As said in the previous section, the implementation of this project has two main approaches. Firstly, the author approached the project using the Arduino platform, using the Arduino Uno board. In the initial stage of the project, only one Arduino Uno is necessary but later, one more will be implemented to develop new features in our box. We can define a structure for this project in a simple way to understand better everything used.

In the first stage, the author assembled one/two Arduino UNOs boards to develop the base for the project. On a second stage, the Bluetooth module was assembled, and the android app was developed to work with the previous stage of the project, exploring this wireless form of connectivity. The third stage was the assembling of the WIFI shield and the development of this communication using a WIFI network and the MQTT broker to enable communication between the two Arduino boards.

In the final stage of the project, the IoT Lab box implementation was changed to be developed with ESP32 devices and the re-assembling of all the sensors and actuators was done, now using these new devices. While using the ESP32, the need to assemble a Bluetooth module and a Wi-Fi module was no longer necessary, since the ESP32 as already incorporated these two modules. There was however the need to adapt the android app previously developed to work with the ESP32. The overview of the architecture of our system, now using the ESP32, is the same as using the Arduino Uno board.

By using these two similar but at the same time different devices from the Arduino platform, the differences between the two were explored and allowed for a bigger development and an educational enrichment since now two devices are used. This allows for a better learning opportunity and experience and the users of this box have now two devices to choose from. These differences and the conclusion taken from the use of these two devices will be discussed in a further section.

4. Implementation

Based on the previous section, an overview regarding the Functional Architecture of this project was exposed. All the details regarding the assembling, the coding, and the implementation must be explained and a guide must be provided so that anyone who wishes to use this box knows how it works. The next section includes an explanation about the different materials used and why they are important to develop our work. After this explanation, we will enter the development of the IoT Lab Box project. All the code produced for this project will be available on the authors' GitHub [1].

4.1. Background

Considering the hardware requirements necessary for our project, this section gives us an overview of the materials necessary for the development of the IoT Lab Box project. Here, we cover all the materials necessary for all communications, before advancing to the implementation process of our system. The selection process of the materials took in also in consideration the key components necessary for an enriched learning process for everyone, providing a versatile project to those who use it. The hardware and software materials used for our project are:

- Arduino Uno; PC; Bluetooth Module (BLE Shield [2] and HC-06 module); MIT App Inventor [3]; WIFI shield using the ESP8266 module; ESP32.

[1] https://github.com/santosandre123/IoTLabBox, accessed 10/2021

[2] https://1sheeld.com, accessed 05/2021

[3] https://appinventor.mit.edu/, accessed 05/2021

4.2. Base Development

The assembling of our IoT Lab box began by choosing sensors and actuators to work with. Having chosen the materials, the assembling process started. Initially, the author began by assembling the TMP36 sensor (analogic temperature sensor). Having assembled this sensor, the author also chose to assemble a LED to light up when the temperature reached a determined threshold. Having both pieces of hardware assembled, the coding procedure took place.

The BLE shield implementation was the first stage of our project. After assembling it, it was tested. The shield did not work as expected since the D1 and D0 pins of our Arduino Uno board were occupied. These pins are responsible for the Serial Communication between the Arduino and the computer and must be clear at all times. To overcome this, a library called SoftwareSerial [4] was used to create new digital pins for the Serial Communication between the shield and the Arduino board. Even with this library implemented, the shield did not work as expected since stability problems were found and the previously installed firmware in the shield, made the development of the project impossible. A new alternative was found, the HC-06 Bluetooth module.

Using this module to develop the Bluetooth communication, the SoftwareSerial library was implemented to allow communication between the module and the Arduino. This worked as expected.

To be able to see the sensor values received in the Bluetooth module, an app was developed. This app was developed using the MIT App Inventor platform, allowing us to create android smartphone apps to visualize the information from the Arduino board on the smartphone. By doing this, a mobile Serial Monitor was developed.

The next step was the implementation of the WIFI shield. The work developed while using the WIFI shield was setting up a local webpage to act as a Serial Monitor and the implementation of the MQTT protocol [5] [6], giving the box the possibility two communicate with two Arduinos through the internet, using specific libraries [7] [8] [9] to enable this process. Using this protocol, one Arduino was used as the Publisher node, sending values, and a second one acted as the Subscriber Node, receiving those same values. Having implemented this, we are now able to have sensor/actuator communication.

4.3. Adaptation of the IoT Lab Box

The author began to think and realized that this box could have applications in certain courses directly. The ACIC course previously approached, is a course where the students use the Arduino Uno to perform laboratory guides and have a first contact with the Arduino world. An interesting idea is to see and prove if this IoT Lab box can be adapted to solve the laboratory guides and to improve some of them by adding to this course wireless communications features.

The ACIC laboratory guides were adapted, alongside the IoT Lab Box to test the system, using these labs as a practical case study. We began by implementing all the features, previously approached and upon implementation, the author was able to make conclusions, regarding the viability of the system when adapted to practical cases like these. The last step of the implementation process was using the ESP32 device. The ESP32 was an alternative found to the Arduino Uno to develop this IoT Lab Box and it was a rather happy surprise. It exceeds the Arduino Uno in computational power, and it is easier to work with. This device has already built into it, a Bluetooth module, a BLE module, and WIFI. By having these features, the need for external hardware is no longer necessary, making it easier to assemble and transport.

The author will develop the project using the BLE module and implement WIFI. Having already developed classic Bluetooth communication, the author shifted his focus to implement the BLE [10] one and compare both. Since the ESP32 has this module incorporated, no need for external hardware was necessary. The android app previously developed, was modified to now incorporate this new type of communication, and the implementation was successful. The WIFI approach was the same as before to have the same base for later comparison. Using the ESP32, a local webpage, and the MQTT protocol were successfully implemented and the conclusions were ready to be made.

4.4. Implementation Conclusions

Based on the previous implementation details of our IoT Lab box adaptation to the laboratory guides from the ACIC course, is time now to make a resume to all the results obtained and formulate conclusions to help us decide if the box is a viable solution as a learning platform and if is it viable. By having a mobile Serial Monitor, using the Serial Monitor from the Arduino IDE is not necessary any-

[4] https://www.arduino.cc/en/Reference/softwareSerial, accessed 05/2021

[5] https://www.arduino.cc/reference/en/libraries/mqtt-client/, accessed 07/2021

[6] https://mosquitto.org/documentation/, accessed 07/2021

[7] https://docs.arduino.cc/tutorials/uno-wifi-rev2/uno-wifi-r2-mqtt-device-to-device, accessed 07/2021

[8] https://www.arduino.cc/reference/en/libraries/wifiesp/, accessed 07/2021

[9] https://www.arduino.cc/reference/en/libraries/pubsubclient/, accessed 08/2021

[10] https://www.arduino.cc/reference/en/libraries/esp32-ble-arduino/, accessed 09/2021

more and because we now have a wireless form of connection to the box, the user does not need to perform a physical connection to the box and can place the box anywhere desired and the interaction to it can be made.

The next step in the development of the IoT Lab box was the WIFI communication. This was concluded with success and the system performed as expected but limitations were found. Now we have a new form of wireless communication and although the local webpage allows us the visualization of the data read by the sensor, the webpage is not able to refresh every time it receives a new value. The process of refreshing the webpage must be made manually. In addition, the connection from the WIFI shield to the Internet is not always stable and can lead to a system crash. The second phase was the implementation of the MQTT protocol. This was done successfully and it was verified that the Arduino Uno with the LED was able to change behavior based on the changes received and that the connection between the WIFI shield and the network was stable and allowed for the exchanging of messages between both devices.

Having concluded with success the implementation of these communications protocols in our IoT Lab Box, it was time to think in concrete case studies to apply our box and see if the box can be a viable learning solution. Having built a project with adaptive capacities to different projects and different types of communications the adaptation to the ACIC laboratory was successful. Now we have a mobile app with a mobile Serial Monitor, allows the user to see multiple sensor data without the need to connect the Arduino Uno to the PC; By having this Bluetooth communication, as long we are within range, using an Arduino Uno with multiple sensors mapping the environment sending the values via Bluetooth is viable; using an Arduino Uno to show a webpage to visualize sensor data via the Internet since the webpage does not have auto-refresh capabilities and the Internet connection is not the most stable. In addition, when using the MQTT Protocol with the Arduino Uno with multiple sensors, the connection is not stable and the system can crash multiple times, making this solution not viable. Comparing the Arduino Uno implemenation to the ESP32, the author verified that the BLE connection is faster than the Bluetooth classic module HC-06, although the implementation is not as simple; The WIFI communications when using the ESP32 are faster and more stable; Using the ESP32 to implement a webpage allows us for a more stable connection and an auto-refresh webpage; the MQTT protocol while using the ESP32 works flawlessly. It allows for a publish and subscribe action without a system crash and finally that the ESP32 is the most viable solution to implement a system like the IoT Lab Box and is a viable future solution.

5. Evaluation

Considering all the implementation described in the previous chapter, we must now perform an analysis of the obtained results. The main features are Bluetooth communications, WIFI communications, and the Implementation of the IoT Lab Box to the ACIC laboratories guides.

5.1. Bluetooth Communications

In this project, two different devices were used to implement Bluetooth Communication. The project used an HC-06 Bluetooth classic module and the BLE module present in the ESP32. Both devices performed as expected and the implementation of both, while being different was made achieving the same objective. By using the Bluetooth devices to send data to our smartphone app to build a mobile Serial Monitor, we must considerer an important factor, time. The sensors are constantly reading new values and sending these new values and having a communication with a bigger delay will not allow us to have reliable data.

We have a measurement performed by the user indicating the latency between a message being processed in the Arduino Uno/ESP32 and arriving at the smartphone. To measure these latency times, the sensors and the smartphone used are the same, the only change is the module behind. The Arduino Uno took 0.978 seconds for the data to be sent and display and the ESP32 takes less than 0.5 seconds and this difference it's due to fact that the Arduino Uno has a computational power smaller than the ESP32 and the BLE communications are faster than the ones from the Bluetooth classic module. The BLE module is an upgrade of the Bluetooth classic but that does not mean that the Bluetooth classic cannot be used. Nevertheless, both times are under 1 second and when considering view sensor data in a Serial Monitor, these types are more than acceptable and prove that using Bluetooth communications whether via Arduino Uno whether via ESP32 are viable.

5.2. WIFI Communications

While developing the IoT Lab Box and while exploring the WIFI communication, different features were created. Using the Arduino Uno and the ESP32, a webpage and development of the MQTT Protocol were implemented. Now, we must evaluate these features and determine if they are viable for our project. As in the previous topic, time is extremely important. On one hand, when implementing the webpage, we must understand how long the messages take to be displayed on the webpage. On the other hand, when using the MQTT Protocol, it is important to see how long the publishing and the subscription procedure take to see if using this protocol is viable or not.

First, we analyze the Arduino Uno working together with the WIFI shield. It takes approximately 5 seconds to establish a connection to the Internet and to send the values from the sensors to the webpage. This is the average time calculated. Sometimes we observe a faster-sending procedure, while in other cases it takes a bit more. Since the implementation of a webpage when using the Arduino Uno does not allow for an automatic refresh, we must refresh the webpage manually. This is not ideal and can cause sometimes problems. If the user refreshes the webpage when the values are being sent, it can cause a crash in the system and the connection to the Internet is lost. Building a webpage when using an Arduino Uno is not a viable solution since the operation does not always perform flawlessly.

When considering the implementation of a webpage using the ESP32, the results are very positive. First, the connection between the ESP32 and the Internet is done very rapidly. The time that the system takes to establish a connection to the Internet and initialize the webpage and send the sensor values to it, takes about 2.323 seconds. Since the ESP32 is cable of having a script allowing the webpage to refresh itself, the sending procedure of the values is done without a problem. The refresh function updates the webpage every two seconds. This refresh action can be reduced for 1 second for example, but while developing this project, a 2-second interval was the optimal one. Every two seconds, the webpage updates itself with the most recent values and they can be visualized. Using the ESP32 to create a webpage with Serial Monitor capabilities is extremely viable and recommended. No matter where the user is, by using the browser to access the IP address where the webpage is located, the values from the sensors can be visualized. For example, if the user wants to have an ESP32 with a specific sensor mapping the environment, the user can see the results in real-time from anywhere as long there is an Internet connection.

Since we can change the time, it takes to refresh the webpage, we can decrease it and develop other projects with it. In this project, we use the webpage to display sensor information, and the two-second interval is adequate to it but let's imagine that we want to control a vehicle using as its brain an ESP32 and our webpage is also responsible for showing us the position of the vehicle. A 2-second update may be too much for it, since in 2 seconds the position changes and we may lose control of the vehicle. The ability to have a refresh action be configured and the power of the ESP32 makes this the most suitable and versatile hardware option.

Another implementation performed using the Internet was the MQTT protocol. The MQTT protocol was implemented with the Arduino Uno and the ESP32. Looking at Table 5 we have an overview of how long the system takes to Publish values. As explained in the previous section, when using the Arduino Uno with multiple sensors, the Subscribing procedure is not recommended since the Arduino Uno does not have the capacity for this task. Nevertheless, the measurement of the time was done using only one sensor in this case. The Arduino Uno takes a few seconds to establish a connection to the Internet and the MQTT protocol. Having these connections established, it begins to send values to the MQTT server. The 3 seconds measurement took into consideration the time the system took after being connected to the MQTT server to publish and to subscribe to the values from the topic. The same measurement, considering the same factors, was applied to the ESP32. Here, we can see an improvement in the performance. Another improvement that plays a huge factor, when deciding which device to use, is the fact that the ESP32 allows for publishing and subscribing to multiple sensors without causing a system crash, and the same is not verified when using the Arduino Uno. These 0.884 seconds measured in the ESP32 refer to the time that the system took to publish the values after being connected to the Internet and the MQTT broker. The connection time to these two is very small and on average took about 0.2 seconds. When comparing the ESP32 to the Arduino Uno, we can see a big improvement, leading to the conclusion that the ESP32 is the viable solution to implement a system using the MQTT Protocol. Even doe our system, when using the ESP32, is cable of performing the publish and subscribing action very quickly, for our project we do not need that type of speed. A timer was implemented in our code, to publish values periodically, allowing for a more stable publish and not overloading our devices. Nevertheless, knowing that our system can perform these tasks quickly, opens the door for future projects where speed is key, like controlling a vehicle, where sending commands at the highest speed possible is key.

5.3. ACIC Laboratory results

After developing our IoT Lab Box system, the user performed the necessary adaptions to implement this project in the ACIC course, mainly the laboratory guides. This was done as an evaluation metric since it proves the scalability and versatility of the system. Having the adaptation of our system to the laboratory guides made, the ultimate test was testing it with people, providing us with an unbiased opinion regarding the functionalities, the difficulty, and the performance of our system. However, this was not possible, due to the pandemic times we live in. The system was developed with the educational goal in mind and to give the possibility to everyone who wishes to learn more about the IoT world and to embrace new projects to have a system allowing them exactly that. Unfortunately, this did not happen. All the conclusions made regarding the performance and the advantages and disadvantages of our system were made by the author.

6. Conclusion

The IoT Lab Box was developed as an introduction to the IoT world. It was developed with several goals being the most important one, the educational. It is important to find ways to increase the interest of students in studying different subjects and when focusing on the IoT world, this project does that. With the development of different types of communication, a new learning experience was created. For everyone, who does not have a background in these subjects, this project is a starting platform to start and explore this new world. The use of both Arduino Uno and ESP32 gives two platforms to develop the project and allows for conclusions and preferences to be created, regarding the module to use. By having Bluetooth and WIFI capabilities, alongside an android app, the base for development is all complete.

It was also proven, that this project has practical applications, using laboratory guides as a practical case study, demonstrating the adaptation capacity of this project. This project can be used in a laboratory context, as demonstrated, but also used for students and other people to explore and try and develop their form of an IoT Lab box. The evaluations results obtained were positive, giving us an understanding of what is and is not possible to do with this system.

6.1. Future Work

Although the system is fully ready to be used, there is always room for the development of new features on top of what was done. While developing the project, ideas came up for the future of our project. Having a project that can be adapted for different purposes, in the future, small laboratory case studies can be developed like using IoT Lab box to create a Face Recognition Door Lock System for the laboratory using either ESP32 or Arduino Uno; create a Hand Sanitizer Dispenser using the IoT Lab Box components with a live update, via Webpage or the Bluetooth App, of the amount of sanitizer present; Integrate the MQTT protocol with the IoT Lab Box smartphone App. Right now, the smartphone app is used as a mobile Serial Monitor and used to send some information to the box. Since this project has the MQTT protocol implemented, in the future the app could be also used to publish and to subscribe to topics. This would allow sending commands and messages from the app to the Arduino as the Bluetooth does; this project has a strong link to courses in software and hardware engineering, but people and courses not related to these types of subjects can also benefit by using this project. For example, by adding chemistry base sensors, like a pH Sensor to the IoT Lab Box, to view the pH of a solution using the mobile Serial Monitor providing an IoT Solution. Bigger practical projects can also be applied by connecting air quality sensors through the university campus, we could have multiple IoT Lab Boxes mapping a bigger environment, and using the mobile Serial Monitor, it would be possible to indicate the Air Quality level present in our University; considering the Tagus Park IST campus, the implementation of an Ultrasonic Range sensor into our project could be used to monitor available parking spots. The IoT Lab Box would then send the sensor information via the Internet to the local webpage, and students, professors and more could always know the occupation level of the campus garage.

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