

Universidade do Minho
Escola de Engenharia

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RTLS Tag – Dispositivo móvel de posicionamento em espaços interiores

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Dissertação de Mestrado

Mestrado Integrado em Engenharia e Gestão de Sistemas de Informação

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RESUMO

Quando se refere o conceito de serviços móveis, umas das classes mais populares são os serviços baseados na localização (LBS), uma vez que este tem um grande impacto nas vidas quotidianas. Por exemplo, quando é necessário encontrar a posição exata de uma pessoa ou objeto no mundo real. Esses serviços estão disponíveis, na sua maioria, em espaços ao ar livre, normalmente utilizando o Sistema de Posicionamento Global (GPS). O GPS apresenta benefícios diariamente, contudo, e apesar de apresentar níveis de exatidão e precisão altos, estes sistemas requerem acesso de linha de visão aos satélites em órbita, assim como, em espaços interiores o sinal fica comprometido. Pelo que, as técnicas de posicionamento para ambientes interiores estão a tornar-se num segmento de mercado que proporciona novas oportunidades de negócios.

O objetivo deste estudo é desenvolver um pequeno dispositivo (designado por tag), que incorpore as tecnologias Wi-Fi e BLE e traga uma solução para o problema de Localização Indoor. Entre outros, o trabalho inclui uma revisão de literatura sobre a localização indoor, sobre as diferentes técnicas existentes, uma análise comparativa de algoritmos, uma análise de tecnologias, a exploração de soluções no mercado e análises comparativas de desempenho e aplicações, e a proposta de uma nova tag e a sua avaliação. Para tanto, seguiram-se as orientações de um método de pesquisa, contemplando quatro etapas: familiarização com a área de posicionamento e navegação em espaços internos, identificação de características desejáveis (ótimas) para a tag e possíveis soluções de hardware, desenvolvimento da tag (hardware e programação) e avaliação do desempenho da solução desenvolvida. Espera-se que esta nova tag permita um melhor desenvolvimento da localização indoor, ultrapassando a dificuldade sentida em outras soluções e respondendo à necessidade de um produto de localização indoor, potenciando uma maior capacidade.

Palavras-chave: Fingerprinting; Localização Indoor, Bluetooth Low Energy e Wi-Fi

ABSTRACT

When referring to the concept of mobile services, one of the most popular classes is location-based services (LBS), as they have a great impact on everyday lives. For example, when it is necessary to find the exact position of a person or object in the real world. These services are mostly available outdoors, typically using the Global Positioning System (GPS). GPS has benefits daily, however, and despite having high accuracy and precision, these systems require line-of-sight access to orbiting satellites, as well as, indoors, the signal is compromised. Therefore, positioning techniques for indoor environments are becoming a market segment that provides new business opportunities.

The purpose of this study is to develop a small device (named tag), that incorporates the Wi-Fi and BLE technologies and brings a solution to the problem of Indoor Localization. Among others, the work includes a literature review about indoor localization, on the different existing techniques, a comparative analysis of algorithms, an analysis of technologies, the exploration of solutions on the market and comparative analysis concerning performance and applications, and the proposal of a new tag and its evaluation. To this end, the orientations of a research method were followed, contemplating four steps: familiarization with the area of positioning and navigation in indoor spaces, identification of desirable (optimal) characteristics for the tag and possible hardware solutions, tag development (hardware and programming) and performance evaluation of the developed solution. It is expected that this new tag will allow a better development of indoor localization, overcoming the difficulty felt in other solutions and responding to the need for an indoor localization product, enhancing greater capability.

Keywords: Fingerprinting; Indoor Localization, Bluetooth Low Energy and Wi-Fi

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GLOSSARY

AP - Access Point

BLE - Bluetooth Low Energy

GPS - Global Positioning System

IoT - Internet of Things

LBS - Location Based Services

RSSI - Received Signal Strength Indicator

WLAN - Wireless Local Area Network

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1. Introduction

1.1. Project Context and Motivation

Indoor positioning consists of locating an object or a person inside buildings. In an outdoor space, the GPS system can be used to estimate the position of something with good accuracy, however, in an indoor space, without a direct line of sight to the satellites, it is impossible to use the GPS to know the position of something accurately. Thus, and thanks to this problem, indoor localization has suffered over time a great demand from companies and researchers.

There are several application examples that can be mentioned, namely by storage companies where there is a constant concern to know where the articles are inside the warehouse; in health to know the location of patients and/or medical/nurse staff; in shopping centres and car parks, it is important to know where to go to reach the desired stores and empty spaces, respectively. In short, for all this it is necessary to resort to positioning and navigation systems for indoor environments.

1.2. Project Objective, Success Criteria and Expected Results

Regarding the objectives and expected results, it can be mentioned that despite the positioning technology in indoor environments having evolved a lot in recent years, it continues to be verified that there are few mobile positioning devices (commonly called tags) available for integration into other systems. Additionally, it appears that the capabilities of existing tags are reduced and, above all, limited in terms of communication with open systems.

Therefore, the objective of this work is to design and implement a tag for indoor positioning systems. The tag must be able to identify existing Wi-Fi and BLE networks in a location and report the collected radio information to an existing service. The tag should be built using low-cost computing platforms (Arduino style) and its implementation will be supported by the experience already developed within the scope of ongoing research projects. Additionally, it is expected that at the end of the project, one or more scientific articles will be written and submitted describing the innovative parts of the work that was carried out.

1.3. Document Structure

The reminder of this paper is organized as follows. In section 2 it is given a brief description about the Indoor Localization techniques and technologies in general. It is also presented some of the related work, briefly describing some of the prior work on Indoor Localization. Section 3 describes the proposed device selection.

Section 4 gives an overview about the work plan development, describing the activities that will be conducted.
Section 5 concludes the document.

2. Literature Review

2.1. Research Strategy

The Research Strategy refers to the step-by-step plan of action that gives direction to the thought process. It enables to conduct the research systematically and on schedule. The main purpose is to introduce the principal components of the study such as research topic, areas, major focus, research design and finally the research methods.

At first the topic was proposed by the advisors and research had to be conducted to fully understand the topic of Indoor Localization since it was the first time that this topic would be covered by the author. For that, this research strategy involves the analysis of already available information such as articles that covered the topic of indoor localization that were recommended by the advisors or that were found to be related to the topic and relevant for gaining insight onto the topic. Human experience, provided by the advisors was also crucial to better understand the research problem and critically analyzing and investigating prior findings of other researchers so that a solution to the problem would be formulated.

2.2. State of the Art

2.2.1. Indoor Localization

Indoor Localization is a method which is used to determine or estimate the location of a user or a device in an indoor environment. Indoor location systems have made it easier to locate people or objects. In an outdoor environment, Global Navigation Satellite Systems (GNSS) can provide good location estimates, however, GNSS-based solutions cannot be used in an indoor environment. In this kind of environment, which is typically called a GPS denied environment, the satellite signals are very poor because of the lack of line of sight between the satellites and the receiver. There has been an increase demand for indoor localization due to the vast number of applications for it. Therefore, another solution had to be made up using sensors and technologies to enable localization (Zghair et. al, 2019).

Due to the vast number of applications that can benefit from a location service in indoor environments, indoor location systems have been an important topic of research and development in recent years. More than a hundred companies are working on this positioning, tracking and navigation technologies and systems. [Fig. 1](#) illustrates the concept of Navigation.

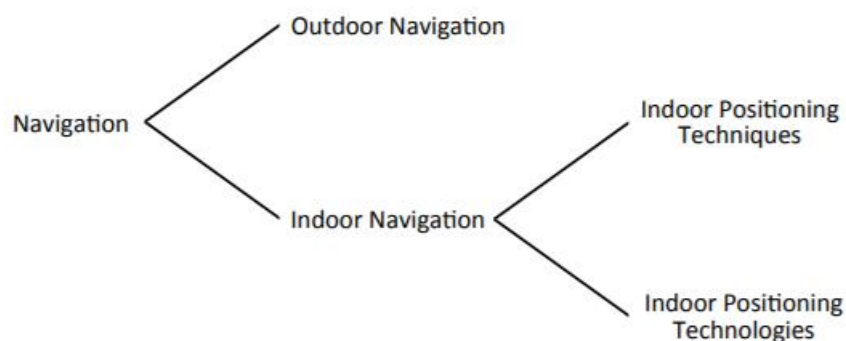


Figure 1 - Flow diagram of Navigation¹

There are many applications of indoor localization: detection of the location of products in the warehouse; monitoring patients, staff, and equipment in hospitals to improve navigation; help customers locate stores or products in a shopping mall; detecting the location to find the place where the car was parked in a parking lot.

¹ This image was taken from the article "A state-of-the-art survey of indoor positioning and navigation systems and technologies" (Sakpere et al., 2017).

2.2.2 Indoor Positioning Techniques

Positioning techniques for indoor environments can be based on the estimation of distance to anchor nodes with known positions and/or on internode measurements. Node cooperation enhances position estimation and is mostly beneficial when traditional localization techniques fail to produce accurate estimation (Yassin et al., 2016).

For this section, the positioning techniques were divided by signal properties and positioning algorithms as shown in [Fig. 2](#).

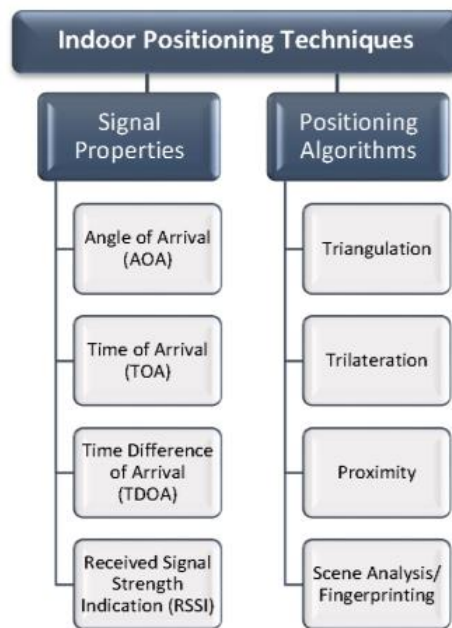


Figure 2 - Indoor Positioning Techniques²

² This image was taken from the article "A state-of-the-art survey of indoor positioning and navigation systems and technologies" (Sakpere et al., 2017).

2.2.3. Signal Properties

In order to calculate the position of a device it is necessary to use geometrical parameters such as angle, distance and signal intensity which are known as signal properties (Sakpere et al., 2017).

Angle of Arrival (AOA)

The angle of arrival technique uses antenna arrays at the receiver's end to calculate the angle by which the transmitted signal affects the receiver by employing and calculating the time difference in the arrival at individual antenna array elements. The position is estimated through the intersection of direction lines starting at the reference points (Sakpere et al., 2017).

Angle of arrival main advantages are that the device or the user's position can be measured in a 2D environment with as few as two measuring units or three measuring units in a 3D environment, and that no synchronization of time is required between the measuring units. However, the drawback is that it has relatively complex hardware requirements and location estimate deterioration will happen as the mobile target moves away from the units of measurements. [Fig. 3](#) illustrates the concept of Angle of Arrival.

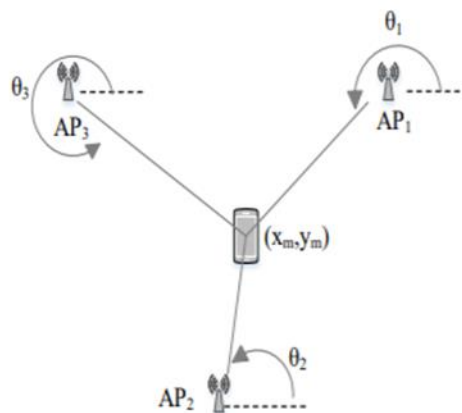


Figure 3 - Localization based on Angle of Arrival (AOA) measurement³

³ This image was taken from the article "A Survey of Smartphone-Based Indoor Positioning System Using RF-Based Wireless Technologies" (Subedi & Pyun, 2020).

Time of Arrival (TOA)

Time of Arrival is used to measure the distance between the transmitter and the receiver by using the signal propagation time. It is possible to find the distance between the reference node and the device by multiplying the propagation speed with the TOA value. Time of Arrival requires strict coordination between the transmitter and the receiver which adds up to the system's cost (Subedi & Pyun, 2020). It has been recognized that with the aid of ultra-wideband technology, the time of arrival technique could best support fine-time resolution. Frequency domain resolution techniques are widely used to achieve high resolution Time of Arrival from the channel frequency response. [Fig. 4](#) shows an example of Time of Arrival adoption.

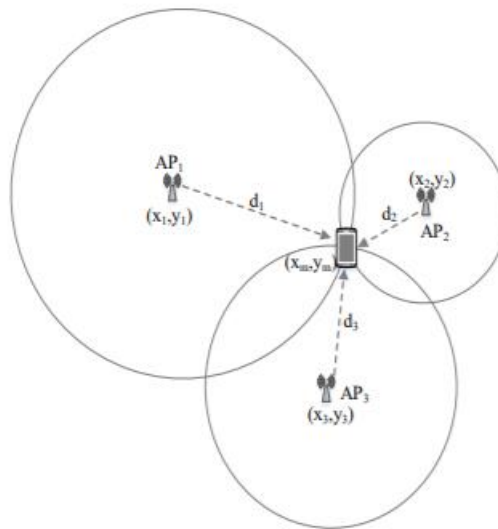


Figure 4 - Localization based on Time of Arrival (TOA) measurement⁴

TDOA (Time Difference of Arrival)

Time difference of arrival technique takes advantage of the difference in signal transmission times measured at the receiver from different transmitters. This is different from the time of arrival technique where absolute signal propagation time is used, in contrast, the latter time measurements are used in place of optional time measurements at each receiving node. The transmitter must be in a hyperboloid with a constant difference in the range between the two units of measurement for each TDOA measurement. Time difference of arrival technique does not require receiver's synchronization; however, the transmitters need to be synchronized (Yassin et al., 2016). TDOA is usually implemented as shown in [Fig. 5](#).

⁴ This image was taken from the article "A Survey of Smartphone-Based Indoor Positioning System Using RF-Based Wireless Technologies" (Subedi & Pyun, 2020).

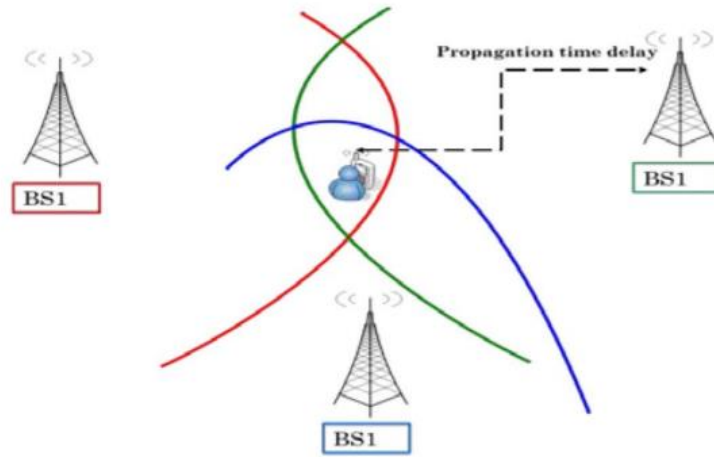


Figure 5 - Time Difference of Arrival (TDOA) technique⁵

RSSI (Received Signal Strength Indication)

Received Signal Strength Indication, as shown in [Fig. 6](#), is one of the most used techniques for indoor localization. It is based on measuring the strength of a signal received from an access point at a client device. It can be assumed that as the number of available access points increases a greater amount of information can be collected, hence, accuracy can be increased over the information obtained. This however also works as a trade-off, as an increase in the number of access points would increase the interference between different signals (Yassin et al., 2016). RSSI techniques are among the cheapest and easiest methods to implement but they do not provide the best accuracy. Filtering is necessary to improve system accuracy using RSSI based localization.

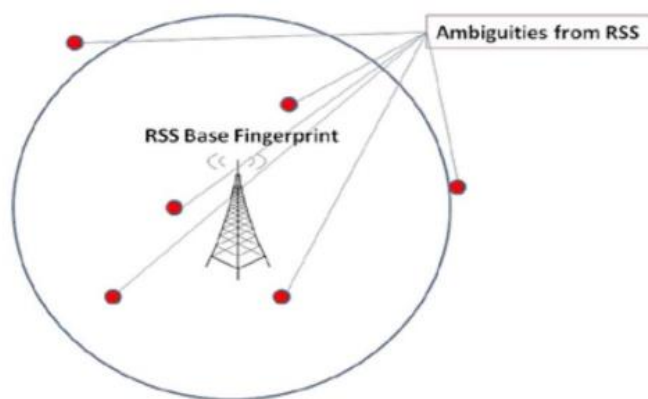


Figure 6 - RSS based Fingerprinting Approach⁶

⁵ This image was taken from the article "Recent Advances in Indoor Localization: A Survey on Theoretical Approaches and Applications" (Yassin et al., 2016).

⁶ This image was taken from the article "Recent Advances in Indoor Localization: A Survey on Theoretical Approaches and Applications" (Yassin et al., 2016).

Advantages and Disadvantages

Every single positioning technique has advantages and disadvantages but most lack accuracy (Yassin et al., 2016).

The advantages and disadvantages of the position techniques are listed in [Table 1](#).

Table 1 - Summary of Signal Properties⁷

| Signal Property | Measurement Metric | Pros | Cons |
|---|---------------------------|-----------------------------|--|
| Angle of Arrival (AOA) | Angle-based | High accuracy at room level | Complex, expensive and low accuracy at wide coverage |
| Time of Arrival (TOA) | Distance-based | High accuracy | Complex and expensive |
| Time Difference of Arrival (TDOA) | Distance-based | High accuracy | Expensive |
| Received Signal Strength Indication (RSSI) | Signal-based (RSS) | Low cost | Medium accuracy |

2.2.4. Positioning Algorithms

In order to calculate the position of an object, positioning algorithms are used. These process the signal property and output a position. In this way, the positioning algorithms allied to the signal property determine the position of an object. It is also important to note that positioning algorithms have advantages and disadvantages, so using multiple of them will improve position accuracy and performance (Sakpere et al., 2017).

⁷ This table was taken from the article "A state-of-the-art survey of indoor positioning and navigation systems and technologies" (Sakpere et al., 2017).

Triangulation

The triangulation technique is used in conjunction with the geometric concept of angles of the triangle to determine the receiver's position. Rather than measuring distances between nodes like trilateration, triangulation-based positioning is based on angle measurements. Although they work similarly, the position of the target node can be determined by intersecting several pairs of angle direction lines with triangulation.

This approach requires only two measuring devices to estimate the location in a two-dimensional plane (Subedi & Pyun, 2020). Three or more devices are usually used for location estimation to enhance accuracy. It requires highly directive antennas or antenna arrays to measure the direction.

Trilateration

The trilateration technique estimates the object's location by measuring the distance from three points of reference based on the triangle's geometric properties. In trilateration it is needed at least three fixed points to determine a position in 2D. Depending on three non collinear distance measurements the target object's real location is calculated (Subedi & Pyun, 2020).

The location of the target object is determined by the intersection of imaginary circles in a 2D dimension plane.

Scene Analysis / Fingerprinting

Scene analysis refers to the type of algorithms that first collect features that are the fingerprints of a scene and then estimate the location of an object by matching online measurements with the closest priori location fingerprints. RSSI based location fingerprinting is commonly used in scene analysis (Subedi & Pyun, 2020).

Fingerprinting technique uses radio signals to learn the user or device's location and it works by collecting the signal values (fingerprints) during an offline phase, measuring the different calibration points throughout the area of interest, and recording it in a database which will then be compared with the online measurements from the database where the system is deployed to estimate the user's location. During the online part the constructed radio map will be used to approximate the position of the tracked object (Eisa et al., 2013). Online positioning therefore requires a selection process for the access points. A range of algorithms are presented to match offline calculations with online calculations. It is important to know that fingerprinting techniques can provide accurate localization estimates however they are very sensitive to environment changes over time.

Characteristics of Positioning Algorithms

The characteristics of each Positioning Algorithm is described in [Table 2](#).

Table 2 - Summary of positioning algorithms⁸

| Positioning algorithm | Signal property | Pros | Cons |
|--------------------------------------|-----------------|--|--|
| Triangulation | AOA | Simple, low-cost and high accuracy at room level | Complex, expensive and low accuracy at wide coverage |
| Trilateration | TOA/TDOA | High accuracy | Complex and expensive |
| Scene analysis/fingerprinting | RSSI | High performance | Complex, expensive, medium accuracy and time consuming |

2.2.5 Indoor Localization Technologies

There are numerous technologies capable of ensuring that someone doesn't get lost geographically. There are artificial and natural techniques, such as satellite signals and radio signals, and celestial bodies and natural landmarks, respectively (Sakpere et al., 2017).

In this section, several existing technologies that aim to provide indoor location services are demonstrated. This theme presents a diversity of algorithms and techniques. Many technologies have evolved to respond to positioning and navigation, however, in this section, indoor environments will be the main focus.

- Wi-Fi

The Wi-Fi technology, also known as IEEE 802.11 standard, operates in the Industrial, Scientific, and Medical (ISM) band. It is mostly used to provide networking capabilities and access to the Internet to a variety of devices in personal, public, and industrial environments. Wi-Fi nowadays has a reception range of about 1 kilometer (km).

Most of the newest laptops, smartphones and other mobile user devices are Wi-Fi enabled, making it the best suitable for indoor localization and one of the most examined localization technologies. Existing Wi-Fi networks are typically deployed for communication purposes rather than location and therefore new and efficient

⁸ This table was taken from the article "A state-of-the-art survey of indoor positioning and navigation systems and technologies" (Sakpere et al., 2017).

algorithms are needed to improve their location accuracy (Zafari et al., 2017).

Challenges in Wi-Fi based Localization System

Wi-Fi based location system is time consuming (surveying the site), cumbersome and multipath is influenced by the existence of physical objects which may interfere with other applications on the 2.4GHz ISM band. It is also important to mention that the variation of the signal strength in relation to time is considered a weakness of this system, causing deterioration in the location accuracy. Simultaneous updating of the signal strength map is crucial, as the movement of people, doors and furniture often causes a variation in signal strength. It is therefore considered the biggest disadvantage of Wi-Fi fingerprint systems (Yassin et al., 2016).

- Bluetooth

Established as IEEE 802.15.1, it comprises of the specification of physical and MAC layers to connect various fixed or moving wireless devices within a particular personal space. Bluetooth Low Energy (BLE), commonly defined as Bluetooth smart, which is the latest version of Bluetooth, delivers an increased data rate of 24Mbps and more energy efficiency with coverage range of 70-100 meters. While BLE can be used with different localization techniques such as RSSI and AoA, most of the existing BLE based localization solutions rely on RSS based inputs as RSS based systems are less complex (Zafari et al., 2017).

One of the advantages of using Bluetooth technology in indoor localization is that devices are small and easy to find in smartphones, laptops, etc.

Challenges and drawbacks of Bluetooth based positioning

There are problems associated with BLE that make such positioning systems difficult, namely, the range (coverage) and signal of radio waves is limited, and they are prone to disturbances such as storms and organic matter which can disturb or distort radio signals. As an RF signal travels through air and other media in an indoor environment, it exhibits certain propagation behaviors or effects, such as absorption, reflection, scattering, refraction, interference, multipath, and attenuation. These behaviors are signal impediments that affect the transmission of a signal between two locations, causing significant loss and degradation of the received signal. Its effects can sometimes be useless and have a negative effect on performance and accuracy.

- Ultra-Wide Band (UWB)

This technology works in the microwave band where the high frequencies can penetrate building materials like walls. The technology is mainly used for short-range communication systems like laptops peripherals and alternative indoor applications.

Ultra-Wide band has been a very enticing technology for indoor localization because of its resistance to interference from different signals, low power consumption, and effective penetration through dense materials (Subedi & Pyun, 2020).

Challenges in UWB-Based Localization System

UWB technology faces numerous challenges induced by extremely cluttered operating environments that cause multipath, NLOS and shadow artifacts. These challenges are cited in the following list:

1. Difficulty in implementing broadband radio devices for a UWB signal with absolute bandwidth greater than 500 MHz. With the advancement of technology, some studies have been developed in order to develop platforms that can reach 10 to 15 cm of precision in positioning.
2. Possibility of interference with the ultra-wide spectrum. This is due to an incorrect configuration or due to the propagation of the UWB signal over the bandwidths that contain the frequency of the existing narrowband system.
3. For its implementation, at least three receivers with direct path unlocked to the transmitter are required for normal ToA positioning algorithm.
4. For the system to be effective and achieve maximum accuracy, it is necessary that the acquisition, tracking and signal synchronization are performed with very high precision in time relation to the pulse rate.

All these problems are currently being studied and analyzed towards the evolution of technology (Yassin et al., 2016).

- Ultrasound

Ultrasound based location systems are referred to as fine grain systems with centimeter level location accuracy. They depend on the time of arrival calculation of the ultrasound signal measured using sound velocity. Ultrasound networks which have been built are either narrowband or wideband. Relatively to the ultrasound positioning system, it has high accuracy at room level. Some ultrasound positioning systems use

narrowband or wideband signals that have shown a high level of accuracy during implementation. These involve the use of ultrasonic tags or nodes on users and objects. These tags or nodes serve as receivers or transmitters; when one is stationary or fixed, the other is in motion (Sakpere et al., 2017).

Ultrasound position systems deliver a range of benefits like low device cost, accuracy, reliability, scalability, and high-power performance.

Challenges and drawbacks of Ultrasound

Large-scale implementation will degrade the advantages of this system. Ultrasonic positioning systems are expensive to deploy and maintain on a large scale. They are usually cheap on the room level.

In addition, ultrasound systems experience multipath effects such as noise, reflection, and interference. Thus, system accuracy and performance are degraded (Sakpere et al., 2017).

- Dead Reckoning

The technique of Dead Reckoning is used to estimate the current position based on the last calculated position and motion information. Here two techniques can be used to estimate a person's travelled distance. The first is pedometer based dead reckoning, in which step detection and step length are estimated and then steps are counted to measure the distance travelled. The other is pedestrian dead reckoning which calculates the distance travelled directly. The inertial measurement unit (IMU) is attached to a person's foot, and it calculates the acceleration and angular velocity changes. The data obtained is then analyzed, transformed into referential motions and the movement's distance and orientation are measured. The advantages of this system are numerous. It is simple, low-cost and accurately estimates position in real time. It is autonomous and does not require external references to determine its position, orientation, or velocity once it has been initialized. In addition, because of the inertial sensors inherent therein, it can smoothly and easily be used in a hybrid method with other positioning systems for pedestrian navigation. It is not affected by signal issues, does not emit nor receive signals or radiation, and does not require a network to work.

Challenges and drawbacks of Pedestrian Dead Reckoning

A major problem with PDR and INS is the gradual drift in operation due to the progressive accumulation of errors over a period of time during motion. This gradually leads to low accuracy. This is due to sensor noise and bias and magnetic disturbances. To eliminate this error there is the possibility of using a hybrid system

with a GPS satellite system or other positioning systems. Thus, the complexity of the system increases, as does the cost (Sakpere et al., 2017).

2.2.6 Performance

The development of indoor positioning and navigation has been studied and analyzed, and consequently, evolving with the aim of guaranteeing scalability, complexity, privacy, usability and precision, among others. Several issues, challenges and limitations have been explored to respond to the need for progress in these systems.

- Accuracy

Good accuracy is a significant user prerequisite for positioning systems. Different systems can have different accuracies. However, the accuracy is still a very challenging area of interest for many researchers in the field. As mentioned earlier, indoor environments due to the presence of obstacles and multipath effects provide a challenging space for location systems to operate. Therefore, it is important for the system to limit the impact of multipath effects and other ambient noise to achieve highly accurate systems. This can require extensive signal processing and noise mitigation which is a highly challenging task. The location system must be able to locate the user or object of interest ideally with an accuracy of 10 cm (known as micro location) (Zafari et al., 2017).

- Cost

Another challenge is the monetary value of the system. Localization systems that require additional infrastructure, that huge corporations might be able to afford whereas smaller organizations are limited in the matters of the costs. Hence, some of the infrastructures' equipment and bandwidth can therefore be avoided by using the existing infrastructure. Therefore, the location system can easily penetrate the consumer market and be widely adopted while keeping the cost low (Zafari et al., 2017).

- Energy Efficiency

The energy efficiency of the indoor localization system is very critical for the widespread acceptance. Most current localization systems use greater energy to deliver higher precision. In today's localization systems it is quite difficult to achieve high precision without draining the battery of the device and this can lead to user's

dissatisfaction. Therefore, there is a need to improve the energy consumption of the localization systems. Technologies such as BLE can be applied, as it has lower power consumption, offloading the computational aspect of the location algorithm to a server and/or any entity that has access to the uninterruptible power supply and has high processing power. The fundamental compromise is between the energy consumption and the latency of the location system (Zafari et al., 2017).

- Scalability

One of the most important requirements is that the system must be scalable. That is to be capable of simultaneously find or provide locate facilities to a wide number of users in a large area. Low scalability can lead to poor system performance. A scalable positioning system means that it functions properly when its scope gets larger. Usually, the performance of localization reduces with the increase in the distance between the transmitter and receiver. Further, a positioning system may require scaling on 2 axes, density and geography. Geographic scaling represents the coverage of an area or volume, whereas density scaling represents the number of units positioned per unit geographic space or area per time period. Wireless signal channels may turn out to be congested as more area is covered or the units in such an area are crowded; hence, computation further or communication infrastructure may be required to do localization. In addition, the dimension of a system is another metric for scalability. A positioning system may locate objects in 2-D space, 3-D space or in both (Liu et al., 2020). Because of all these challenges there is a lot of room for improvement in this field.

2.2.7 Applications

The LBS service is required for both indoor and outdoor environments. In this section, a detail of the main applications of indoor location is presented. Indoor positioning and navigation for mobile devices occupied 4 billion dollars in 2018 in the market. This is a reliable, easy-to-use and accurate solution for indoor positioning and navigation that has the potential to open the door to new applications. The creation of new business opportunities in numerous scenarios is indeed regarded as a cornerstone in realizing the vision of the Internet of Things (Yassin et al., 2016).

A. Asset Management and tracking: Detection of the location of products in the warehouse

Location-based services include asset tracking and enable factory automation to ensure workplace safety. Asset management will also allow for better inventory management and optimized operation management.

Additionally, personnel and asset tracking analytics and motion data collection that are employed have proven to be outdated so the use of novel energy efficient techniques and algorithms will eliminate the need for expensive proprietary hardware (Khanh et al., 2020).

B. Health Services: Monitoring patients, staff, and equipment in the hospitals to improve navigation

Health sector can greatly benefit from indoor localization as it can help save valuable lives. It can help both the hospital staff, the patients as well as the visitors. If a patient needs medical assistance, the current protocol requires broadcasting the message or paging a specific doctor or staff member who may not be in vicinity of the patient. The delay in the arrival of the staff might even cause the death of the patient. Similarly, broadcasting the message will cause other staff members to receive irrelevant messages. A location-based solution would allow to track the position of the staff members. In case of emergency, the localization system would find the staff member who is in close vicinity and has the necessary qualification to handle the emergency (Marques et al., 2012). This will avoid the aforementioned delay as well as not spam the other staff members. Indoor localization can also allow the doctors to track various patients and track their mobility to ensure patient safety. Visitors who intend to visit patients can find their destination using a localization system without any hassle.

C. Contextual Aware Location based Marketing: Help customers locate stores or products

There are several types of usability of these applications, however, they can be used to direct a user to a store located inside a building, access a specific book in a library, the boarding gate at an airport, among other examples that this type of systems benefits. iBeacons provides proximity-based services for travelers to enhance their experience. In this way, JFK in New York, Heathrow London, Miami International and many other airports have started to use it so that all their tourists feel integrated in the whole space. As well as for public transport, such as buses, there is the LBS app that can be used at bus or train stations to navigate to the bus stop (Zafari et al., 2017).

D. Location-Based Services: Detecting the location to find the place where the car was parked in a parking lot

With the growth of cities that has been observed in recent decades, some spaces and buildings have become huge and complex. This is the case for large shopping centers and parking spaces. In these spaces it is not

always easy to find a particular car, especially if the visitor is not a regular user of the same space. These problems can be minimized using navigation systems for indoor environments. These tools are like the common GPS system, which are used to find the way to a certain destination. It facilitates navigation within the parking lot. The main function of these solutions is to indicate the shortest way to a certain car.

2.3. Critical View of State of the Art

This point is particularly important as it reflects the entire theoretical framework where the essence of this work fits. At first it was sought to analyze other studies related with indoor localization and several applications to obtain comparative information regarding the critical success factors present in a process of this nature. What values a tag from the perspective of users is the effectiveness of able to deliver quality services. Together, these services must provide the geographical accurate location of the user. The fundamental principle of indoor localization is that it does not have access to satellites to know the location of a user. As an indoor device, this tag does not focus on GPS or other outdoor technologies that enable the localization, but rather indoor technologies to provide a location in an indoor structure.

The main conclusions drawn from the state-of-the-art study were the following:

- Indoor localization services are an integral part of localization systems.
- Localization is critical and knowing the whereabouts of any asset or user in an indoor environment is an untapped niche market.
- There is scientific evidence that effective solutions have been implemented for indoor localization processes but there is room for improvement.
- There are several good practice frameworks and standards for managing localization. Several studies prove the reach of the benefits of increasing the different number of technologies and techniques, improving the efficiency and effectiveness of location services, noise effect reduction and improvement of the productivity of the solutions, when implemented successfully.
- The most commonly used technology is the IEEE 802.11 standard, commonly known as Wi-Fi.
- The target technologies of this study case are Bluetooth and Wi-Fi to be implemented within a tag and using the fingerprinting technique. The literature review found studies that prove the existence of a high probability that this choice will lead to reach the expected benefits.
- However, there are common mistakes that can lead to the failure of a tag development and implementation, and these should be avoided.

The study case to be developed will focus on measuring the impact of the indoor localization processes and the efficiency, effectiveness, and robustness of this tag.

3. Work Developed so far

Real-time location systems (RTLS) tags are wireless devices that equip to people, objects, or any physical things to digitally track their real-time location and movements throughout large facilities or localized areas. For example, in environments like smart factories, businesses will use tags in a real-time location system to digitally track workers, powering critical safety use cases such as collision avoidance or safety zoning. They'll also track key assets like production equipment, vehicles, and inventories to support enterprise asset management, automation, workflow optimization and more. Other industries, like healthcare use clinical-grade RTLS tags to help track staff, patients, and key medical equipment like defibrillators and more for real-time visibility that helps them deliver vital care in urgent scenarios.

3.1. RLTS Tag – specifications and requirements

- Effectiveness

Our tag must receive and send data with good transfer speeds and there should be no losses of information.

- Cost

The tag must be inexpensive in order to be economical to have multiple tags on various objects.

- Autonomy (energy consumption & battery)

The tags' autonomy must be quite high (for example, several months) so that there is no need to constantly recharge the tags' batteries.

- Size and Weight

The size and weight of the tags must be remarkably small and light to be able to place it on any object.

- Operating System Limitations (privacy and energy)

The Operating System should not be a hindrance because of the restrictions it may have regarding data privacy and power consumption for the device.

- Start & stop (with accelerometer) hibernate

The tag must have a start and stop system with the help of an accelerometer. When it is verified that the object in which the tag is inserted is not being used, the tag will be able to transition to a "hibernate" state that limits its operation to save energy. Likewise, it must transition from this state to "active" as soon as the object starts to move.

- Channel Duality (the server communicating with the tag, and the tag with the server)

The tag must be able to communicate with the server as well as receive data from the server.

- Shifting communication protocols (from UDP to TCP and vice-versa)

The tag should be able to transition from mode UDP to mode TCP. In mode UDP, communicates through a UDP protocol that uses less energy and resources in exchange for less reliability and mode TCP in which it communicates via a TCP/IP protocol having greater information reliability at the cost of higher energy costs.

- Openness

The openness of the system is determined primarily by the degree to which new resource-sharing services can be made available to the user. It is based on a uniform communication mechanism and published interface for access to shared resources.

- Standalone

The device must be able to function independently of other hardware. This means it is not integrated into another device. It can act as a standalone reader and/or transmitter of data.

3.2. RLTS Tag – Core Skills

- Soldering

Soldering is not a skill detained so it is difficult to do the soldering of a particular product. It might be a couple simple solder joints or require special reflow tools.

It might be required to do some reflow or basic rework with SMD components. A heat gun, Heaterizer or other tools might be required, and a good understanding of SMD soldering as well as PTH soldering are required.

- Programming

If a board needs code or communicates somehow, there are needs to know how to program or interface with it. The programming skill is all about communication and code.

The toolchain for programming is a bit complex and will examples may not be explicitly provided. It will be required to have a fundamental knowledge of programming and be required to provide own code. It may be necessary to modify existing libraries or code to work with specific hardware.

- Electrical Prototyping

If it requires power, it is needed to know how much, what all the pins do, and how to hook it up. References to datasheets, schematics, and know the ins and outs of electronics is required.

Consulting a datasheet for calculations to determine a component's output format, linearity, and do a little math to get what is needed is central. It will be used a datasheet or schematic beyond basic pinouts.

3.3. Microcontroller Boards Selection

The tag to be considered should deliver both precise 2-4 meters level accuracy via Wi-Fi and BLE and positioning up to 500 m for high-performance location tracking that supports diverse RTLS needs. Featuring low-power consumption, wireless configurability and industrial-grade reliability, deployment-ready hardware that can be easily set up, configured and maintained. Supporting ranging, real-time tracking and bi-directional communication.

It was decided to build the tag around a microcontroller board, to minimize the hardware development effort. At first, many microcontroller boards were considered that could be used as the main component of a tag, bearing in mind that they would later be disregarded based on the functional requirements that were important. [Table 3](#) shows the first set of boards that were considered.

Table 3 - Preliminary Research

| Name | Wi-Fi | Bluetooth | Price Range |
|----------------------|--------------|------------------|--------------------|
| Arduinos | Yes | Yes | Low |
| Beaglebones | Yes | Yes | High |
| SparkFuns | Yes | Yes | Medium |
| ESP32 Modules | Yes | Yes | Low |

A table listing all the specifications of each microcontroller board is available in the section [Preliminary Research](#).

After the initial consideration, many more microcontroller boards were explored, and a few previous considered ones were disregarded. That is because of functional requirements. A focus on the size and weight of the boards and more extensive research was what drove this next section to consider the following, as shown in [Table 4](#).

Table 4 - Outlining Possibilities

| Name | Length | Width | Soldering |
|------------------|---------------|--------------|------------------|
| Arduinos | Medium | Medium | No |
| SparkFuns | Medium | Medium | No |

| Name | Length | Width | Soldering |
|---------------------------------|---------------|--------------|------------------|
| ESP32 Modules | Small | Small | Yes |
| ESP32 Development Boards | Medium | Medium | No |

In the section [Outlining Possibilities](#), an extended the analysis is displayed to get a more complete picture.

Finally, a verdict had to be reached, not only regarding functional aspects of the board but also extras that would be practical and useful for the work to be developed. These four boards were considered as optimal and suiting for the project. All four boards listed in [Table 5](#) will be purchased and worked upon.

Table 5 - Final Decision

| Name | Justification |
|------------------------------------|--|
| Beetle | A small-scale electronic device with a great range of benefits such as: low on power consumption, an enticingly small form factor, a surprising amount of functionality and a lot of computational power |
| SparkFun Thing Plus | A powerful Wi-Fi and Bluetooth MCU module, scalable and adaptive. Easy to use and it utilizes the Qwiic Connect System which means no soldering or shields are required to connect it. |
| Arduino Nano RP2040 Connect | A versatile plug & play board with dual core, connectivity, audio and machine learning capabilities. Also takes less time to compile with the benefits of a full Arduino Cloud support |
| ESP32 Module | Based on its value for money, wide range of features, small size and relatively low power consumption, it is well suited to the IoT application. A good understanding of soldering is required. |

In [Final Decision](#), it is given a whole perspective of what was decided and what the microcontrollers boards are all about.

4. Activity Plan

4.1. Gantt chart

The work to be developed is designed for a 12-month extension (beginning in the month of October 2021 and ending in October 2022). It is anticipated that this work will involve performing the following tasks:

1. Familiarization with the area of positioning and navigation in indoor spaces. [M1 – M3]

(Reading of Articles; Relate the articles; Study of real cases)

2. Identification of desirable (optimal) characteristics for the tag and possible hardware solutions. [M4 – M6]

(State of the art; List of requirements and features; Weighting of possible solutions)

3. Tag development (hardware and programming). [M7 – M9]

(Device construction; Server implementation; Microcontroller programming; Deployment)

4. Evaluation of the performance of the developed solution. [M10 – M11]

(Data collection in real environment; Reliability tests and scenario development; Analysis of the data collected; Autonomy tests)

5. Dissertation writing. [M4 - M12]

(Pre-thesis; Thesis)

6. Writing and submission of one or more scientific articles describing the innovative parts of the work done. [M12 - M13]

The present Gantt chart, depicted in [Fig. 7](#), serves to better demonstrate the planning of the work to be developed.

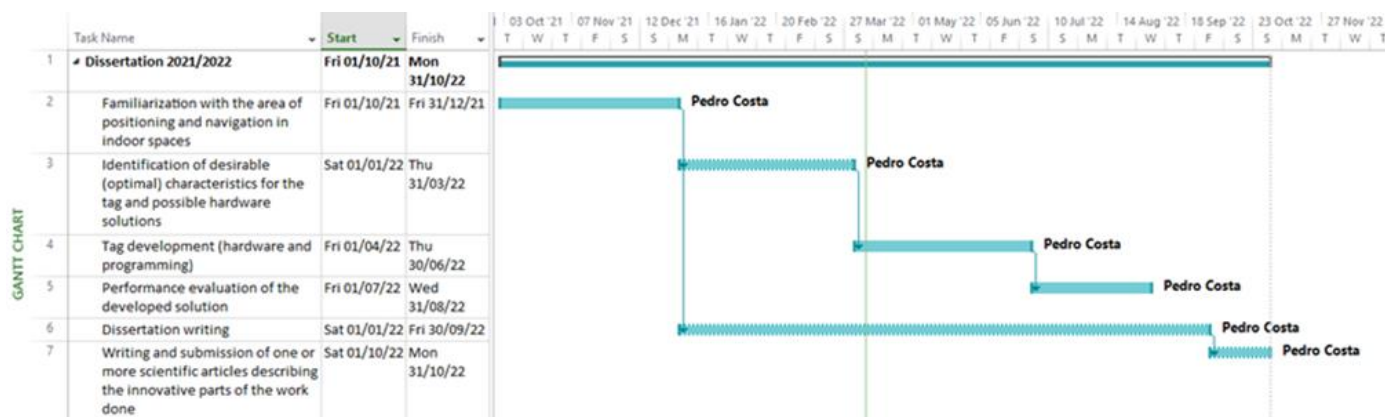


Figure 7 - Gantt Chart

5. Conclusion

Indoor localization has already been used to improve customer experience in indoor areas. This work focused on the main problems of the present time, where a large system such as the GPS fails in indoor environments, therefore, it was necessary to think about the dimension of this problem and a way to solve it.

A framework is presented on themes that encompass Indoor Localization systems and what they represent in the functioning of an environment. Subsequently, a set of evaluations and research was developed with a view to identify which tags could respond to the problem. Then, the results obtained are shown, identifying advantages and possibilities inherent to the use of different microcontroller boards. To conclude this study, it is possible to identify a set of tags, relating them to the work to be carried out in the future.

At the end of the study, it was possible to conclude that the fingerprinting technique presented a high quality and therefore is increasingly used in the indoor localization industry. However, additional efforts are required to improve the performance of these systems so that applications that are highly dependent on user location can provide better services to its users.

After this report has been completed, an exploratory analysis will be carried out on the quality of the microcontroller boards and an investigation and experience of the same, which is quite a difficult task due to the high knowledge requirements needed.

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ANNEX


Preliminary Research

| Product | Brand | Wi-Fi | Bluetooth | Cost | Size | Weight | Board | Microcontroller | USB Connector | PINS | Connectivity | Sensors | Communication | Clock Speed | Memory |
|---------------------|------------|--------------------|-------------------------|-------|-----------------------|--------|----------------------------|---------------------------------------|---------------------|--------------------------------------|------------------------------|---|---|--|---------------------------------------|
| Nano RP2040 Connect | Arduino | 802.11b/g/n | Bluetooth® and BLE v4.2 | 21 € | 45mmx18mm | 6g | Nano RP2040 Connect | Raspberry Pi RP2040 | MicroUSB | 22 digital, 20 with PWM and 8 analog | ATECC608 A-MAHDA-T Crypto IC | LSM6DSOXTR (6-axis) | UART | 133 MHz | 16MB Flash IC |
| | | | | | | | | | | | | | I2C | | |
| | | | | | | | | | | | | | SPI | | |
| Black Wireless | BeagleBone | 802.11b/g/n 2.4GHz | Bluetooth 4.1 plus BLE | 100 € | - | - | Nano RP2040 Connect | 2x PRU 32-bit | USBclient/USBhost | 2x 46 pin headers | - | - | - | 800MHZ | 4GB 8-bit eMMC on-board flash storage |
| Blue | BeagleBone | 802.11bgn | Bluetooth 4.1 and BLE | 118 € | - | - | AM335x 1GHz ARM® Cortex-A8 | 2x PRU 32-bit 200MHz microcontrollers | USB2client/USB2host | 2x 46 pin headers | - | Sensors: 9 axis IMU (accels, gyros, magnetometer), barometer, thermometer | GPS, DSM2 radio, UARTs, SPI, I2C, 1.8V analog, 3.3V GPIOs | 2x32-bit 200-MHz programmable real-time units (PRUs) | 4GB 8-bit eMMC flash storage |
| AI | BeagleBone | 2.4/5GHz WiFi | Bluetooth | 113 € | 8.9cm x 5.4cm x 1.5cm | 48g | - | - | USBtypeC | - | - | - | - | 533 MHz | 16GB on-board |
| | | | | | | | | | USBtypeA | | | | | | |

| Product | Brand | Wi-Fi | Bluetooth | Cost | Size | Weight | Board | Microcontroller | USB Connector | PINS | Connectivity | Sensors | Communication | Clock Speed | Memory |
|-----------------------------------|------------|----------------------------------|--|---------|----------------------|--------|-----------------------------|---|-------------------|-------------------|--------------|---------|---|------------------------------|---------------------------------------|
| | | | | | | | | | | | | | | | eMMC flash |
| Green Wireless | BeagleBone | WiFi 802.11 b/g/n 2.4GHz | Bluetooth 4.1 with BLE | 56 € | - | - | AM335 x 1GHz ARM® Cortex-A8 | 2x PRU 32-bit microcontrollers | USBclient/USBhost | 2x 46 pin headers | - | - | 2x Grove connectors (I2C and UART) | - | 4GB 8-bit eMMC on-board flash storage |
| Enhanced | BeagleBone | ? | ? | 100 € | - | - | TI AM3358 ARM® Cortex A8 | 2x PRU 32-bit microcontrollers | USBclient/USBhost | 2x 46 pin headers | - | - | - | - | 4GB 8-bit eMMC on-board flash storage |
| Thing Plus | SparkFun | 802.11 BGN | Integrated dual-mode Bluetooth (classic and BLE) | \$20.95 | 2.30 x 0.90 Inches | - | Dual-core Tensilica LX6 | - | MicroUSB | 38 pins | - | - | high-speed SPI, UART, I ² S and I ² C | Up to 240MHz clock frequency | 16MB of flash storage |
| C3 WROOM Module | ESP32 | IEEE 802.11 b/g/n-compliant | Bluetooth LE: Bluetooth 5, Bluetooth mesh | \$3.50 | 18.0 × 20.0 × 3.2 mm | - | - | 32-bit RISC-V single-coreprocessor, up to 160 MHz | - | - | - | - | GPIO | 160 MHz | 4 MB SPI flash |
| | | | | | | | | | | | | | SPI | | |
| | | | | | | | | | | | | | UART | | |
| | | | | | | | | | | | | | I2C | | |
| | | | | | | | | | | | | | I2S | | |
| C3 WROOM Development Board | ESP32 | WiFi IEEE 802.11 b/g/n-compliant | Bluetooth LE: Bluetooth 5, | \$10.00 | - | - | - | 32-bit RISC-V single-coreprocessor | MicroUSB | - | - | - | - | 160 MHz | 4 MB SPI flash |

| Product | Brand | Wi-Fi | Bluetooth | Cost | Size | Weight | Board | Microcontroller | USB Connector | PINS | Connectivity | Sensors | Communication | Clock Speed | Memory |
|---------|-----------|-------------------|----------------|--------|------|--------|---|-----------------|---------------|---------|--------------|---------|---------------|-------------|--------|
| | | | Bluetooth mesh | | | | | , up to 160 MHz | | | | | | | |
| ESP32 | GeekCreit | 2.4 GHz dual-mode | ? | 8.25 € | - | - | Tensilic a Xtensa ® Dual- Core 32-bit LX6 | - | - | 48 pins | - | - | ADC | - | - |
| | | | | | | | | | | | | | UART | | |
| | | | | | | | | | | | | | PWM | | |
| | | | | | | | | | | | | | DAC | | |
| | | | | | | | | | | | | | SPI | | |
| | | | | | | | | | | | | | I2C | | |
| | | | | | | | | | | | | | I2S | | |

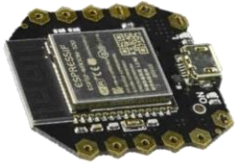
Outlining Possibilities

| Name | Picture | Number of pins | Length | Width | Module | Wi-Fi | Bluetooth | IDE | Soldering | Price | Link | DataSheet |
|------------------------------------|---|----------------|---------|-------|-----------------|-------|-----------|---------|-----------|---------|-----------------------|-----------------------------|
| SparkFun Thing Plus |  | 28 | 59mm | 24mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 18,50 € | Link1 | Datasheet 1 |
| Arduino Nano RP2040 Connect |  | 30 | 45mm | 18mm | Nina W102 uBlox | Yes | Yes | Arduino | No | 21 € | Link2 | Datasheet 2 |
| Arduino Nano 33 IoT |  | 30 | 45 mm | 18 mm | Nina W102 uBlox | Yes | Yes | Arduino | No | 16 € | Link3 | Datasheet 3 |
| Arduino MKR WiFi 10 |  | 28 | 61.5 mm | 25 mm | Nina W102 uBlox | Yes | Yes | Arduino | No | 27,90 € | Link4 | Datasheet 4 |


| Name | Picture | Number of pins | Length | Width | Module | Wi-Fi | Bluetooth | IDE | Soldering | Price | Link | DataSheet |
|--------------------------------|---|----------------|---------|---------|--------------|-------|-----------|---------|-----------|---------|-----------------------|-----------------------------|
| BEETLE |  | 14 | 35mm | 34mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 15,95 € | Link5 | Datasheet 5 |
| ESP32 Development Board |  | 36 | 57mm | 28mm | - | Yes | Yes | Arduino | No | 15 | Link6 | Datasheet 6 |
| Adafruit HUZZAH32 |  | 28 | 51.0mm | 22.7mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 17.62 | Link7 | Datasheet 7 |
| Realtek |  | 16 | 24mm | 16mm | RTL8720DN | Yes | Yes | Arduino | Yes | 7,10 € | Link8 | Datasheet 8 |
| TTGO |  | 32 | 40.27mm | 31.07mm | - | Yes | Yes | Arduino | No | 15,87 € | Link9 | Datasheet 9 |

| Name | Picture | Number of pins | Length | Width | Module | Wi-Fi | Bluetooth | IDE | Soldering | Price | Link | DataSheet |
|--------------|---|----------------|-------------|-------------|--------------|-------|-----------|---------|-----------|---------|------------------------|------------------------------|
| FireBeetle |  | 36 | 53mm | 24mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 19,90 € | Link10 | Datasheet 10 |
| E-paper |  | 32 | 48.25m m | 29.46m m | ESP-WROOM-32 | Yes | Yes | Arduino | No | 13,95 € | Link11 | Datasheet 11 |
| LuaNode |  | 30 | 51.45m m | 23.37m m | ESP-WROOM-32 | Yes | Yes | Arduino | No | 9,95 € | Link12 | Datasheet 12 |
| NodeMCU |  | 36 | 48mm | 26mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 12 | Link13 | Datasheet 13 |
| ESP32 Module |  | 36 | 25.2mm | 18mm | - | Yes | Yes | Arduino | Yes | 10 | Link14 | Datasheet 14 |

Final Decision

| Preference | Name | Picture | Number of pins | Length | Width | Module | Wi-Fi | Bluetooth | IDE | Soldering? | Price | Link | DataSheet | Justification |
|------------|--------|---|----------------|--------|-------|--------------|-------|-----------|---------|------------|---------|-----------------------|----------------------------|--|
| 1 | BEETLE |  | 14 | 35 mm | 34 mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 15,95 € | Link1 | Datasheet1 | A small-scale electronic device with a great range of benefits such as: low on power consumption, an enticingly small form factor, a surprising amount of functionality and a lot of computational power |

| | | | | | | | | | | | | | | |
|---|-----------------------------|--|----|-------|-------|-----------------|-----|-----|---------|----|---------|-----------------------|----------------------------|---|
| 2 | SparkFun Thing Plus |  | 28 | 59 mm | 24 mm | ESP-WROOM-32 | Yes | Yes | Arduino | No | 18,50 € | Link2 | Datasheet2 | <p>A powerful WiFi and Bluetooth MCU module, scalable and adaptive.</p> <p>Easy to use and it utilizes the Qwiic Connect System which means no soldering or shields are required to connect it.</p> |
| 3 | Arduino Nano RP2040 Connect |  | 30 | 45 mm | 18 mm | Nina W102 uBlox | Yes | Yes | Arduino | No | 21 € | Link3 | Datasheet3 | <p>A versatile plug&play board with dual core, connectivity, audio and machine learning capabilities. Also takes less time to compile with the benefits of a full Arduino Cloud support</p> |

| | | | | | | | | | | | | | | |
|---|--------------|---|----|--------|------|---|-----|-----|---------|-----|----|-----------------------|----------------------------|---|
| 4 | ESP32 Module |  | 36 | 25.2mm | 18mm | - | Yes | Yes | Arduino | Yes | 10 | Link4 | Datasheet4 | Based on its value for money, wide range of features, small size and relatively low power consumption, it is well suited to the IoT application. A good understanding of soldering is required. |
|---|--------------|---|----|--------|------|---|-----|-----|---------|-----|----|-----------------------|----------------------------|---|