VComp

Final Report

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1.Front Page

VComp is a new generation technology company that is founded by five enthusiastic engineering candidates. From the day of foundation, all partners are making almost-professional contributions, with amateur-like spirit and excitement. Although the research interests of all partners are different, the company uses this variety of expertise areas for creating a technical fusion, which results in tailor-made and creative solutions for hard-to-solve problems. From the “fusion” point of view, VComp is ready to propose unique solutions for your most problematic issues, with an approach like “fusion-jazz improvisation”, which makes the words variety and excitement meaningful.

Mission & Vision:

Mission: To provide high quality, advanced and reliable products, and solutions to national and international customers by focusing on technological improvements and to gain the ability to develop new technology areas.

Vision: To preserve continuous growth in the global market, to be preferred by competition power, to be trusted, to be eco-friendly, and human consciousness as a technology firm by fulfilling the establishment purpose.

Company Organization:

The members of the VComp come from the different areas of the Electrical Electronics Engineering department. Since each team member is competent in different areas, VComp handles the requirements of a project more systematically and professionally. Beyond that, the interconnection between team members makes VComp dynamic and regenerative. One can see the company structure in Fig.1

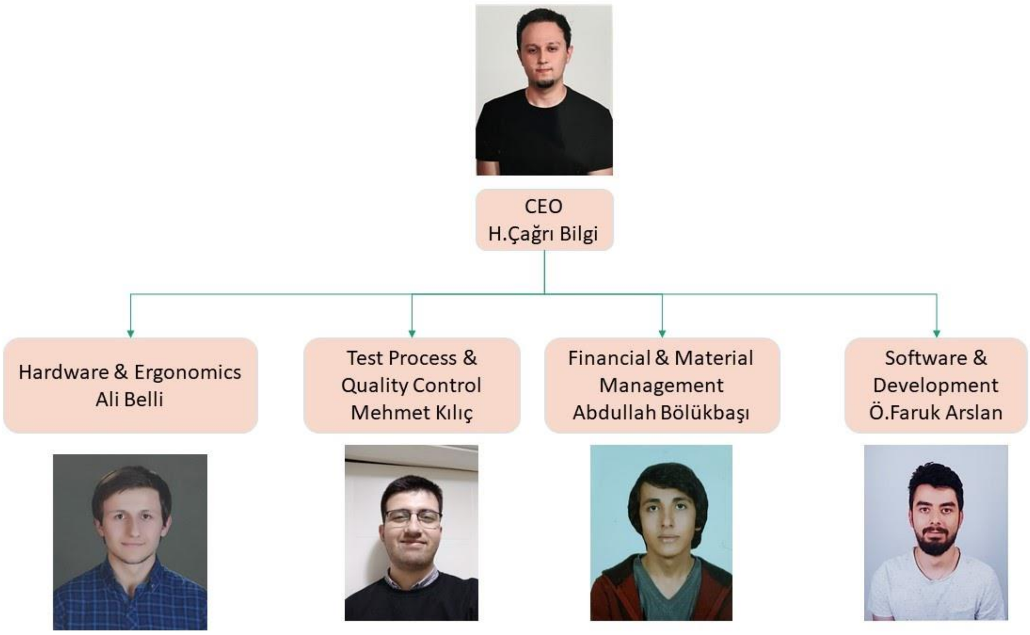

Figure 1: Organizational structure of VComp

Today, VComp is excited to announce the launch of eVCO3, a modern Museum Audio Guide and Monitoring System, and in this report, technical information of the product will be explained in detail.

2.Executive Summary

In recent years, the customer's attitude towards the service that s/he is taking has dramatically changed as time management and individual customer experience becomes more and more demanded by customers, companies have started to offer configurable options and suggestions depending on customers interests to customize their experience.

As interior architecture of museums gets more complex with new artistic approaches and large numbers of art pieces, offering a more personalized tour experience to the visitors could save a lot of time and increase the customer satisfaction. Although the system is designed for museums, it could be modified for new applications in case of demand.

VComp is excited to announce its new product, “eVCO3”, which is a smart solution for museum guidance. eVCO3 includes anchors, tags, a central processing unit, an optional monitor depending on the clients need and a commercial software. “eVCO3” is designed by the skilled and dynamic team of VComp, and ready to create an intelligent customer experience for even the most complex museums, by using the state-of-art technologies. VComp has worked on eVCO3 for 28 weeks, and the cost of this product is 176.31$

“eVCO3” system focuses on both museum management and visitor experience. By using our product, the visitors are enabled to move freely around the galleries without participating in a guided tour group while still being informed about the item they are visiting. Since eVCO3 might be used for long visits, it is designed power-efficiently in order to maximize the battery life. Moreover, depending on the visitor's initial purchases, the system does not allow them to visit the galleries that are not paid for. If a visitor still enters a warning that is asking for additional payment will be given to the visitor.

From the museum management point of view, the system enhances the observability of museums by real time monitoring of each individual visitor. By this way, management of museums becomes easier.

3. Introduction

3.1. Problem Statement

Museums are the places that the visitors roam around extremely valuable art pieces. Many visitors attend guided tours to be able to get information about the art pieces they are visiting. However, these guided tours have drawbacks. Since the route of such tours are pre-designed by the tour guides, visitors are not allowed to roam around freely as they wish. Guided tours are not personalized, and visitors are not free to choose what they visit. However, a person may want to see only a particular part of the museum and pay money only for that part. On the other hand, as the attendees increase it becomes harder to hear and follow the tour guide. From the museum’s point of view, managing such a crowded place full of valuable art pieces is getting harder for the museum managers.

eVCO3 is an electronic system developed by VComp in order to solve the problems stated above. The system offers a personalized visit experience for visitors and state of art monitoring of the museum for museum crew. eVCO3 provides personal audio guidance for each visitor and navigates them through the museum during their visit. Audio guidance system informs the visitor about the art piece that is being visited at that instant. Moreover, it warns the visitors if they enter a room that is not paid for or If a certain section reaches a predetermined maximum occupancy, visitors should be warned and recommended to go to a different section. From the management point of view, the system monitors real time positions and payment data of each visitor. By this way, eVCO3 enhances the control of the museum by providing a complete monitoring of the whole facility and the visitors.

3.2. Scope and Organization of the Report

The scope of this report is finalizing solution approaches according to the requirements and test results of the project.

First of all, the overall solution is discussed in the solution part. After the definition of the overall system, working principle of the product is illustrated. Subsystem level requirements are stated, and technical information is given for the solution of each subsystem. In addition, conducted tests and results are provided.

Secondly, VComp provides end-product specifications, performance tests and user guide for eVCO3.

4. Solution

4.1.Overall System

eVCO3 is an audio guide system that is designed for museums. The system basically tracks the position of the visitor and depending on the position the system gives information about the art pieces and the general announcements about the museum. Moreover, the position of the visitors can be monitored by the museum crew in real time; therefore, the system has a communication interface. In addition, the system has sufficiently long battery life to conveniently allow an entire visit to the museum, so power management is another issue to control. Furthermore, VComp puts emphasis on the comfort of the user, and designs ergonomic devices.

Depending on the requirements of the project and objectives of the company, the system is divided into 7 subsystems: 2D localization, audio guide, monitoring, communication interface, power management, and mechanical design. Fig. 4.1.1. shows the system level block diagram. Fig. 4.1.2 shows operational flowchart. Fig. 4.1.3 shows interactions between subsystems and signal interfaces. Figs 4.1.4 and 4.1.5 show the final product.

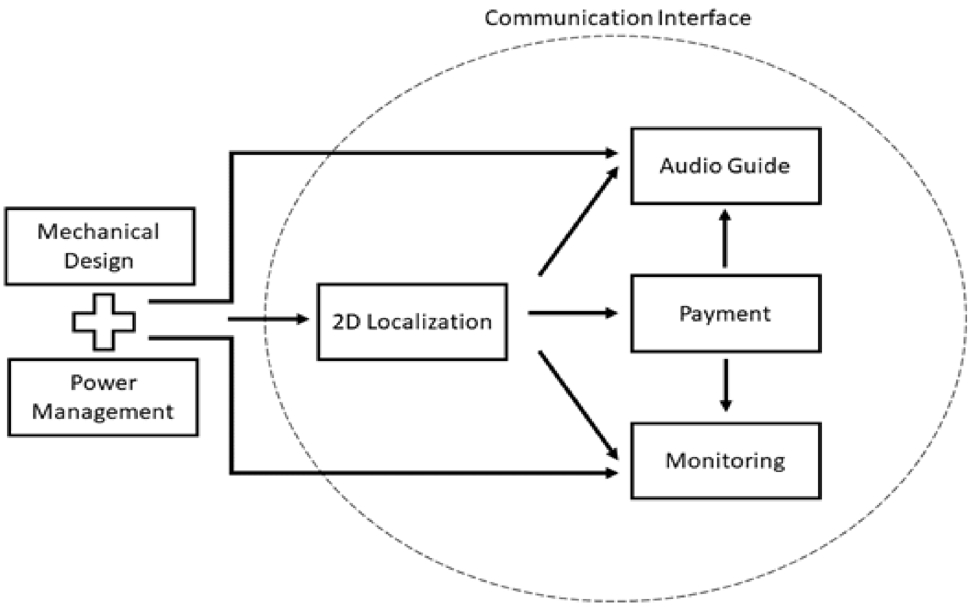

Figure 4.1.1. Overall system level block diagram

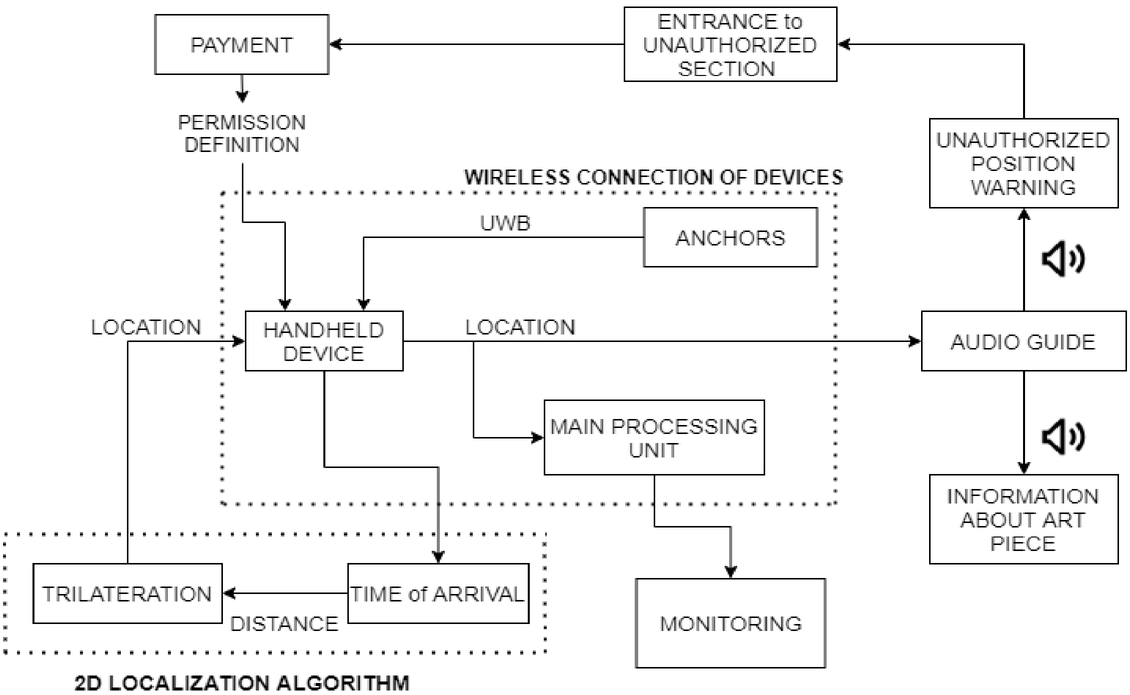

Figure 4.1.2: Operational flow chart

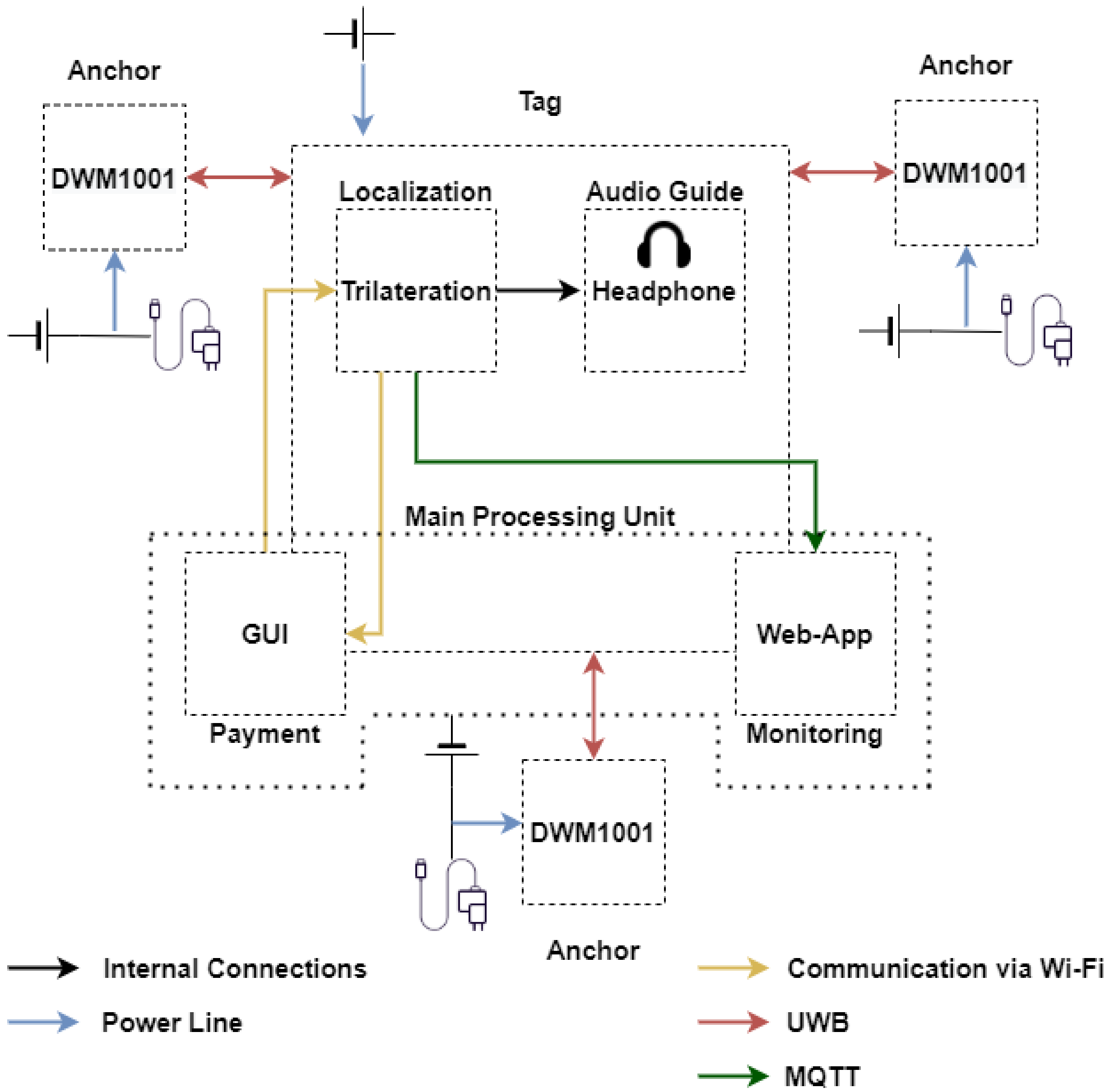

Figure 4.1.3: Interaction between subsystems and signal interfaces

Figure 4.1.4. Stationary devices

Figure 4.1.5 Handheld device

4.2. Overall System Requirements

- System determines the location of visitors with at most 50 cm error.
- System updates position information of each visitor in 1 second during motion.
  - ➢ The 2D localization subsystem satisfies these requirements
- The system starts informing the visitor if the distance between visitor and artwork is less than or equal to 1 meter.
- If a certain section reaches a predetermined maximum occupancy, the new visitors warned and recommended to wait or go to a different section.
  - ➢ The audio guide subsystem satisfis these requirements
- System provides the real time position of each visitor on the map.
- Monitoring page is accessible from any device connected to LAN.
  - ➢ The monitoring subsystem satisfies these requirements
- The system ensures reliable connection of all devices throughout the visit.
  - ➢ The communication subsystem satisfies this requirement
- The battery of both the hand-held and stationary devices must provide a tour for visitors without charging the battery again. The estimated maximum visit duration is 2 hours.
  - ➢ The power management subsystem satisfies this requirement
- The system should detect disallowed entrances and give responses to the visitor during the trip about the payment for the additional sections' entrance at most in 1 seconds.
  - ➢ The payment subsystem satisfies this requirement
- The shapes of the hand-held devices are well-designed to ensure ergonomics for the visitors.
- The hand-held device should be weighted less than 250 grams.
  - ➢ The mechanical design subsystem satisfies these requirements

4.3. Subsystems

4.3.1.Positioning and 2-D Localization Subsystem

4.3.1.1. Description

As VComp, we are designing systems and generating solutions regarding indoor localization problem and real time location tracking. eVCO3 is a product that can be used in museums to ensure precise localization of the individual visitors. In terms of management of the crowded and large museums the positioning of the individuals becomes more important. With the help of proper hardware and user friendly software eVCO3 enables indoor positioning with high precision.

4.3.1.2.Subsystem Level Requirements

- System should work with at most 50 cm error margin.
- System should update position information of each visitor in 1 second's time interval when they are moving.

4.3.1.3. Main Solution Procedure

The solution approach for localization subsystem is based on using UWB (Ultra-Wide Band) modules to obtain 2-D position of the visitors. For this reason VComp preferred to use DWM1001 modules which are containing UWB sensors and required circuitry within a single electronic board. These DWM modules use Time of Arrival (ToA) and Time Difference of Arrival (TDoA) based trilateration algorithm to obtain position data. Solution approach will be detailly examined in two subtopics as follows:

Hardware:

In this part the critical problem with UWB sensors is required circuitry design. After searching for PCB designs and electronics VComp decided that it will cost a considerable amount of time and budget. Therefore, company started look for a complete board which contains all required electronics. There are different types of boards but by considering budget and overall system design VComp decided to move with DWM1001 modules form DecaWave. One can see the brief comparison of DWM1001(complete board) and DWM1000(single UWB sensor) in below;

DWM1000 Module	DWM1001 Development Board
● Cost efficient	Expensive
● Compact	Bigger in size and weight
● Requires extra PCB design	Easy to implement (Complete Board)
● Not much support from company	Widely used and supported by company

Decawave DWM1001 Development Board contains single chip CMOS Ultrawideband integrated circuit which support IEEE 802.15.4-2011 UWB standard. It operates at data rates of 6.8 Mbps in 30 meters range. It also uses UWB Channel 5 with 6.5 GHz and supports up to 10 Hz update rate for individual tag moreover it supports up to 150 updates per second per cluster. By considering design requirements DWM1001 will be satisfy the expectation of the company.

Algorithm & Software: The bandwidth of UWB signals extremely large, exceeding 500 MHz. This offers many advantages, and it improves reliability. It contains different frequency components and some of them can go through or around the obstacles. Therefore, reflection and interference will be less problematic in UWB based positioning which very big problem for other solution approaches such as BLE or Wi-Fi.

To obtain position, UWB module uses Time of Arrival (ToA) and Two Way Ranging (TWR) approaches. In ToA approach, positioning done by utilizing the time difference of arrivals of the RF signals to obtain the distance between reference anchor and tag.

To obtain precise location from ToA approach, tight synchronization between anchor and tag is required. This requirement can be avoided by implementing the well-known two-way-ranging (TWR) algorithm, which relies on a sequence of two or more packet exchanges between the two devices (anchor and tag) and involves the transmission of packets in both directions. Dual-sided transmission between anchor and tag means that both anchor and tag must be active to obtain accurate position, which will be inefficient in terms of power consumption concerns. For the sake of accuracy, eVCO3 will use active tag and anchors instead of using passive tags but thanks to stationary detection algorithm, tag will notice when handheld device becomes stationary and decrease the power consumption by lowering the computations in device.

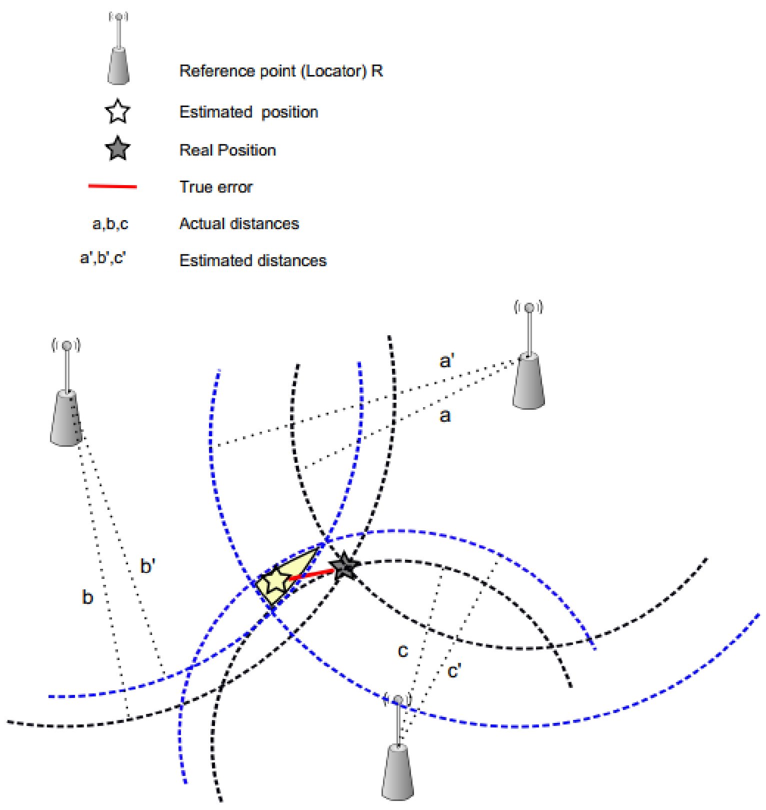

Figure 4.3.1.3.1 : Trilateration Algorithm

TWR algorithm is used in the DWM1001 module and process will be given below detailly:

Two Way Ranging (TWR)

1. The anchor transmits a message to the tag & records the time the message left its antenna (Let us call it t_1)
2. Tag receives the message & sends back a reply message.
3. Anchor records the time it receives the reply (Let us call it t_2)
4. After calculating time difference, anchor calculates the distance by using the given formula.

$$d = c*(t_2 - t_1)/2$$

d= distance between tag and reference anchor

c= speed of the light

This calculation is based on ideal case; however, there is a time delay in the hardware (turnaround time). DWM1001 location engine is using given below formula in a much advance form however the source code of the location engine is unpermitted. Therefore, eVCO3 uses distance measurements between two devices directly to apply own trilateration algorithm.

$$T_T = 2*T_t + T_{TA}$$

T_T= Total Time

T_t= Time of flight of the signal

T_{TA}=Turnaround time in the tag


```
b'DIST,3,AN0,1926,0.00,3.00,0.00,1.82,AN1,2ACC,3.00,1.50,0.00,1.39,AN2,1928,0.00,0.00,0.00,1.85,POS,1.41,1.52,0.25,54\r\n'
{'id': '1926', 'x': '0.00', 'y': '3.00', 'dist': '1.82'}
{'id': '2ACC', 'x': '3.00', 'y': '1.50', 'dist': '1.39'}
{'id': '1928', 'x': '0.00', 'y': '0.00', 'dist': '1.85'}
{'x': '1.41', 'y': '1.52'}
b'DIST,3,AN0,2ACC,3.00,1.50,0.00,1.30,AN1,1926,0.00,3.00,0.00,1.85,AN2,1928,0.00,0.00,0.00,1.90,POS,1.43,1.52,0.32,58\r\n'
{'id': '2ACC', 'x': '3.00', 'y': '1.50', 'dist': '1.30'}
{'id': '1926', 'x': '0.00', 'y': '3.00', 'dist': '1.85'}
{'id': '1928', 'x': '0.00', 'y': '0.00', 'dist': '1.90'}
{'x': '1.43', 'y': '1.52'}
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{'id': '1928', 'x': '0.00', 'y': '0.00', 'dist': '1.84'}
{'x': '1.43', 'y': '1.52'}
```


Figure 4.3.1.3.2. Received data from UWB module

In DWM1001 module Decawave gives software support for users and in this software some critical functions are working as predefined way. Although users can reach some of the source codes, location engine source code is hidden. Therefore, obtaining distance from ToA is unknown processing from our side. After some trials to reach or modify this part of the source code, we could not reach the desired level. As a result, decision of the team is using our own trilateration approach, which is using the 1-D distance measurements coming from the ToA calculations between each anchor and handheld device(tag).

One can see the localization error between true position and VComp trilateration algorithm estimation in below given Fig.4.3.1.3.3. Where true position denoted with “x” symbol.

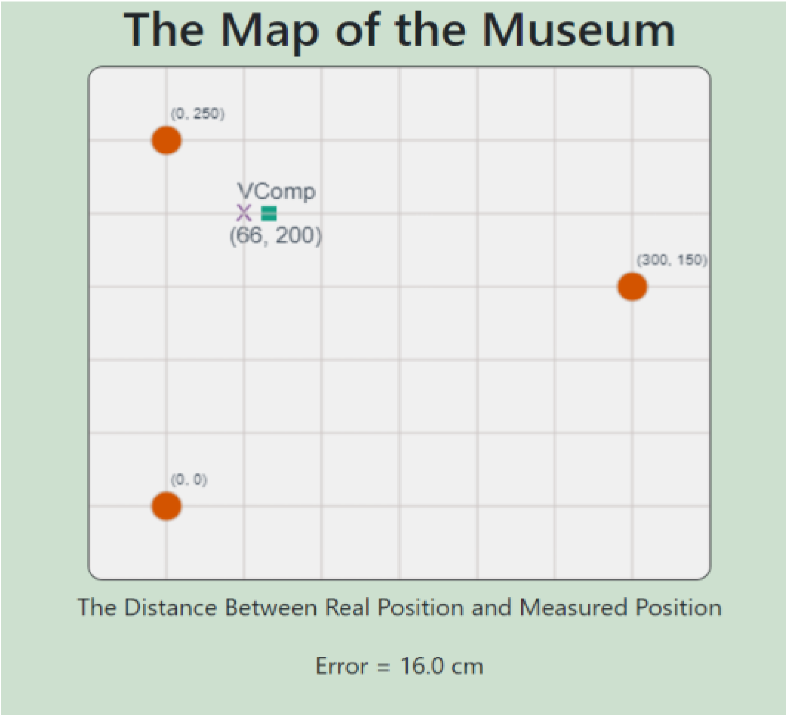
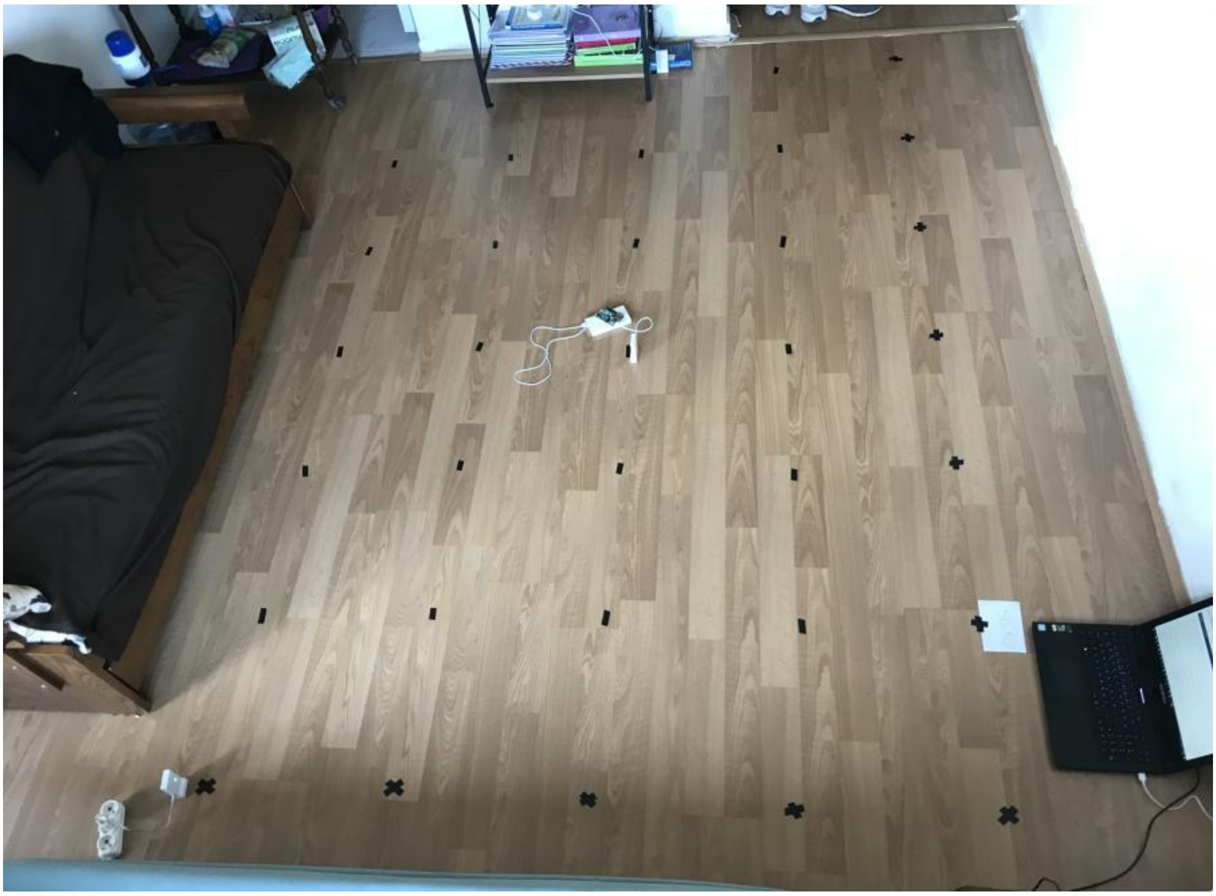


Figure 4.3.1.3.3. Error in the position

4.3.1.4. Tests and Results

To test 2-D Localization subsystem, VComp designed a test setup which is fulfilling the requirements of the subsystem. In this test setup 7.5 m^2 room is used and each 50 cm step distance marked for clear understanding. Position of the tag is changed, and measurements are obtained in real time. During the test process, previously seen problems such as obtaining accurate position at the edges of the room, losing line of side by obstacles are carefully examined and the detailed test results can be seen in the below given figures for different situations.

Test 1: Clear line of sight & visitor in center of the room



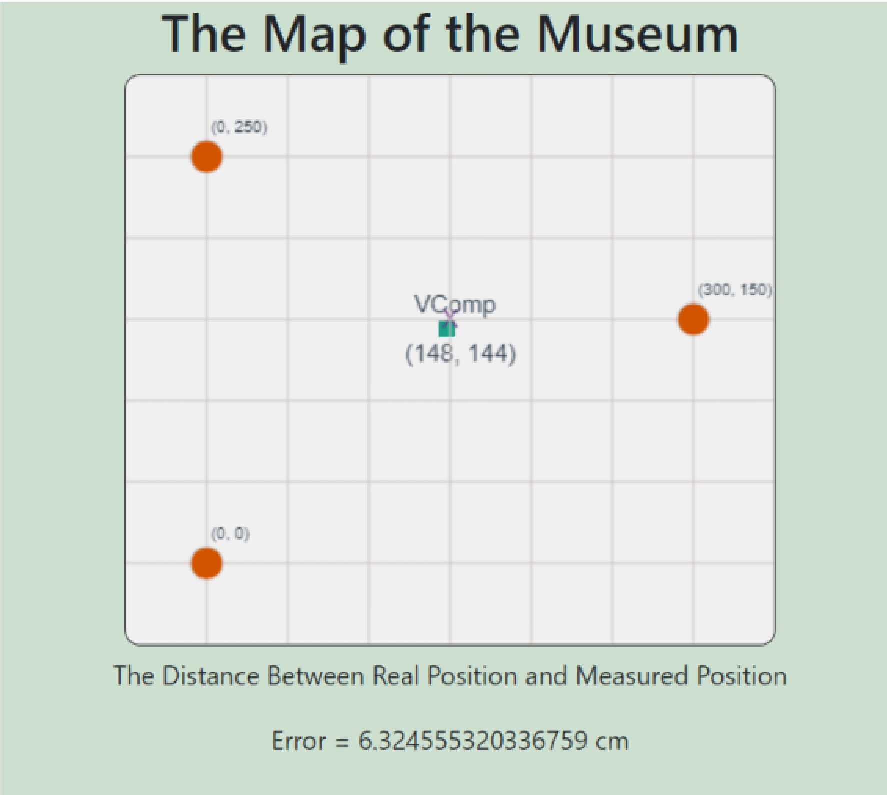
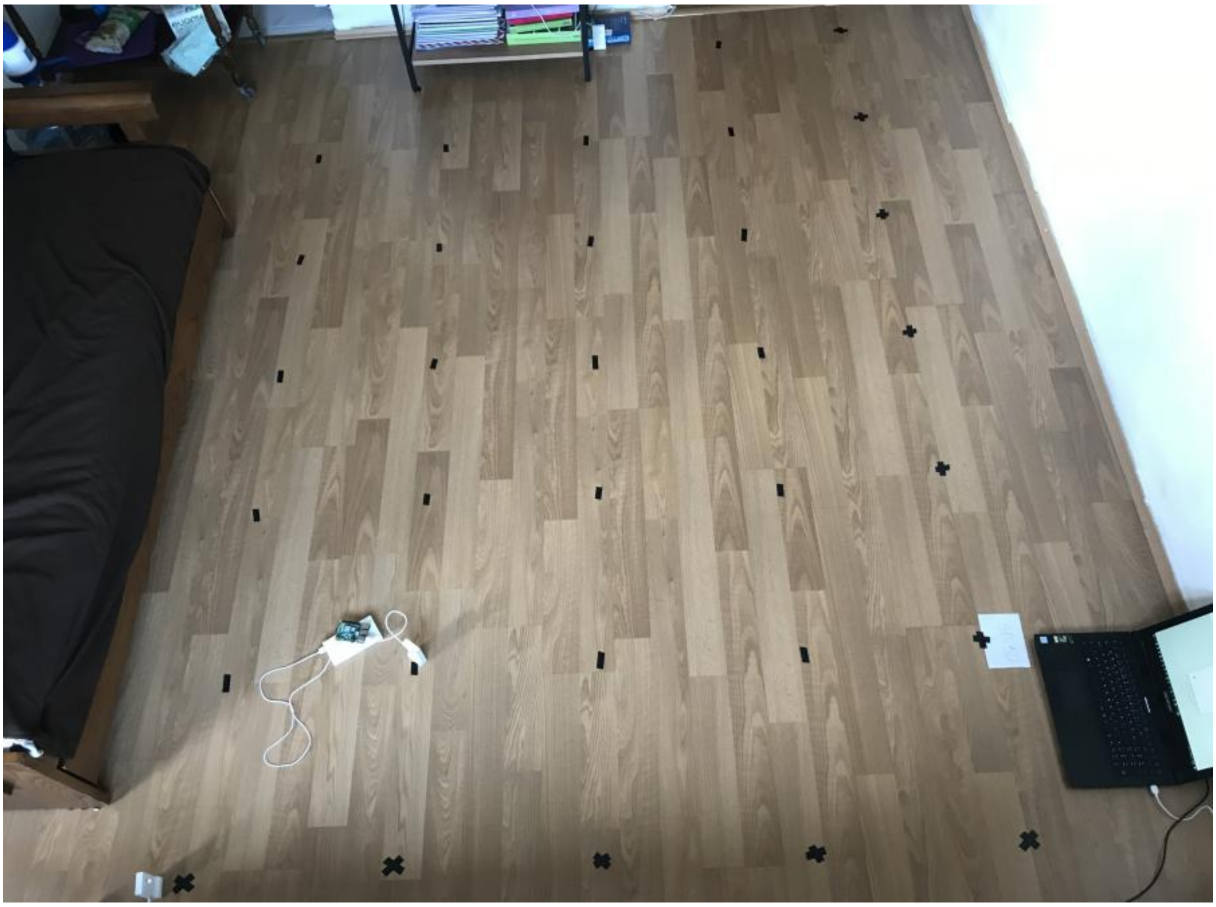


Figure 4.3.1.4.1. Test 1 setup and result

Test 2: Clear line of sight & visitor in center of the room



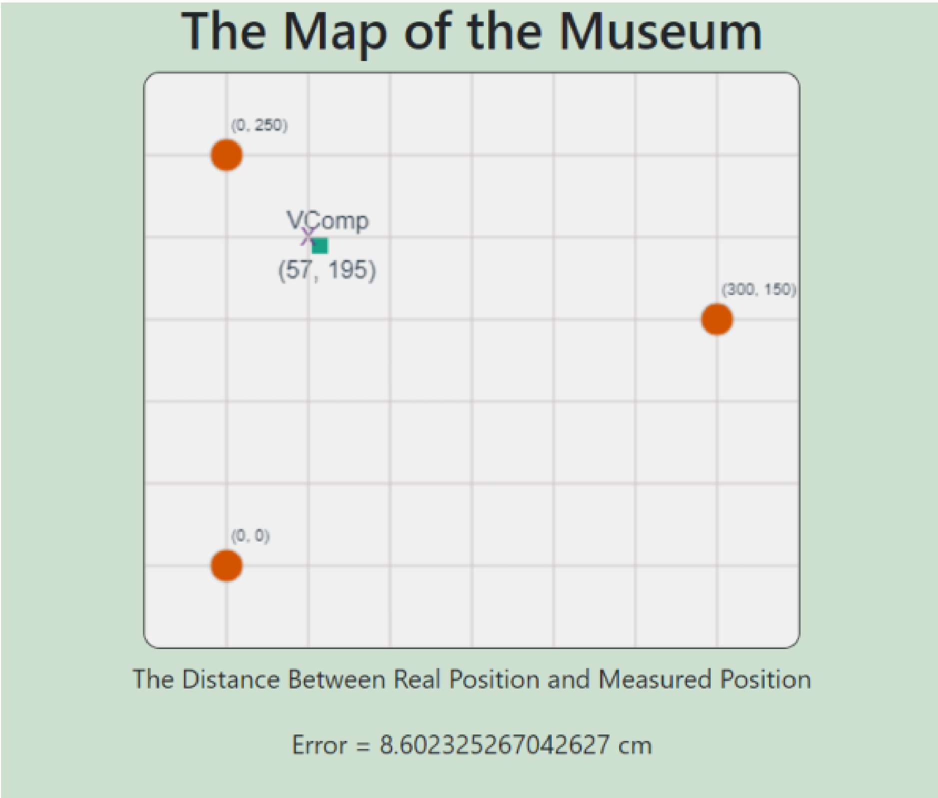
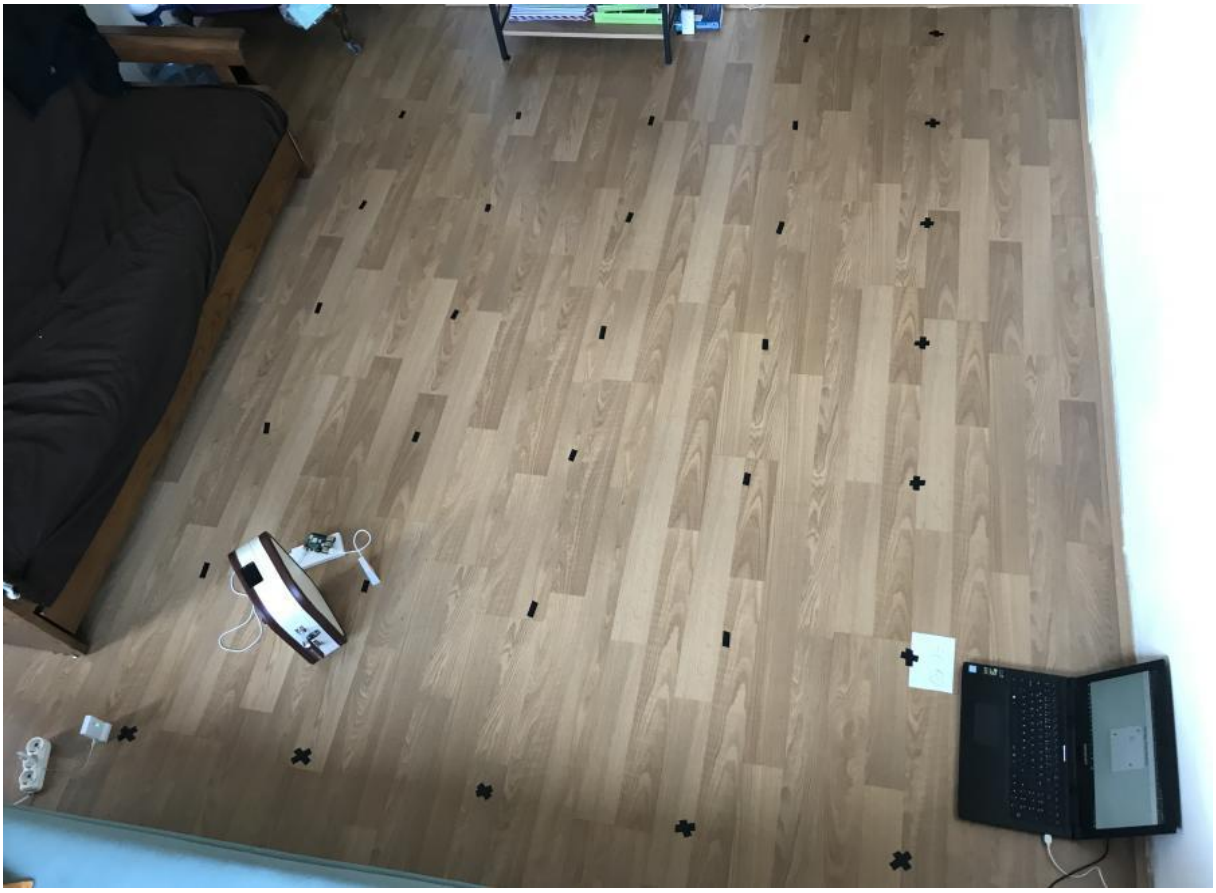


Figure 4.3.1.4.2. Test 2 setup and result

Test 3: Losing line of sight(obstacle) & visitor in center of the room



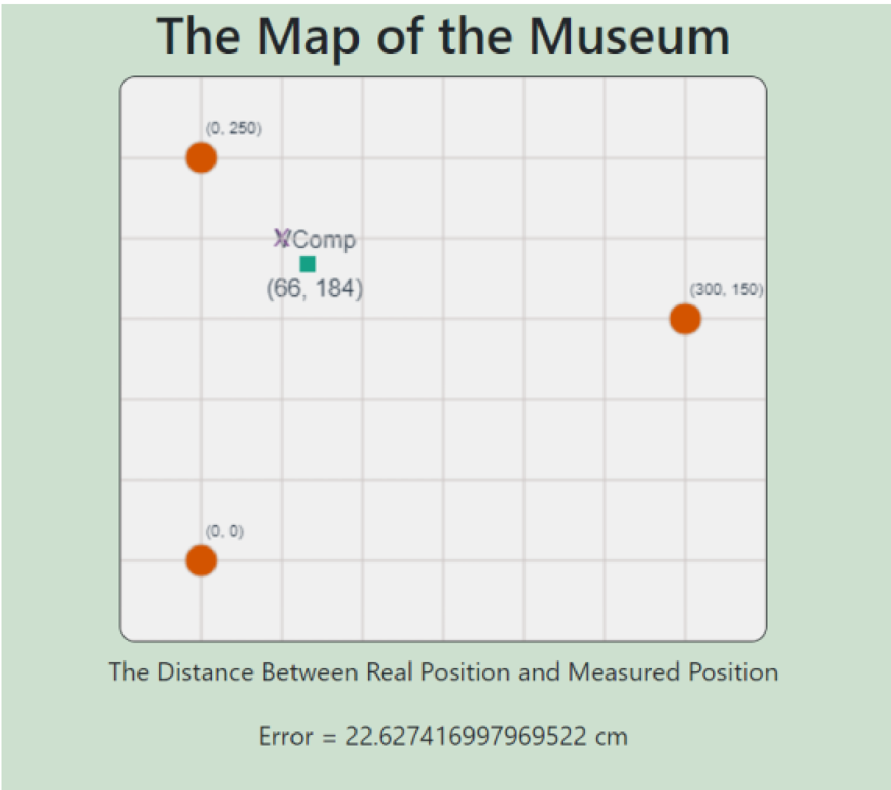


Figure 4.3.1.4.3. Test 3 setup and result

Test 4: Losing line of sight & visitor in edge of the room

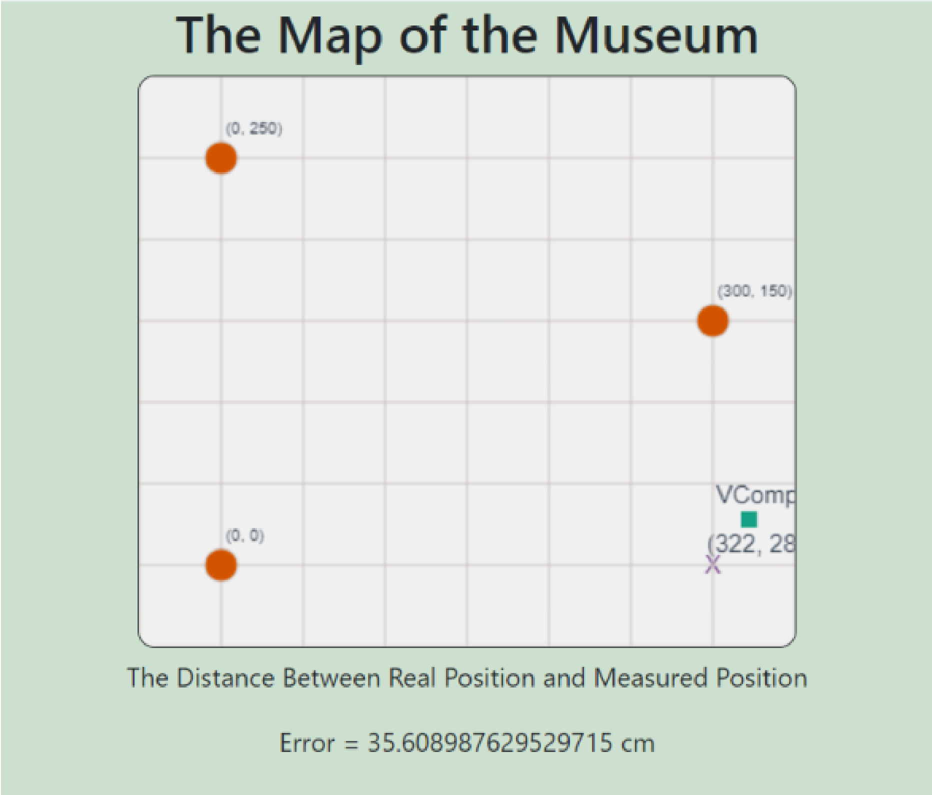


Figure 4.3.1.4.4. Test 4 setup and result

After obtaining above given test results for 2-D localization subsystem, VComp decided to simulate two section with properly placed three anchors. The overall requirement of the project was simulating the 2-D localization of a museum with at least 2 sections. Because of the psychical handicaps, company have to simulate two section case with one large room by creating two virtual rooms inside it. In this setup each section contains 3 display items and overall system 3 anchors for localization for the handheld device. Company noticed violation of the 1 meter requirement between electronics and display items; however, because of the physical limitations this configuration was the only option for two section – six display item case. One can see the prepared museum structure in below given Fig.4.3.1.4.5

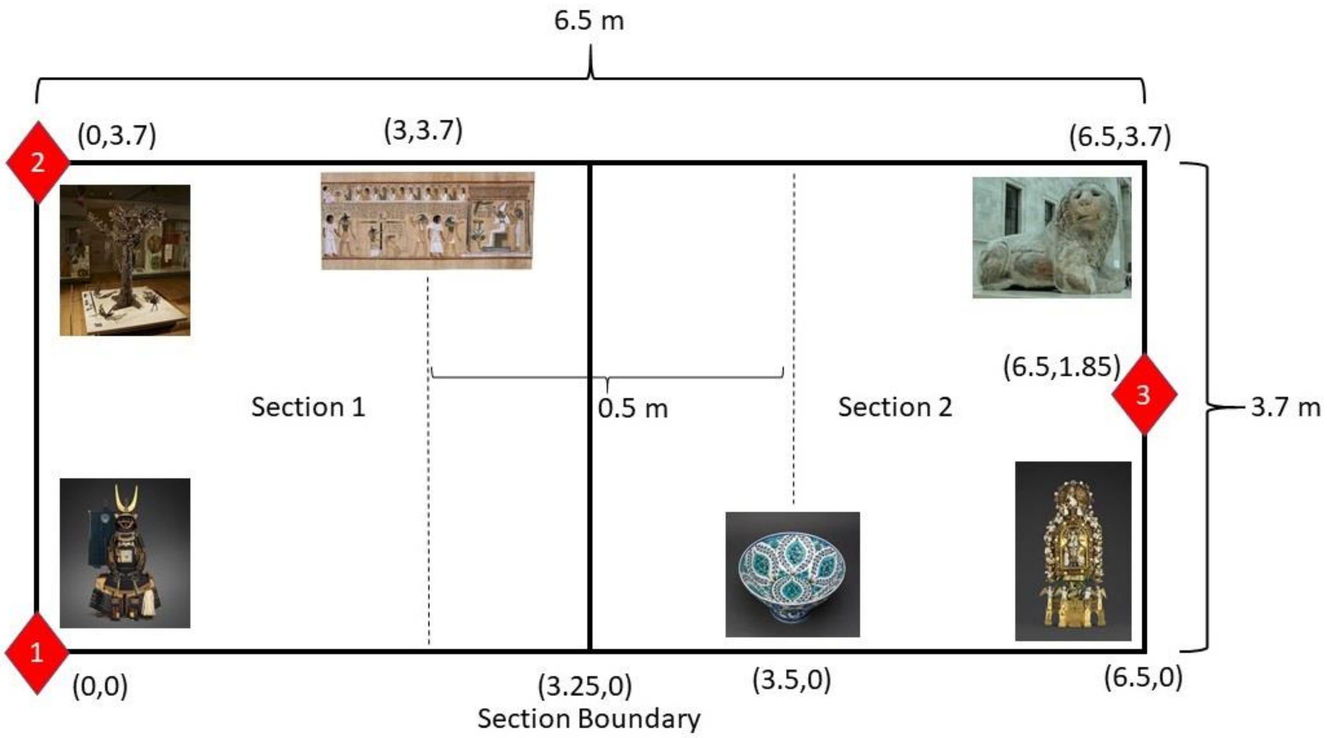


Figure 4.3.1.4.5. Two Section Setup

After overall system demonstration to the coordinator, VComp decided move on project with two section and five display item configurations to obey 1 diameter requirement between stationary devices and display items. After re-configuration of the museum, one can see the overall layout in below given Fig.4.3.1.4.6.

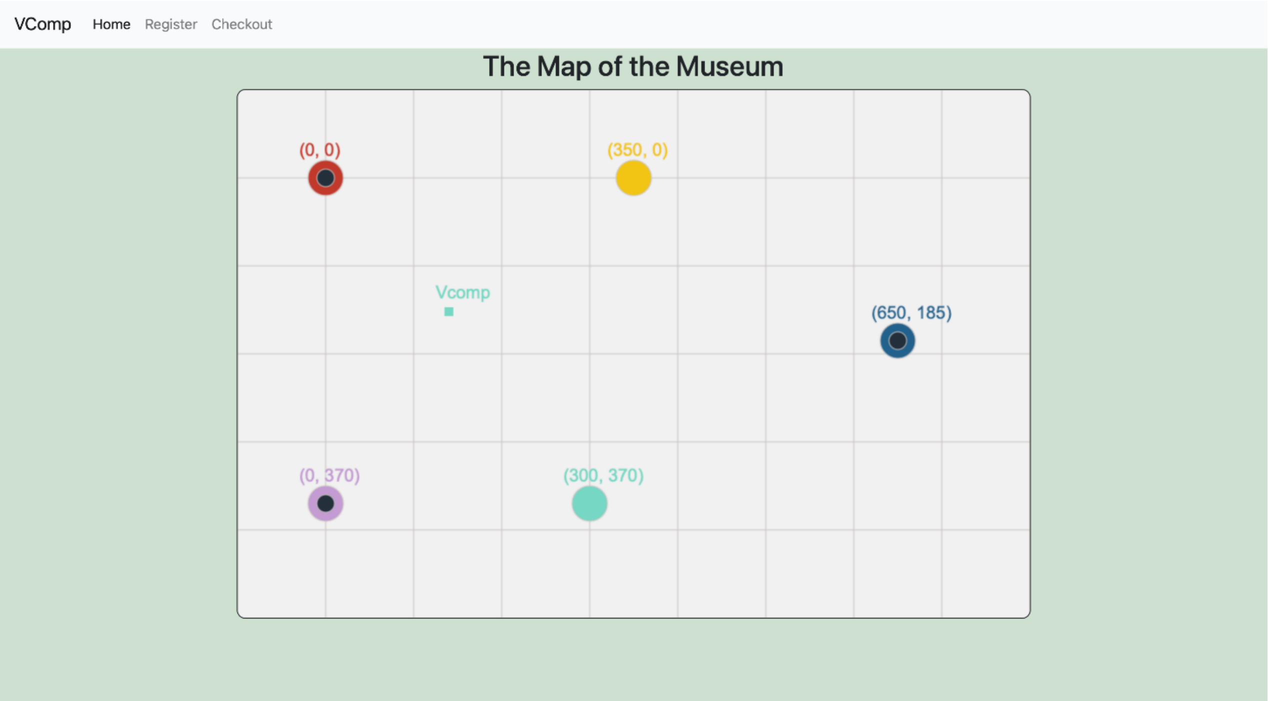


Figure 4.3.1.4.6. Two Section Setup with 5 Display Items

One possible problem with this configuration is the distance between two closest display items and section boundary. If at these display items localization error passes 25 cm level in other section direction it may create problems for audio guide subsystem. However, during design process and tests, company ensure the clear line of side for these specific display items such that position error always stays lower than 25 cm.

After ensuring the accuracy of these two display items VComp had complete tests for overall system which is highly based on the accuracy of 2-D Localization subsystem and one can see the positioning errors for these tests in below given figures.

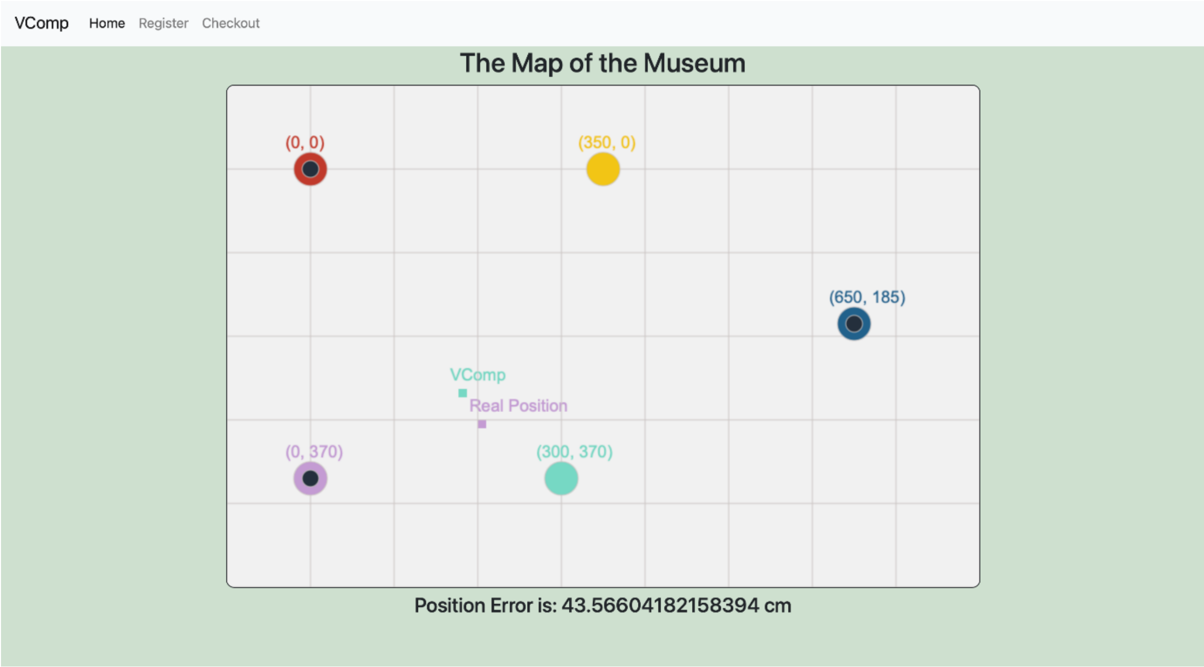


Figure 4.3.1.4.7. Error in case 1

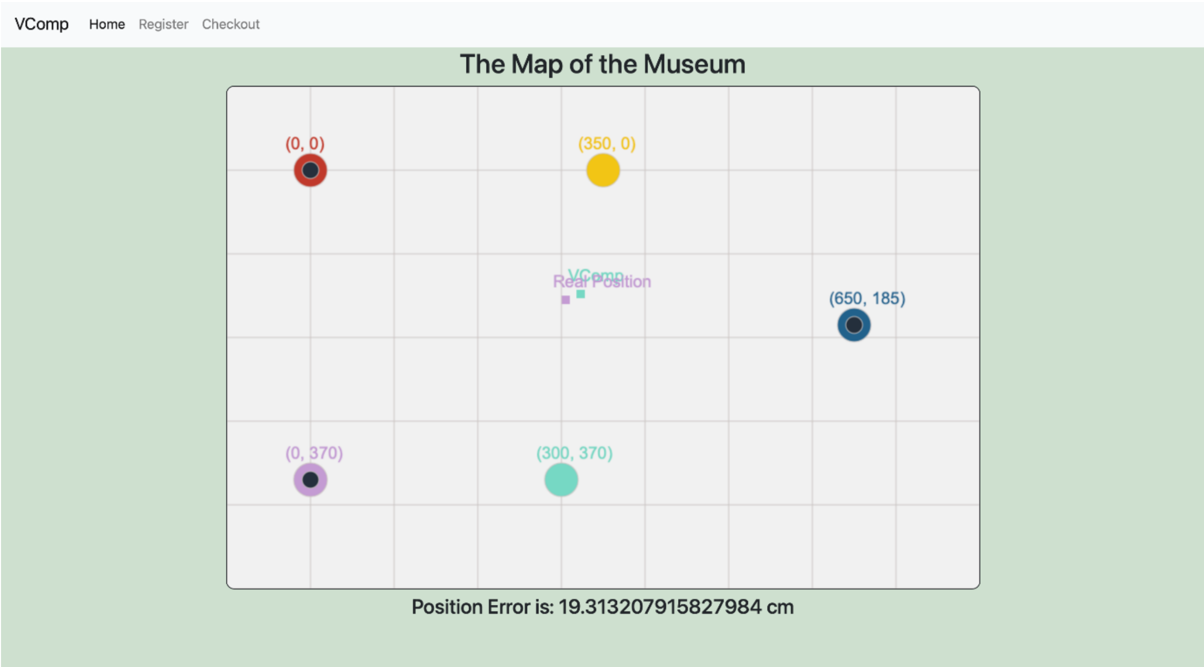


Figure 4.3.1.4.8. Error in case 2

For position update requirement, eVCO3 tested with predefined trajectories and upcoming position data is observed from the WebApp and source codes. Before the tests, company expect the update rate as follows.

- Update in each half a second during the stationary case **(0.5 Hz)**
- Update in each second during the motion case **(1 Hz)**

By observing received data rate, it is verified that system obeys the update rate requirement, and it was also shown to DS coordinator during overall system demo.

4.3.2. Monitoring Subsystem

4.3.2.1. Description

While eVCO3 tracks the visitors and navigates them through the museum, the user, the museum crew, would be able to follow all the process including real-time positions of each visitor and general overview of the museum through a graphical user interface. Although a complex software carries out all the process, users will be able to use the system without needing any kind of technical knowledge. Monitoring interface can be reached by any device connected to the local network. From this point of view, the monitoring subsystem will serve the ease-of-use objective of the project.

4.3.2.2. Subsystem Level Requirements

- Map of the whole museum can be seen on a single page.
- The monitoring subsystem will provide the real time positions of the visitors on the map.
- Monitoring page must be accessible from any device connected to LAN.

4.3.2.3. Solution Procedure

VComp provides a browser-based web app written in python. This application does not require any setup or download. Instead, it is broadcasted by the main processing unit and it can be reached by using a local IP address. The python script that broadcasts the web-app also includes the paho-mqtt client library to be able to communicate with handheld devices. It shares the payment data, which is registered through registration page, to related handheld devices and retrieves the position data published from handheld devices. Main processing unit reaches all the system data through the MQTT network by subscribing to multiple topics and broadcasts the relative information on the web-app. This web-app can be reached by using any electronic device that is connected to the local network such as smartphones, tablets, and computers. New visitor registration is also carried out by using this web- app, which is also a part of the payment subsystem.

Since the monitoring system will be used by the museum crew, it is important to provide easy-to-use monitoring software. In order to provide the simplest solution, Flask, which is a micro web-app framework in python, is used.

The monitoring subsystem interface can be used as follows.

- Users reaches the web-app by using the local IP address.
- Registration of the new visitor is done by using the "Register" tab. Following information are required for registration.
  - Name of the visitor
  - E-mail address of the visitor
  - Number of the device that is to be assigned for the visitor.
  - Section payment information.

Fig.4.3.2.3.1 shows the registration screen.

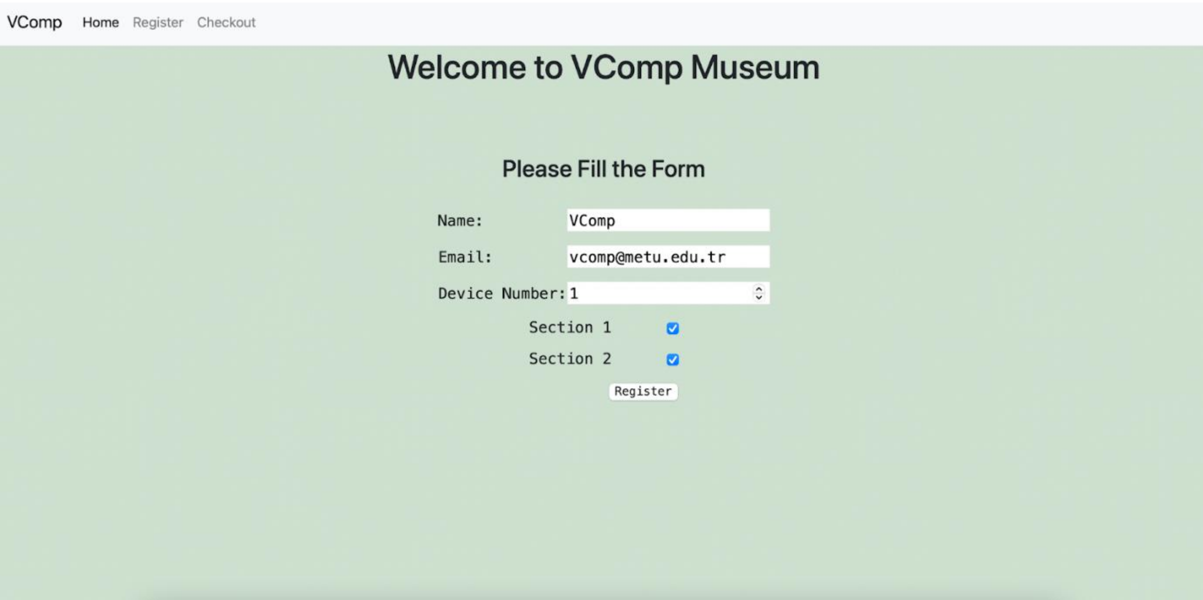


Figure 4.3.2.3.1: WebApp Registration page

- After registration is completed, the handheld device is powered up. Until the position information is received (approximately 45 seconds) the position of the visitor is seen at the point (0,0).
- After the handheld device starts operating, information of the visitor can be seen on the map in real time. Fig.4.3.2.3.2. shows the monitoring screen.

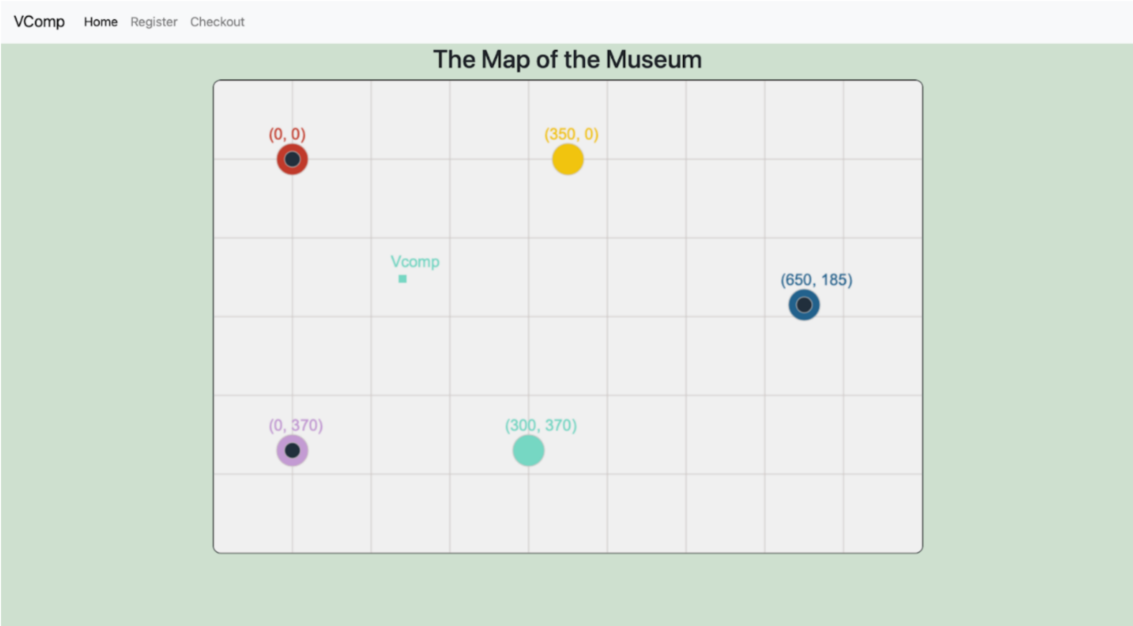


Figure 4.3.2.3.2: WebApp Home page

- When the trip is over, the checkout process is done by using the "Checkout" tab of the web-app by entering the assigned device number. Fig.4.3.2.3.3. shows the "Checkout" screen.

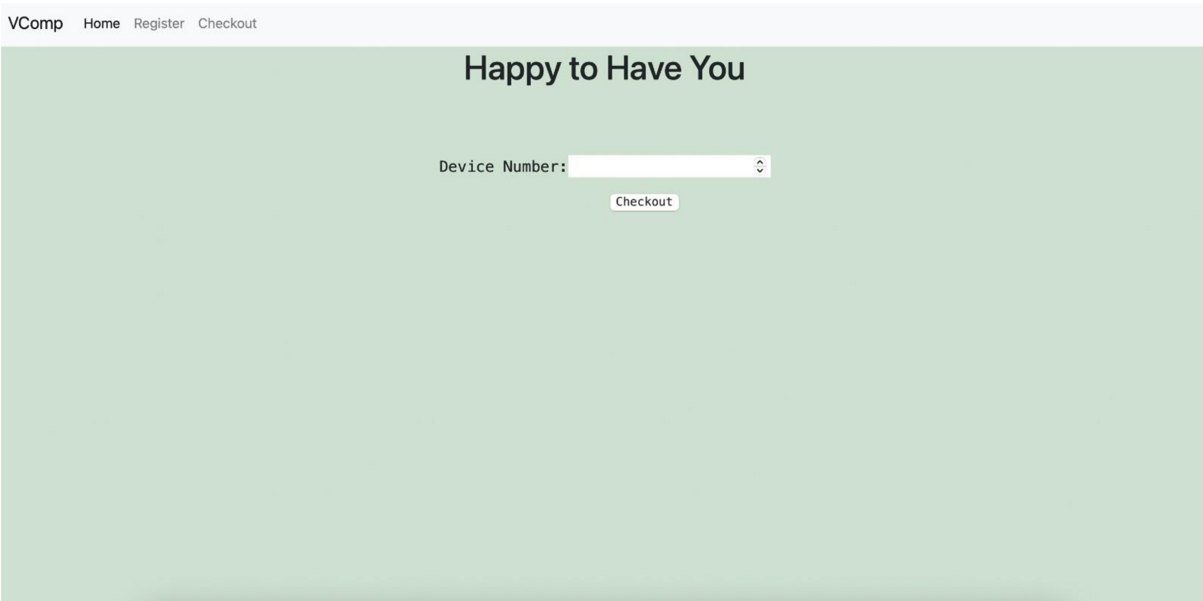


Figure 4.3.2.3.3: WebApp Checkout page

4.3.2.4. Tests & Results

Monitoring subsystem is tested by running the website on the Raspberry Pi and reaching it through any device connected to the local network. Test procedure is as follows:

- Connect to the local network by using any electronic device such as tablet, smartphone or laptop. Reach the web-app by using this link: https://<hostname>:5000/.
- Check whether all the devices are connected to the MQTT network.
- Register a new visitor.
- Check whether the information if the visitor and the real time position is available or not on the web-app. Fig. 4.3.2.4.1. shows the real time position of the defined visitor on the map of the room.

Test result is provided below. During the demo, all the test steps are followed and verified. Therefore, all the subsystem level requirements are satisfied.

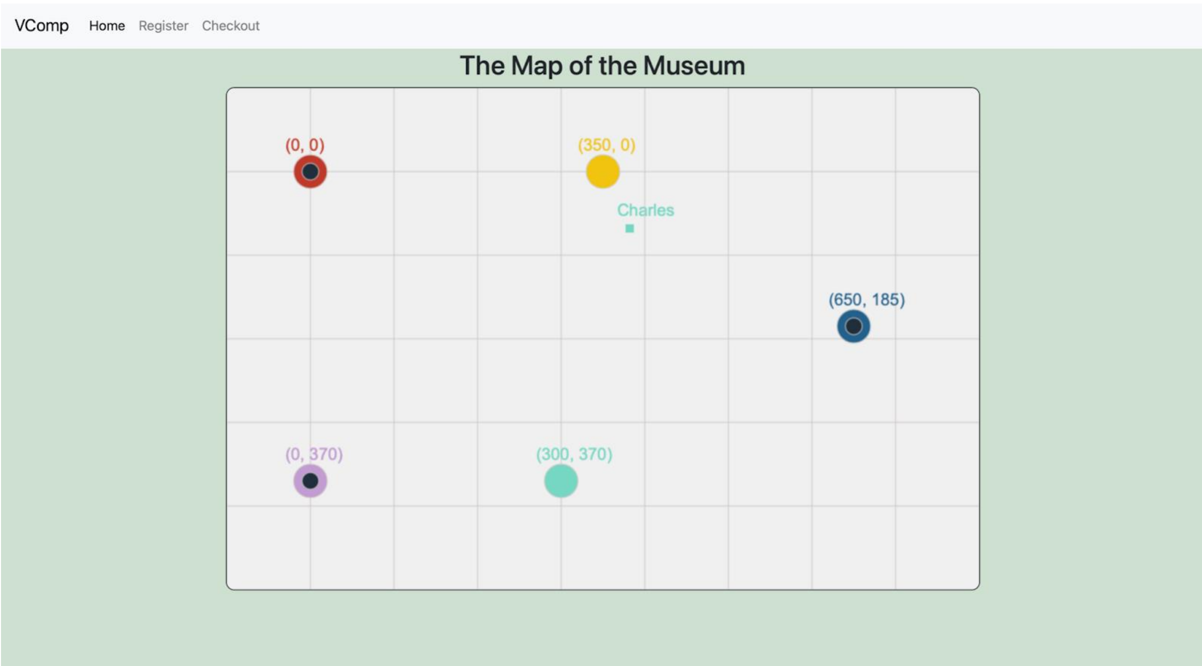


Figure 4.3.2.4.1: WebApp Page

4.3.3. Audio Guide Subsystem

4.3.3.1. Description

Besides finding positions of the visitors, eVCO3 includes an audio guide inside the system. By looking at the present location of the individuals; system informs the visitors about the artwork and gives general announcements about the museum.

This is a critical improvement on the user satisfaction since it provides personal guidance inside larger and crowded museums.

4.3.3.2. Subsystem Level Requirements

- Audio guide should inform the visitor if the distance between visitor and artwork is less than or equal to 1 meter.

- If a certain section is not paid for yet, the system informs the visitor and warns him/her about potential penalties.
- If a certain section reaches a predetermined maximum occupancy, the new visitors should be warned and recommended to go to a different section.

4.3.3.3. Main Solution Procedure

The audio guide subsystem operates according to the real-time position information. Therefore, real-time localization of the visitor is the crucial part of the audio guide. After determining the position of the visitor, the system informs the visitor about artworks and gives general announcements of the museum such as payment, emergency situations etc. Audio guide is on throughout the trip and it is triggered when a visitor enters the predefined range of the specific artworks. If a visitor leaves that zone the informing process is interrupted.

Designed handheld devices have enough memory for initially loaded informative voice files. These voice files are stored in .wav format in the SD card of Raspberry Pi 4 located in the handheld device. The handheld device calculates the real time position information by using UWB sensor readings, according to the current location, the player object is triggered. The sound is delivered through an earphone which is connected to Raspberry Pi from an audio jack. Due to the hygienic concerns, visitors are expected to bring their own earphones along with them.

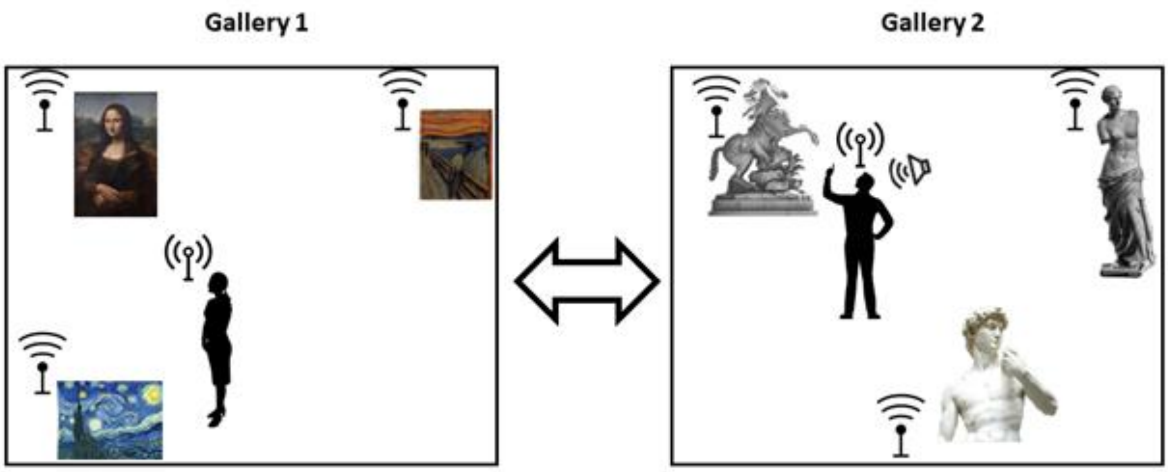


Figure 4.3.3.3.1: Museum Illustration

4.3.3.4. Tests & Results

Having the monitoring and communication subsystems operational is a pre-requisite for the test. The test plan of audio guide is given as follows:

- Go to the 1m distance for each artwork in section 1. Check whether the audio information is given for each artwork.
- For the case the gallery 1 is paid and gallery 2 is not paid, try passing from gallery 1 to gallery 2. Check whether an audio warning is given or not.
- Define gallery 2 as crowded beyond the limit. Try passing from gallery 1 to gallery 2. Check whether an audio warning is given or not.

Test steps above are followed in the demo test with the DS coordinator and all these steps are successfully verified. Since all these test steps are determined depending on the requirements, having all the steps successful means that all the subsystem level requirements are satisfied.

4.3.4. Communication Subsystem

4.3.4.1. Description:

eVCO3 is a device that provides a visitor monitoring solution in museums. In order to perform monitoring, besides determining the exact location of visitors, a solid communication network between IoT devices and the main processing unit must be provided. Therefore, VComp gives high importance to the communication subsystem. This subsystem connects handheld devices with the main processing unit and this connection is established with MQTT network protocol since all handheld devices and the main processing unit are connected to the same LAN.

MQTT communication protocol is used in our system to transfer the position information from hand-held devices to the main processing unit and also to send some alerts to the visitors during their trip if they enter a gallery which they are not allowed to or the occupancy is exceeded.

4.3.4.2. Subsystem Level Requirements

- The connection subsystem enables reliable connection throughout the visit.

4.3.4.3. Main solution procedure

In order to establish a connection between devices, LAN is required. Company is assuming there exists a LAN inside a museum but if there is no LAN exists inside a museum then it will be created by using a Raspberry Pi zero with an antenna as a wireless access point. Up to the museums with 3 galleries, this will be enough to connect all the devices wirelessly.

After the successful connections, the main problem to be solved is the handling of sending and receiving data in a wireless network. To solve that, MQTT protocol is used in eVCO3. VComp prefers using the MQTT network protocol because it provides extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. The MQTT protocol runs over TCP/IP.

The MQTT protocol defines two identities.

- **Broker:** An MQTT broker is a server that receives all messages from the clients and then routes the messages to the appropriate destination clients.
- **Clients:** An MQTT client is any device that runs an MQTT library and connects to an MQTT broker over a network.

In Fig. 3.3.4.3.1, one can see the basic scheme of the MQTT broker and clients.

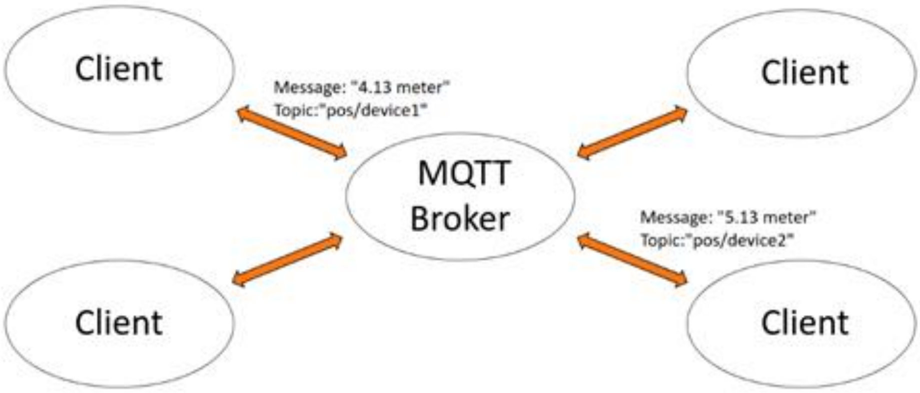


Figure 4.3.4.3.1: The basic scheme of the MQTT framework

The broker acts as a post office, MQTT does not use the address of the devices but uses the subject line called "Topic", and anyone who wants a copy of that message will subscribe to that topic.

Multiple clients can receive the message from a single broker (one to many capability). Similarly, multiple publishers can publish topics to a single subscriber (many to one).

In our system, we use a software called Mosquitto MQTT broker that runs inside the central processing unit which has a static IP address, and port 1883 is allocated for the broker. Moreover, in our system, the clients are hand-held devices and the main processing unit. Paho-mqtt python library is used in hand-held devices and in the central processing units because they are powered by Raspberry Pi modules.

The localization algorithm will run inside the hand-held devices of each visitor. So, the hand-held devices will publish the location information on predefined topics. For example, hand-held device1 publishes its position information on the topic called “pos/device1”. The central processing unit will be subscribed to each topic and receives all the messages that have been sent by the hand-held devices. It uses this data in the monitoring subsystem. On the other hand, each of the hand-held devices is also subscribed to a pre-defined topic to receive information from the central processing unit such as the alerts that are given when the visitor enters the gallery which he/she does not allow to.

4.3.4.4. Tests & Results

After successful connection, each device publishes its successful log message to their assigned topics. By looking at the monitoring and the localization subsystem test results, one can see the success of the communication subsystem. Since at the background of those subsystems the data traffic is controlled and delivered by the communication subsystem.

4.3.5. Payment Subsystem

4.3.5.1. Description

In this subsystem, we deal with the museum tour's payment and prohibition to enter the galleries that the visitor did not pay for. There are two kinds of payment: the initial payment at the museum entrance and the payment that is updated during the tour at the information desk. At the initial payment, permissions will be given to the visitor according to the purchase of him/her at the entrance by using an interface developed for the use of employees. On the other hand, for the payment during the tour, if the visitor decides to enter a section that is not previously paid for, the payment information can be updated at the information desk.

4.3.5.2. Subsystem Level Requirements

- The system should provide direct payments for the facility owners and active payment during the visit via the information desk.

- The system should detect disallowed entrances and give responses to the visitor during the trip about the payment for the additional sections' entrance at most in 1 seconds.

4.3.5.3. Solution Procedure

The subsystem's solution includes only software implementations because the hardware that is already added for the other subsystems is enough to imply payment functions. The payment sessions are conducted manually. At the beginning of the visit, the visitor pays at the entrance desk, and the permissions of the visitor to the paid sections are added via Web-App by the museum crew to the main processing unit. Then, the information is sent to the hand-held device via Wi-Fi and stored there until the end of the visit. After the payment, the visitor is allowed to enter the galleries. During the visit, if the visitor enters to a new section that is not paid for, the hand-held device quickly announces that the visitor must pay an additional fee to visit this section. If the visitor does not leave the section, the acknowledgement repeats, and the device does not play any other sound until the visitor leaves the section or goes to the information desk and pays for the section. The payment information will be resent to the handheld device.

To be able to implement the required functions of the subsystem, an algorithm has been developed in a software manner. Throughout the project, we have built up the software by using the Python programming language. For the sake of simplicity and harmonization of the subsystems, the Python language is also used for developing the software of the subsystem. The primary use of the software is to provide a GUI for employees to assign the visitor's permissions to the hand-held device and run the algorithm for the payments during the visit. To be able to make the acknowledgement quickly, the location data can be directly used to give the warning. Since the location of the visitor is updated in one second, the system can detect the entrance to a non-paid section with at most 1 second delay. Illustration of the complete payment process is given in Fig. 4.3.5.3.1

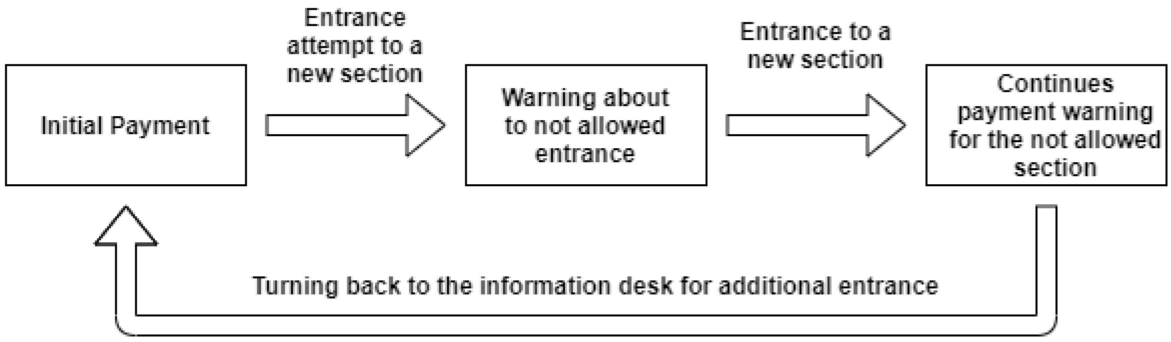


Figure 4.3.5.3.1: Illustration of the payment process

4.3.5.4. Tests & Results

The test that is applied to prove the promised functions of the system is mainly on the permission check of the visitor. As a demonstration, a fictionalized visitor pays for the visit permission of one of the galleries. After the payment, the visitor begins to walk inside the permitted section. The functionality of the sound acknowledgement is checked during the tour. At the end of the test tour, to understand whether or not the entrance desk can recognize a new section entrance, the visitor enters a new section that was not paid before. If the system can recognize these actions, we can say that the subsystem works successfully.

After completing the tests, we found that we have reached the aim of the subsystem by checking whether the system responds to the not allowed section entrance within 1 second and keeps the warning until the visitor leaves the section. The results are checked by controlling the sound output of the device, and they satisfy the requirements of the subsystem.

4.3.6. Power Management Subsystem

4.3.6.1 Description

Power management is a very critical part of the system. It is divided into two parts as battery management and power supply for stationary devices located near the artworks. For the battery management part, the battery could handle long operation time, which is satisfactory for one tour of a visitor without recharging, and it should be light enough not to tire the customers during their visit.

At the other part, the stationary components could also be supplied with batteries; however, for the stationary devices, the weight is not that critical.

The subsystem deals with the power system problems by calculating the devices' power consumption and finding appropriate batteries under consideration of their voltage and current ratings.

4.3.6.2. Subsystem Level Requirements

- The battery of both the hand-held and stationary devices (with battery operation) must provide a tour for visitors without charging the battery again. The estimated operation duration is 2 hours for handheld devices.

4.3.6.3. Solution Procedure

Hand-held Device: As mentioned in the subsystem level requirements, the system should provide a sufficiently long operation time. To be able to calculate the operation time requirements, we went through the details of the processor and sensor used to construct the hand-held device. We have worked with the Raspberry Pi module to read data from the sensors and process the algorithm and we decided to use the DWM1001 UWB module as a sensor. The Raspberry Pi does not have the ability to read UWB signals directly; therefore, there is a need for an additional sensor connected to the main module. The Raspberry Pi could both run the DWM1001 and communicate with it via one of its USB ports. Therefore, there is no need for an additional connection between the battery and the DWM1001 module. The measured current and power consumption results can be seen under Appendix-A.

From the results, for minimum 2-hour operation time, a battery having a minimum 770 mAh must be selected by calculating an average 0.385 Ah power consumption. The most effective battery solution is using Li-ion battery packages. We have selected two of 2200 mAh batteries to supply the handheld device, which helps to operate the handheld device over 5 hours.

Figure 4.3.6.3.1: The Li-ion battery used in handheld device.

The Li-ion battery shown in Fig. 4.3.6.3.1 has 3.7V rated voltage. Since a minimum 5V should be applied for running the Raspberry Pi, we used 2 of this battery in series with the help of the battery holder. Furthermore, a 5V voltage regulator was added to regulate the input voltage to a suitable level to supply the Raspberry Pi. The regulator is given in Fig. 4.3.6.3.2. The complete power diagram of the handheld device is given in Fig. 4.3.6.3.3.

Figure 4.3.6.3.2: LM2596 5V step down voltage regulator

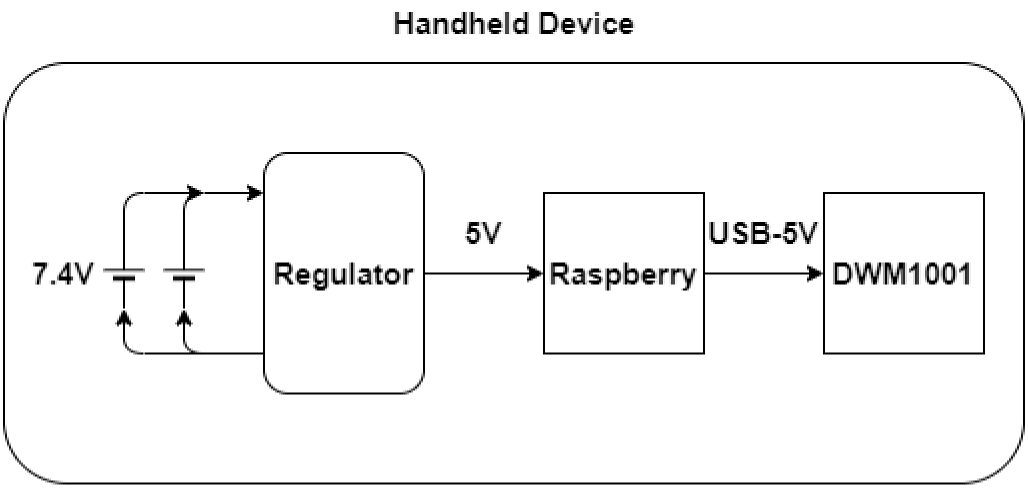


Figure 4.3.6.3.3: Power distribution diagram of the handheld device

Stationary Devices: The stationary devices should be supplied with suitable batteries. The stationary device only includes a DWM1001 module inside it. The module is fed by an input voltage of 3.4V, which is regulated to 5V inside the module. The current drawn from the device is measured and provided in Appendix B. Average current drawn from the device is 120 mA. For at least 2 hours operation, 240 mAh battery should be selected. A battery having 850 mAh is selected for stationary devices which helps to operate the handheld device over 3 hours.

4.3.6.4. Tests & Results

To be able to decide whether the batteries are enough to satisfy the requirements, we directly measured the input currents, and by using them and the properties of the batteries, we have decided how much time the system would work before a recharging.

We have already tested the operation over 2 hours during the overall system tests, and we have not been faced with any problem for both handheld and stationary devices.

4.3.7. Mechanical Design Subsystem

4.3.7.1. Description

In this subsystem, the primary motivation is designing ergonomic and good-looking mechanical cases to the electronic components of the eVCO3 product package. There are two different mechanical cases that must be designed for the stationary parts and hand-held device. Although the mechanical design part mainly focuses on the shape of the devices, there is also another consideration which is about the cooling of the devices. The instruments used in the eVCO3 package may experience overheating. Therefore, during designs of the mechanical cases, we also considered the heating problem and gave some window areas on both handheld and stationary devices cases.

4.3.7.2. Subsystem Level Requirements

- The hand-held device should be so light that the device's weight is not uncomfortable for the visitor. For example, an average mobile phone is weighted around 200-250 grams with additional accessories; therefore, the weight of the handheld device should be maximum around these values.
- The shape of the hand-held device should be well-designed to ensure ergonomics for the visitors. The held part of the device must be sat to the hand of the visitor.

4.3.7.3. Solution Procedure

As mentioned in the subsystem level requirements, the hand-held device should be ergonomic; therefore, 3D-printer was used for production of the cases for the devices because light and flexible designs could be done with low manufacturing cost using 3D-printers. After the production of the 3D printed parts of cases, the electronic devices were mounted into the cases by the help of bolts and nuts. The cases' model was developed by considering how the mountings of the devices could be done. For the production and creation of the solid parts, there is a need for a software environment, and we have used Solidworks to design the CAD models of cases. The designed case for the stationary devices is shared in Fig. 4.3.7.3.1. When the engineers were designing the shape of the hand-held device, they tried to secure ergonomic and good-looking goals. The chassis of the hand-held device is given in Figs. 4.3.7.3.2, 4.3.7.3.3 and 4.3.7.3.4.

Figure 4.3.7.3.1: Stationary device

Figure 4.3.7.3.2: Hand-held device chassis and arrangement of the components

Figure 4.3.7.3.3: Chassis of the hand-held device

Figure 4.3.7.3.4: Handheld device

To show the importance of lightness for eVCO3, the weights and dimensions of the stationary and hand-held devices are calculated and given in Tables 4.3.7.3.1 and 4.3.7.3.2, respectively. From the results, it can be said that the desire for lightness has been ensured.

Table 4.3.7.3.1: *The weights of the stationary and hand-held devices*

	Stationary Device	**Hand-held Device**
Raspberry Pi 3A+	**-**	**29 g**
DWM1001	**~10g**	**~10g**
Battery	**24*2=48 g**	**2*48=96 g**
Voltage Regulator	**-**	**11.23 g**
Case	**31.72 g**	**120 g**
Total	**~89.72 g**	**~266.23 g**

Table 4.3.7.3.2: *The dimensions of the stationary and hand-held devices*

	Dimensions(mm³)
Stationary Device	**93*86*30**
Hand-held Device	**168.3*59*45.8**

On the other hand, the component that is the most problematic in terms of heating is the Raspberry Pi. There are some heatsinks located on the critical parts of the Raspberry Pi, and there are some openings on the chassis of the handheld device. We have examined the setup during the overall system tests for more than 5 hours, and there was not any problem because of the heating.

5.Results and Analyses of Performance Tests

All the test procedures are performed, and each subsystem has been tested separately. However, we must integrate all the subsystems together to test the overall system. In Fig.5.1. connection and correlation between all subsystems are given. Although each subsystem is tested separately, integration phase was difficult. Since all the subsystems must work in accordance. After few adjustments in the software, we have tested the overall subsystem. The test procedure of overall subsystem is as follows

1) Locate the stationary devices and central processing unit considering the labels on them and positions on Fig 5.1.

2) Power up stationary devices and the main processing unit.

3) Connect to the local network using any electronic device. Reach the web-app. Register for a new visitor. Enter the sections that are paid from the UI.

4) Wait for the position of the visitor to be updated. This indicates that the communication subsystem is successfully started.

5) After successful connection, the handheld device will appear on the map. Check whether all the stationary and hand-held devices are seen on the map of the room. If they are, this means that the monitoring subsystem is successfully started.

6) Having monitoring and communication subsystems operational, walk through the predefined points in the room with the hand-held device. Compare the coordinates of the predefined points with the localization results. Note the difference.

7) Go to the 1m distance for each artwork in section 1. Check whether the audio information is given for each artwork.

8) As a test case go to section 2, which is not paid yet. Check whether an audio warning is given or not.

9) If step 8 is successful, update the payment data and go to section 2. Repeat steps 7 and 8 in section 2.

10) Set the occupancy limit of section 2 as full, check whether an audio warning is given or not.

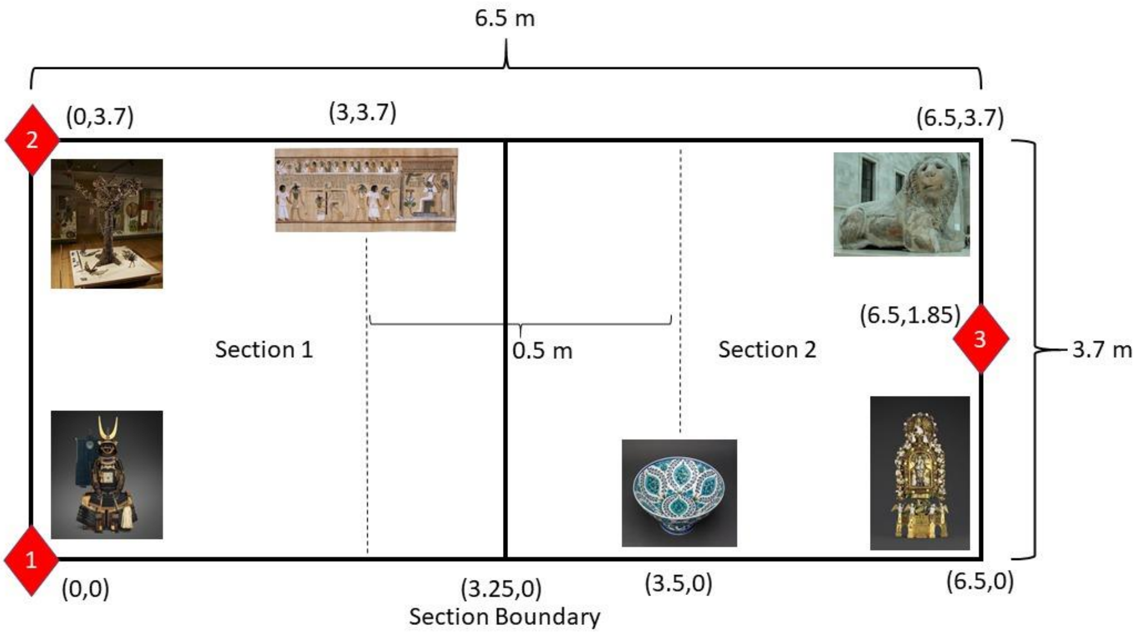


Figure 5.1: Museum Illustration

Performance Criteria

Performance criteria are determined according to the system-subsystem level requirements and test steps. For overall system to satisfy minimum requirements, it must collect over 60 points.

1. Monitoring page is accessible from any device connected to LAN.
2. All the devices are seen in the monitoring screen.
3. System determines the location of visitors with at most 50 cm error.
4. The system starts informing the visitor if the distance between visitor and artwork is less than or equal to 1 meter.
5. If the visitor tries to visit a section that is not paid, the system warns the visitor.
6. The system ensures reliable connection of all devices throughout the visit.
7. If maximum occupancy limit has exceeded, then the system warns the newcomer.

Table 5.1. Performance Evaluation Rubric

Criteria	Fulfilled	Needs Improvement	Failed
1	10 pts	5 pts	0 pts
2	10 pts	5 pts	0 pts
3	10 pts	5 pts	0 pts
4	10 pts	5 pts	0 pts
5	10 pts	5 pts	0 pts
6	10 pts	5 pts	0 pts
7	10 pts	5 pts	0 pts

Test steps are followed in the demo to our DS coordinator. First 6 requirements are fulfilled, and our system collects 60 points. However, seventh criteria has not been tested because we only had one handheld device. In the final demo, seventh criteria will also be tested.

6. Deliverables

eVCO3 includes three deliverable packages namely, hardware, software and technical documents.

- ## Hardware

a.Handheld device: eVCO3 includes handheld devices to be given for each visitor. This device has following features:

- Removable and rechargeable battery.
- Ergonomic and compact design.
- Mounted Raspberry Pi for localization.
- Headphone output.

b.Stationary devices (x3) : eVCO3 includes sensors located around the art pieces for localization. The sensors can use the grid or a battery as a power source depending on the user's desire.

c.Battery Charger: A battery charger will be delivered to recharge the batteries of the devices.

d.Central Processing Unit: eVCO3 includes a central processing unit that operates web-app and communication networks.

e.Li-Ion Batteries (x5): Rechargeable li-ion batteries are provided for handheld and stationary devices.

f.Powerbank: A powerbank is provided to power the central processing unit up.

- ## Software

eVCO3 includes a browser-based web-app for monitoring the visitors. Web-app will include a GUI and museum crew will use this web-app to manage the payments of the visitors and track them during their visit.

- ## Documents

User's manual and warranty certificate will be provided with the eVCO3. User's manual includes information about the system and explains how to use the system. Two years of warranty is provided with the system. This warranty is documented with the warranty certificate. Related documents can be found in the appendix.

7. Cost Analysis

System level cost analysis is conducted, and it is provided in the Table 7.1.

Table 7.1. The expected cost analysis of the system

Components	Quantity	Total Cost ($)
Raspberry Pi 4	1	45
Raspberry Pi 0 W	1	10.6
LM2596 Voltage Regulator	1	1.65
Li-ion Battery - 2200 mAh	2	6.47
Li-ion Battery - 850 mAh	3	8.65
Battery Charger	1	5.49
Battery Holder	1	0.55
Powerbank	1	5
3D Printed parts	-	18.4
Additional Mounting Equipment	-	2.5
DWM1001	4	72
Total Cost		**176.31 $**

8.Compatibility Analysis

While designing the product, VComp considered the compatibility of each subsystem with each other. To realize that, VComp first established a solid power management system. After ensuring the power management, next step is creating reliable network between each subsystem. VComp uses same programming language, which is Python, in all subsystems. Therefore, interconnection between them is compatible. Since all subsystems have highly connected each other, during tests the compatibility of the overall system is also tested and satisfied.

9.Discussion

Safety risks in the overall system are very low; however, in eVCO3 product VComp provides a handheld device to users which contains some electronic cards and battery inside. Throughout the museum tour if someone feels an unexpected warming up on the handheld device, please go to the information desk and change the handheld device. Other than possible problems related to battery, VComp will not expect any safety issue.

In eVCO3, VComp designed an indoor positioning algorithm with accuracy of maximum 50 cm error. The system is configured to work within a museum specifically; however, thanks to its compact form it can be easily reconfigurable for other applications such as smart electronics for houseworks(robot vacuum cleaner) or tracking robots in a warehouse and increasing the efficiency of inventory. Especially in inventory management, accurate indoor localization can make critical improvements such as optimizing the routes of robots by reaching higher accuracies with higher speeds. By re-configuration of eVCO3, VComp can supply highly beneficial and accurate indoor positioning to big retail companies. Moreover, VComp thinks that eVCO3 can be used in large hospitals for surveillance and guidance purposes for both doctors and patients. Since new hospitals are designed to be more complex and large scale, an accurate guidance will be very helpful for management and sustainability.

When eVCO3 based products are used widespread in warehouses or hospitals, the environmental cost of this system will be the cost of batteries and plastic cases. It is believed that as technology improves and new battery management options will be available, VComp will design more power efficient devices with using less plastic materials for cases. Further assumption of the company is that the UWB technology will be available on the smartphones in near future, therefore the system will require only stationary devices and eliminate the usage of handheld devices which will further decrease the battery and plastic usage for products.

10.Conclusion

This paper includes the result of the entire design process. First, company organization and basic information about the project is given. Second, executive summary and introduction are provided.

After completing the introduction section, the final solution procedure is explained in both system and subsystem levels. First, the overall system is explained. Second, subsystems and requirements are defined. Then, solution procedures are discussed including related calculations, circuit diagrams and flowcharts. Finally, test plans and results are provided and discussed. By discussing the subsystems in detail, the solution part is completed.

After this point, first, the deliverables that are going to be provided as the final product are stated. Detailed cost and compatibility analyses are done. The Discussions section is also provided before the conclusion. Finally, the other required documents are provided in the appendix section.

At the end of this report, the project design process is finalized and the eVCO3 is ready to launch now!

11.Appendices

Appendix A

Figure-1: Minimum and maximum peak currents measured from the input of handheld device.

$P_{in}=V_{in} *I_{in}$, where I_{in} =(470+300)/2 mA and V_{in} =2*3.7 V

Min. battery storage(mAh) = 385*2=770 mAh

Figure-2: Minimum and maximum peak currents measured from the input of stationary device

$P_{in}=V_{in} * I_{in}$, where I_{in} =(140+100)/2 mA and V_{in} =3.4 V

Min. battery storage(mAh) = 120*2=240 mAh

Appendix B

USER'S GUIDE

This chapter includes usage instructions that must be followed when starting and operating the eVCO3. Unexpected faults and contemporary damage may occur if these instructions are ignored. Product subject to the guarantee and free technical support **if and only if** these instructions are followed.

Starting the System

1. Place all the stationary devices at their predefined locations. Power them up.
2. The monitoring application can be accessed by any device connected to the local network.Type following URL to the URL bar of the web-browser: https://<hostname>:5000/.

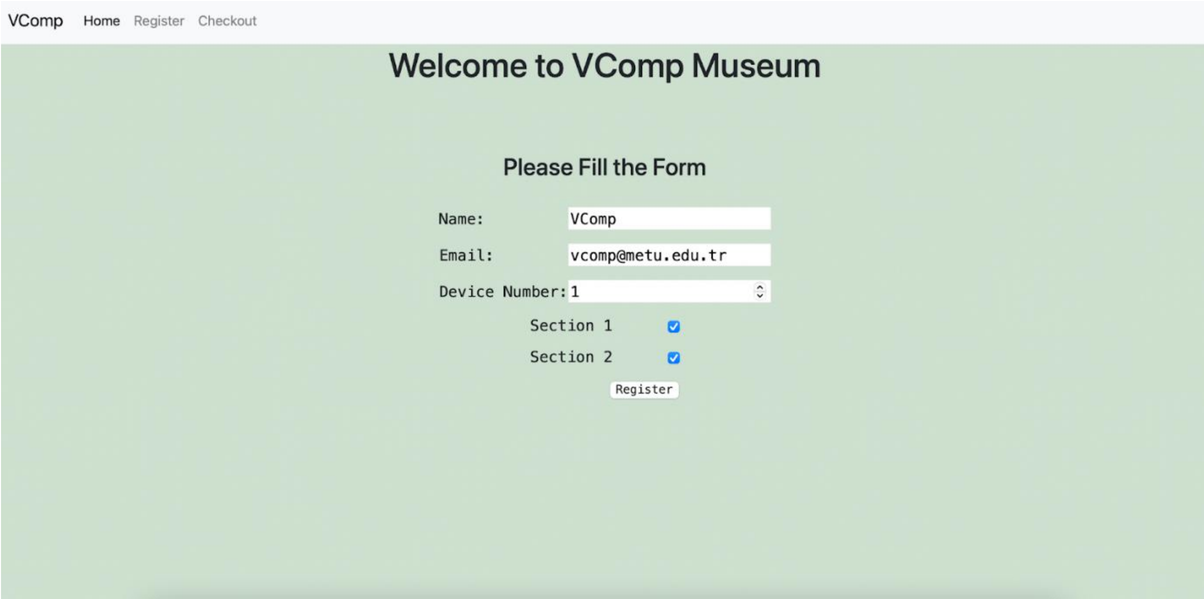


Figure-3: WebApp Interface

3. System is on and ready to register new visitors

Visitor Registration

1. Click on the “Register a Visitor” tab on the monitoring screen.
2. Fill in the information bars in the registration screen.
3. Click on the “Register” button.
4. Power-up the handheld device to be given to the visitor. Wait for 45 seconds. This delay is required for the handheld device to boot properly. Device is ready to use when its location is seen on the monitoring map.

Visitor Checkout

1. Checkout process can be done from checkout tab on the web-app.
2. Enter the device number that is w assigned to the visitor and click on “checkout” button

Shutting Down the System

1. Checkout of all handheld devices must be done before shutting down the system.
2. After being sure that there are not any handheld devices connected, shut down the devices by simply cutting the power.