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- RESEARCH ARTICLE-

Localisation and Museum Artifact Visual and Audio Presentation Using Bluetooth Beacon Technology

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Abstract

In this study, the purpose is to provide an efficient and original indoor area localization and presentation via picture and the voice assistance in a museum, using beacon devices based on the Bluetooth Low Energy technology infrastructure and embedded electronic circuit systems. In this context, a localization procedure is carried out via a Bluetooth module and an embedded microcontroller. A hardware as well as a software was developed in order to read the data broadcasted from radio frequency beacons, which support Bluetooth 4.0 technology. By using AT commands and a location identification system as well as a software which is designed and implemented on a microcontroller system detects the nearest beacon, therefore the desired area, based on the ID numbers of beacons and received signal strengths. Using this system, visitor locations can be determined and visitors are provided with visual or audio content based on their distance to the artworks. This study may be a prototype base application for future developments.

Keywords:
Localisation, Bluetooth Low Energy, beacon, Arduino, AT commands.
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Introduction

There are several alternatives for acquiring information about locations or for finding out how to reach a specific destination (Zafari, et al. 2019). Current technologies regarding localization vary

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depending on whether the location is an indoor or outdoor area. The fact that most of our lives are spent indoors, as well as the complicated inner structures of the indoor areas, have brought about the need for a technology to be used for various purposes indoors (Yassin et al., 2017). Although Global Positioning System (GPS) is sufficient for identifying outdoor locations, more sensitive signals that are not affected by indoor conditions are needed for the identification of indoor locations (Cheng et al., 2016). The fact that GPS hardware is not compatible with indoor technology as well as the instability of wireless signals in terms of interference, reflection and diffraction, efforts for indoor localization have been directed at alternative methods and technologies using Radio Frequency Identification (RFID), 802.11, and Bluetooth signals. There are many different indoor localization techniques, each with their own strengths and weaknesses (Chawathe, 2008).

As technologies which provide indoor location information have the potential to be used in indoor areas visited by a high number of visitors such as airports, university campuses, office buildings and museums (Jiménez A. R. and Seco F. 2017), they have attracted great attention from technological sectors and business organizations (Koonen, 2018). Provision of more information to users in indoor areas and this becoming an independent sector have led to the development and improvement of research concerning these technologies (Pelant et al., 2017). However, technologies providing indoor area localization are still not so widely used. Furthermore, they are not standardized or advanced enough to be offered to users and cover sensor platforms (Dickinson et al., 2016).

The increasing popularity of location information has accelerated studies regarding default location (Kajioka et al., 2014). For this purpose, investigations carried out in indoor areas reveal that methods such as Wireless Fidelity (Wi-Fi) and RFID which have become popular especially within the last decade are preferred for indoor localization purposes, despite having some disadvantages. Limitations imposed on Wi-Fi by factors related to environment and power supply as well as the fact that RFID requires special equipment for the user to perform localization pose a challenge for indoor localization. Such disadvantages have given rise to a need for a new indoor localization technology. Low cost - low energy BLE technology which emits BLE signals has an advantage over other indoor technologies thanks to its suitability for use in indoor areas as well as its ability to maintain signal strength at a steady level (Wang et al., 2016).

Many technologies applied in indoor areas can be used for the purpose of artifact presentation in museums (Jiménez A. R. and Seco F., 2017). Quick Response (QR) and Augmented Reality (AR) which are among the methods used in order to access content such as information and visuals about the artifacts in museums. However, they have some disadvantages too. QR allows for scanning the code about the information concerning artifacts through a smart device, while AR technology allows visitors to access 3D images of selected artifacts via smart devices. Visitors of National Palace Museum of Taipei have the opportunity to access information about the visuals they select by rotating them clockwise or counterclockwise via smart devices or phones. Both technologies have certain requirements for operation. In museums where QR code technology is used, visitors should scan the QR codes of the artifacts via their smart phones or devices in order to access the content of their choice through Wi-Fi (He et al., 2015, and Pelant et al., 2017).

BLE technology is used in indoor areas such as shopping malls, airports and universities as well as in museums, with the purpose of giving information about artifacts or collection items based on the visitors' locations. For example, Giasemi et al., (2015), made mobile information recordings about historical buildings by using beacons that emit BLE signals, offering historical content to visitors based on their locations. The project was conducted in Leicester Castle, Leicester, England. Through the Beacon-based localization application, visitors of Leicester Castle were provided with audio or visual content, depending on their needs. This way visitors' interest was kindled and they were able to make advantage of their historical sightseeing experience to the fullest extent. Likewise, in a study conducted by (He et al., 2015), information about the artifacts and collection items in the museum were transmitted to visitors' smart devices, with the purpose of arousing interest towards the artifacts and providing more historical information to the visitors.

Material and Methods

Bluetooth Low Energy

Bluetooth 4.0 or Bluetooth Low Energy (BLE), also known as Bluetooth Smart, is a low-energy wireless network technology. BLE was first introduced in 2010, as part of Bluetooth 4.0 (Kajioka et al., 2014). As the latest version of Bluetooth technology, BLE allows for contactless remote data exchange, like the classical Bluetooth signals. The released Bluetooth 4.0 version has such advantages as high speed, low energy and power consumption efficiency. Low energy requirements of BLE are of vital importance for beacons which can be activated by small coin cell batteries for months. BLE signals emitted by beacons can be detected by Bluetooth 4.0 modules (Gast, 2014). Bluetooth devices which enable the use of BLE technology are being manufactured in increasingly larger quantities day by day (Hou X. and Arslan T., 2017). Recently, many operating systems support BLE technology and Bluetooth 4.0-based ibeacon devices, manufactured by the Apple trademark in 2013 have received great attention (Kajioka et al., 2014, Sharhan et al., 2015).

Beacon Technology

Beacons are devices which are based on BLE infrastructure and used for wireless communication. Thanks to their low energy consumption, BLE beacons can operate for a long time on coin cell batteries. They are low-cost, light, small and easy-to-install devices (Kajioka et al., 2014, Han et al., 2018, Pelant et al., 2017). The images of BLE beacon used in the study w/ and w/o case have been given Figure. 1.

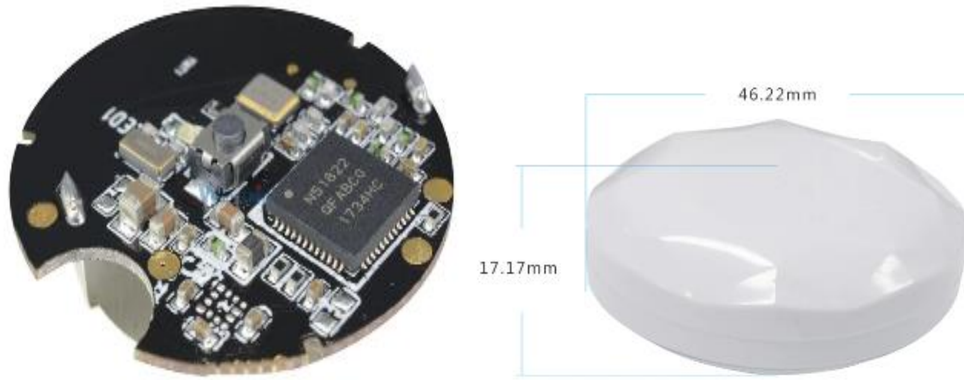

Figure 1. BLE beacon images with and without case used in the study.

One of the most important features of Beacons is that this technology basically offers a one-way communication. The user's smart device is only a receiver; no data can be transmitted via the device. Beacon protocol transmits only. In other words, it is a broadcaster that transmits data packets to the users. In order to detect the smart devices of users in indoor areas, beacons send data packets with intervals ranging from 20 ms to 10 seconds. The shorter the data sending intervals are, the more quickly beacons can detect the devices to which they send the data packets and as a result, the more energy they consume (Allurwar et al., 2016). Therefore, the battery life is shortened.

Beacons have Unique Identifiers (UID) which render them unique. By means of UID, beacons can be distinguished and easily tracked. Beacons emit radio signals on a regular basis, which enables them to detect devices with Bluetooth hardware as soon as they enter the range. The signals they emit make it possible for beacon modules to be used as an RSSI-based indoor localization system. In addition, proximity calculations can be made based on the mid-to-high and low signals received by the application. Beacons have a total of 160 bits of data packet, comprised of 128 bit Universal Unique Identifier (UUID), 16 bit major and 16 bit minor. UUID is used for defining the entire beacon network, allowing for instance to define the enterprise to which the beacon module belongs in a unique way. The 16 bit major data packet is used for the purpose of defining a small group within a large beacon network. Likewise, the 16 bit minor data packet is used in order to distinguish between individual beacons. This way, the lowest level of the hierarchy in a series of beacon modules can be determined (Allurwar et al., 2014). And, TX power is used in determining the proximity to a certain beacon (He et al., 2014). Figure 2 represents the functioning of the beacon data.

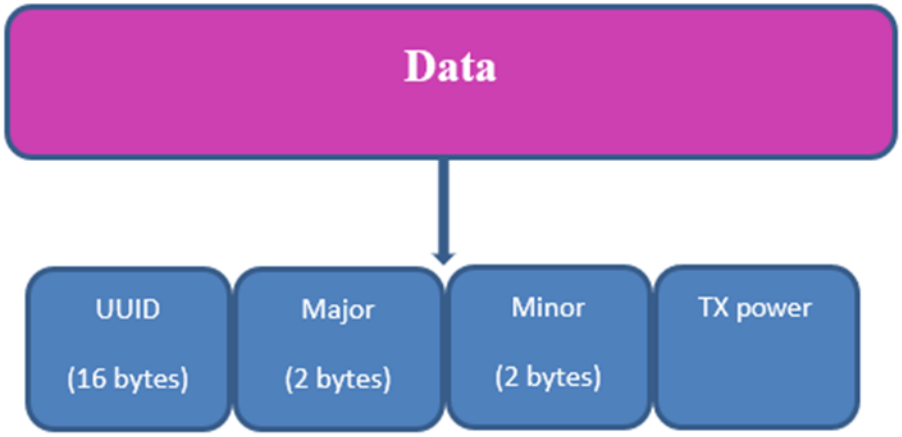

Figure 2. Beacon data packet representation.

The devices to communicate with beacons must be compatible with the Bluetooh 4.0 technology. These devices catch the passive signals emitted by beacons to perform their location-related tasks (Han et al., 2019). In other words, users can be provided with location contents by beacon devices that emit passive signals in indoor areas, depending on proximity. Automatic information transmission for advertisements and coupons in shopping malls with beacon system installations is a classic example for the use of beacons. Beacons can provide routing in order to attract potential customers to isles and/or stores in shopping malls. They can also be utilized in evacuation processes at times of disaster. As a result of the growing competition, restaurants are also in need of this technology which provides real-time and low-cost automation. Apart from its use for retail and marketing purposes, this technology can provide visitors of museums and cultural centers with detailed information about historical artifacts and exhibited items (Allurwar et al., 2014). Beacon technology enables visitors to obtain more historical information about the collections in museums.

System Design

Conventionally, operations carried out with beacons are based on the transmitting of certain information, advertisements and contents by beacons via the signals they emit upon detecting users' smart devices. In such applications, the use of beacon technology requires users to download the relevant applications via their smart devices, to activate Bluetooth connection as well as location notifications and to allow beacon communication within the indoor area they are visiting. Beacon devices will be nothing more than interesting and well-designed small plastic boxes unless these actions are performed. However, in our study, in order to eliminate this process, a system comprised of an HM-10 Bluetooth module, Arduino microprocessor, Nextion smart display and an MP3 decoder circuit was designed to function as a substitute for smart phones. Figure 3 shows the block diagram of the system.

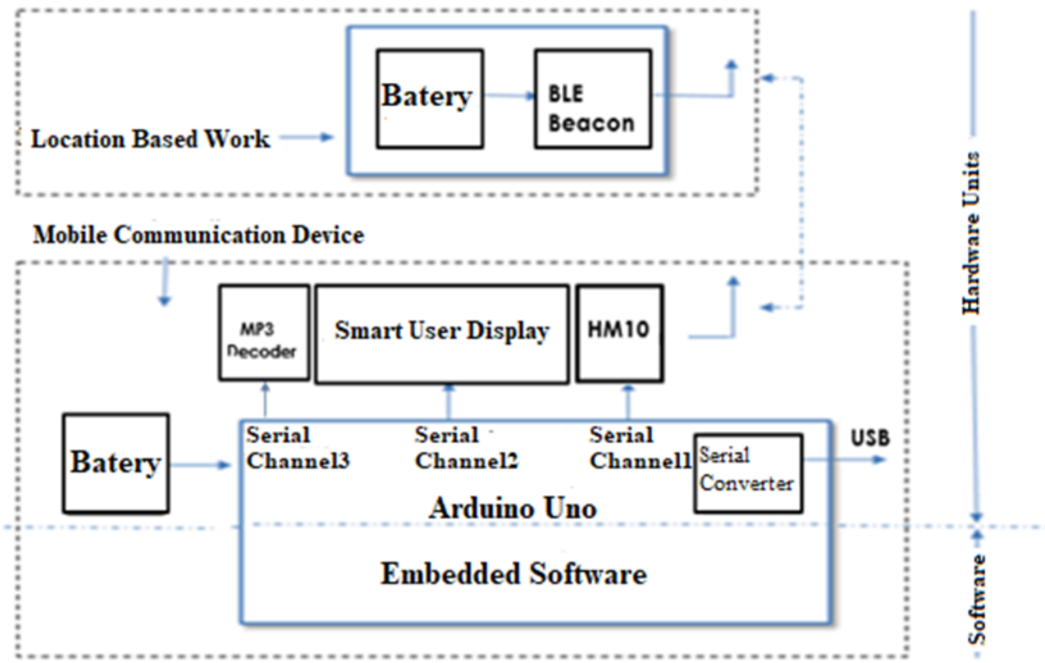

Figure 3. Block diagram of the system.

Beacon IDs are defined in the Arduino within the system used by the users, designed to be used in museums. The beacons whose IDs have been defined emit BLE signals on a regular basis. This way, beacons send the place name, location info, presentation or advertisement specified in the Arduino over and over again. HM-10 detects the data packets transmitted by the beacons, establishing communication between the Arduino and the beacons. Based on the localization information provided by beacons, our study made use of a Nextion smart display as well as an MP3 decoder circuit for the purpose of providing information about artifacts to visitors in museum applications. Arduino communicates with the smart display and MP3 circuit to which visuals, audio files and relevant information has been uploaded beforehand. The system used by a visitor allows for information transmission about the nearest artifact (that is, the beacon with the highest level of RSSI power).

Experiments and Results

Nextion smart display is programmed via its own editor, designed specifically for the smart display. Artifact data view on the editor display that was used is shown in Figure 4. The information, visuals and audio files that were previously uploaded to the smart display and the MP3 circuit via an SD card are offered to visitors by the system we have designed. Relevant data is provided upon the detection of visitors in a museum by the beacon that broadcasts with the highest RSSI value. This way, visitors can easily access audio and visual information about the artifacts in a museum. When a visitor is walking around in a museum and gets near the Sophist sculpture, for instance, the images to be displayed on the Nextion smart display are shown in Figure 5 in their proper order. When the visitor moves towards another artifact, s/he can access the relevant information through the system s/he uses.

Arduino, HM-10 Bluetooth Module, Nextion Smart Display and MP3 Decoder which are the components of the system that has been designed, are encased in order to provide ease of use and pleasant appearance to the user. Encased display views for both when near an artifact and away from artifacts are shown in Figure 6.

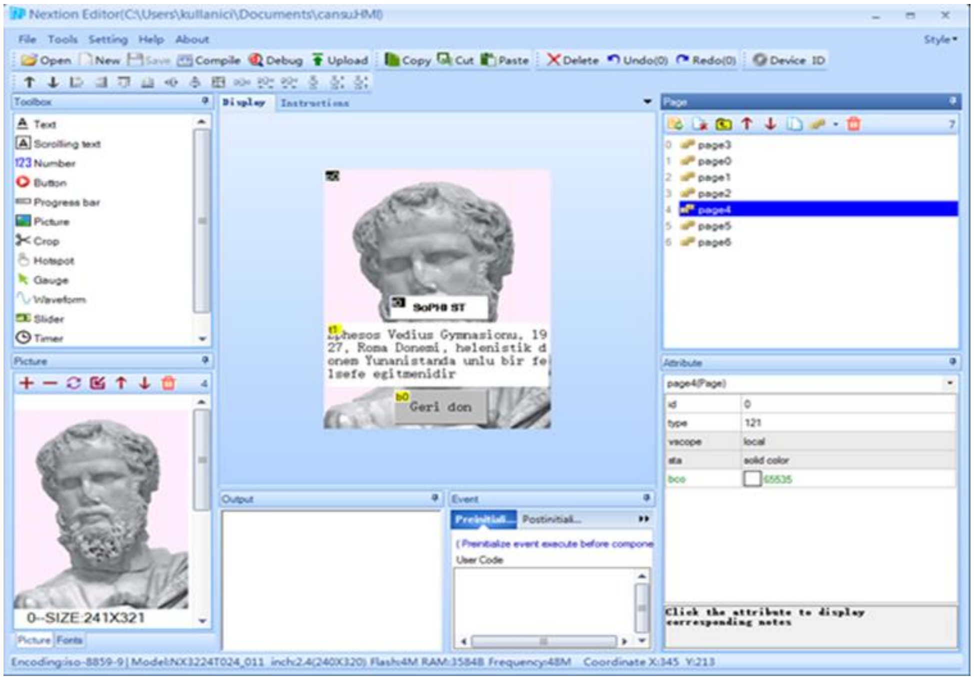

Figure 4. Artifact data display on Nextion smart card editor.

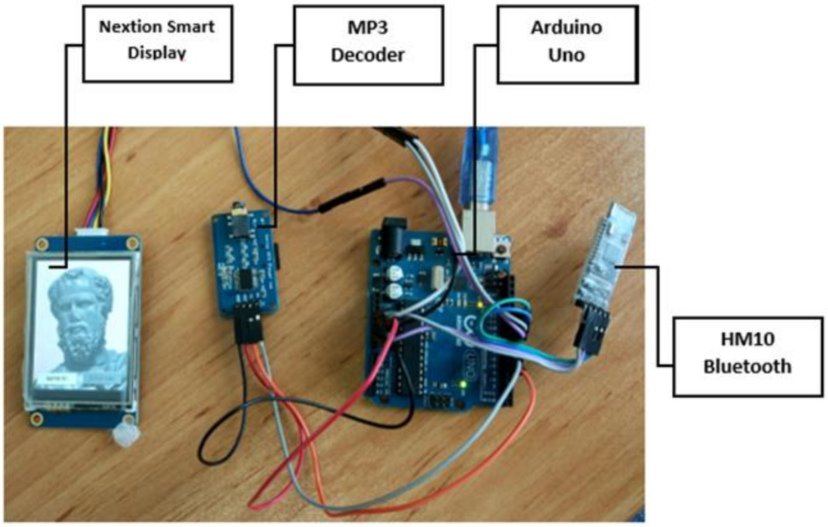

Figure 5. Nextion smart display view near an artifact in prototype.

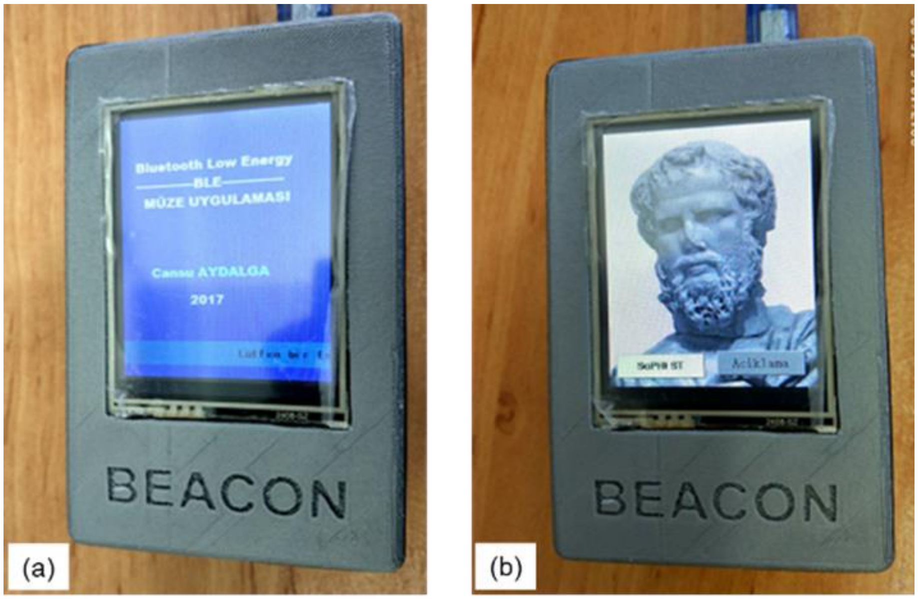

Figure 6. Smart display view **(a)** away from artifacts **(b)** near to artifact.

In the study, software codes were written in Arduino and then uploaded, allowing Arduino and the Bluetooth module to communicate. Explanations for the AT commands used in the software are given below:

```
mySerial.write("AT");
```

This is a test command. It is used in order to check whether the connection has been established or not.

```
mySerial.write("AT+MODE0");
```

This is a command that is used via a series connection (RXD/TXD), and is valid only until a central device is connected to the module.

```
mySerial.write("AT+DISI?");
```

This is a command that is used in the software in order to search the beacons in the area. When the command AT+DISI is displayed, the ID values below are read and used for comparison after being classified. These values include ID's of two different Bluetooth beacons. Sample ID values of Bluetooth Beacons are given in Table 1.

Table 1. ID Values of the used Bluetooth Beacons.

Beacon	Module 1	Module 2
p1: Factory ID	4C000215	4C000215
p2: Beacon ID	FDA50693A4E24FB1AFCFC6EB07647825	FDA50693A4E24FB1AFCFC6EB07647825
p3: Major and Minor Values, Measured Distance	271B271BC5	27113A41C5
p4: MAC	AAC70A804B65	E75138D0D6CD
p:5 RSSI	-064	-081

OK+DISISOK+DISC:4C000215:FDA50693A4E24FB1AFCFC6EB07647825:271B271BC5:AAC70A804B65:-064OK+DISC:4C000215:FDA50693A4E24FB1AFCFC6EB07647825:27113A41C5:E75138D0D6CD:-081OK+DISCE

OK + DISC: [p1: p2: p3: p4: p5]

p1: Factory ID (length 8), p2: Beacon ID (length 32), p3: Major Value (length 4), Minor Value (length 4), Measured Power (length 2), p4: MAC (length 12), p5: RSSI (length 4)

As experimental evaluation, when power consumption and latency times are needed to determine, 7.4V 850mA li-ion battery is seen enough for one visitor up to 10 hours of operation, which may last one day without charge. Also, multiple user condition does not effect the success. Because, BLE devices broadcast the ID only. Multiple listener mode receivers communicate n devices at the same area. In this Study, multiple BLE device related to current space is limited to six.

Although the power-save mode is not activated on the BLE device, the application is not affected by battery life. But, the reason for that is application itself. If the application like personnel tracking around a gate, or localization by using multi-beacon, the battery life of the BLE device is critical. The difference between other passive RF technique like RFID and active BLE technology is in power usage. RFID technology is driven by an external signal burst, which also supplies power.

Conclusion

The system has been designed for the purpose of conveying content to visitors via BLE signals emitted by beacons installed near museum artifacts. (He et al., 2015) and (Giasemi et al., 2015) also have conducted similar studies concerning museum applications, using beacons. Museum or historical site visitors have been provided with audio or visual information depending on their visiting behaviours, rather than using conventional methods.

However, in this study, as in the others, the system operates in connection with the smart devices of users. That is to say, audio or visual contents about the artifacts in a museum are transmitted to their smart devices, which can become a disadvantage in some cases. In these both studies, users are required to have their smart phones or devices with them, to download the relevant applications and to activate their Bluetooth connections.

In this study, the system that has been designed made it possible to eliminate such disadvantages. For the purpose of providing information about museum artifacts, a hardware was developed featuring BLE Beacon model, Arduino microcontroller card and Bluetooth 4.0 module as well as a software that is specific to it. The system was designed to efficiently and originally perform indoor localization in a museum by reading the data transmitted by the beacons. Thanks to this system, visitors can be provided with visual or audio content in indoor areas, based on their locations. Thus, museum visitors can easily access content about artifacts without the need for any conventional means such as guides or plates; all they need to do is to go near the artifact they would like to learn about.

Although the power-save mode is not activated on the BLE device, the application is not affected by battery life. But, the reason for that is application itself. If the application like personnel tracking around a gate, or localization by using multi-beacon, the battery life of the BLE device is critical. The difference between other passive RF technique like RFID and active BLE technology is in power usage. RFID technology is driven by an external signal burst, which also supplies power.

BLE Technology has many advantages and approaches on power consumption. The BLE device may be configured in several power save modes depending on the purpose. In this study, the device control loop is choosen proper to museum-like visiting tests which requires medium class energy saving mode. Latency time is not critical for our application and multi-tenancy problem was solved by classical RSSI filtering.

Nevertheless, power consumption in this work, is not based on only BLE device properties. Arduino card and HMI device do not support power save modes, because of that, power consumption is not the first priority for the application. Bigger battery required for long term usage, but present 850mA battery is enough for small scale area in visit.

The system which has been designed to be used in museum applications has the potential to be used in other indoor areas. The same method can be used to markets, libraries, hospitals and warehouses, storage areas in order to locate any product or utility. The system suggested and implemented during this study shows that active low power BLE technology may help lots of localization and human assistance applications. As the system is developed as prototype, the circuit is composed of discrete equipments which may cause stability issues and relatively higher power consumption. final products must be developed on a single board including every component and they must have low power solutions. At the same time, the system principle may applied on a smartphone with only software development.

Bluetooth Low-energy systems are hot topic today and the application areas are growing every day spanning localization to other new branches. Although the principle is very similar, every application adds a new vision to the solution. Our study covers not only the localization problem, but also informant additions on BLE technology. Also our work is open to be developed for industrial and personal usages like sound assisted direction information for blind persons. In this study, the aim is to develop an experimental system, which is a prototype for future applications, based on BLE signal acquisition and validation tests. Because of this, fast prototyping techniques, Arduino and HMI screens, are used. The researchers know that final product should be more robust and secure. The work in this purpose is on going.

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