



University of Minho
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Embedded systems

Project: Report

Marketing Digital Outdoor with gesture interaction — Analysis

Group 8

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List of Listings

List of Abbreviations

Notation	Description	First used on page nr.
API	Application Programming Interface	17
CLI	Command Line Interface	15
COTS	Commercial off-the-shelf	13
CSI	Camera Serial Interface	1
DB	Database	15
DC	Direct Current	2
ERD	Entities-Relationships diagram	13
GIF	Graphics Interchange Format	18
GPIO	General Purpose Input/Output	1
HDMI	High-Definition Multimedia Interface	1
HW	Hardware	i
mA	milliampere	3
MDO-L	MDO Local System	7
MDO-RC	MDO Remote Client	11
MDO-RS	MDO Remote Server	11
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor	9
PCB	Printed Circuit Board	i
PoE	Power over Ethernet	2
REST	Representation State Transfer	17

List of Abbreviations

Notation	Description	First used on page nr.
SoC	System-on-a-Chip	1
SW	Software	iii
TCP/IP	Transmission Control Protocol/Internet Protocol	14
TTL	Transistor-Transistor Logic	1
UI	User Interface	13
UML	Unified Modeling Language	13
URL	Uniform Resource Locator	17

1. Design

In this section the theoretical foundations are used to design a viable solution, accordingly to the requirements and constraints listed. In the design phase, the product development starts, specifying the system in terms of hardware and software and its associated interfaces, the error handling required, and the design verification.

1.1. Hardware specification

The first step for system design is the HW specification. This can be pictured as a block diagram, this block diagram was already shown and mentioned in section ?? on Fig. ??.

1.1.1. Architecture

Although that in the analysis phase an overview of the HW architecture was conceptualized, in this section, a more specific HW architecture is illustrated, using a block-diagram.

As it can be seen in Fig. 1.1, the Raspberry Pi is the main controller and it is powered by the Power Supply through USB-C. The Power Supply also supplies via Micro-USB the LCD Display control board and the Fragrance Diffusion Actuator. The LCD Display board connects to its board through 50-pin Transistor-Transistor Logic (TTL) and the board connects to the Raspberry Pi through High-Definition Multimedia Interface (HDMI). The Speakers also connect to the LCD Display board through JST PH2.0. Beyond being powered up, the Fragrance Diffusion Actuator also connects to the Raspberry Pi through the General Purpose Input/Output (GPIO). What also connects to the Raspberry Pi through GPIO are the Motion Detection sensors. Lastly, the Camera connects through Camera Serial Interface (CSI) to the Raspberry Pi.

1.1.2. Main Controller

The main controller was also previously mentioned because it makes part of one of the requirements of this project: use the Raspberry Pi 4B (Fig. 1.2). This System-on-a-Chip (SoC) has several of specifications [1]:

1.1. Hardware specification

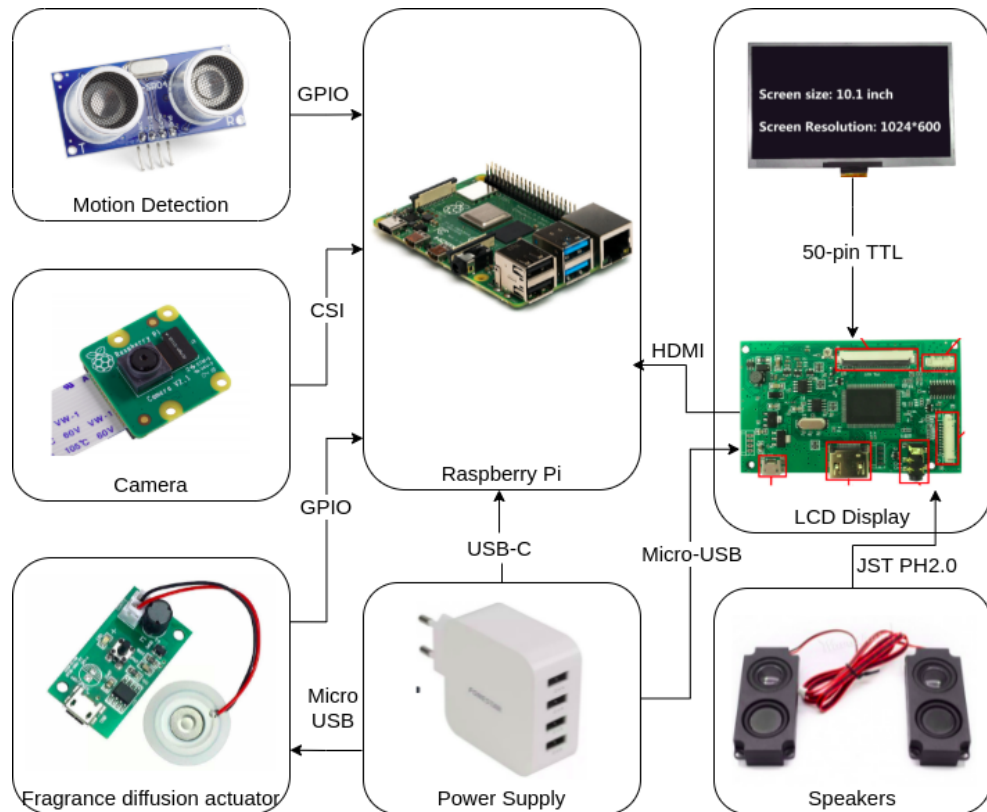


Figure 1.1.: HW architecture Block Diagram

- Processor: it has the Broadcom BCM2711 processor, quad-core Cortex-A72 (ARM v8) 64-bit with 1.5GHz;
- Memory: this model has 4GB LPDDR4 with on-die ECC;
- Connectivity: it has a 2.4 GHz and 5.0 GHz IEEE 802.11b/g/n/ac wireless LAN, Bluetooth 5.0 with low energy, one Gigabit Ethernet port, four USB ports in which two are 3.0 and another two are 2.0;
- GPIO: it has a standard 40-pin GPIO header that is fully backwards-compatible with previous boards;
- Video and Sound: it has two HDMI ports that support up to 4kp60, a 2-lane MIPI DSI display port, a 2-lane MIPI CSI camera port and a 4-pole stereo audio and composite video port;
- Multimedia: H.265 (4Kp60 decode), H.264(1080p60 decode and 1080p30 encode) and OpenGL ES 3.0 graphics;
- SD card support: Micro SD card slot for loading operating system and data storage;
- Input power: it has 5V Direct Current (DC) via USB-C connector (minimum 3A), a 5V DC via GPIO header (minimum 3A) and Power over Ethernet (PoE) - enabled (requires separate PoE HAT);
- Environment: it has a range of operation between 0°C and 50°C.

1.1. Hardware specification

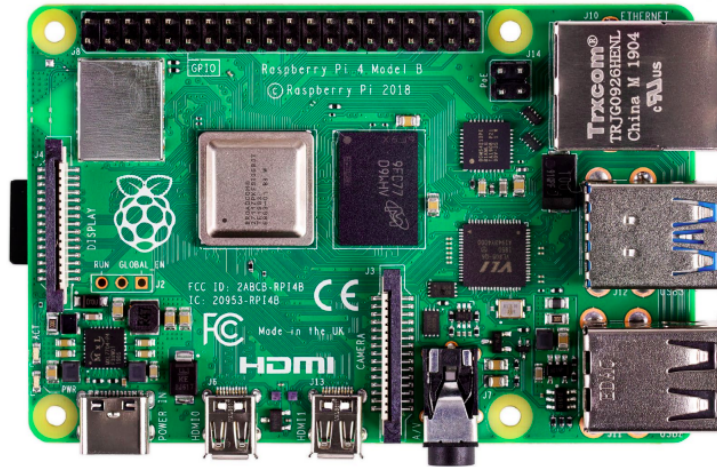


Figure 1.2.: Raspberry Pi model 4B

SD Card

Since this Raspberry supports SD Card, it will be used a micro SD Card with 16 GB that will store everything that is necessary to run the system and handle it.

1.1.3. Motion Detection

For the motion detection, it was already mentioned in section ?? that the best option is to use an ultrasonic sensor. Thus, the sensor that has been chosen is the **HC-SR04 Ultrasonic Sensor**. This sensor has the following specifications [2]:

- Operating Voltage: 5V DC;
- Operating Current: 15 milliamperes (mA);
- Operating Frequency: 40 KHz;
- Maximum Range: 4 meters;
- Minimum Range: 2 centimeters;
- Ranging Accuracy: 3 millimeters;
- Measuring Angle: 15 degrees;
- Trigger Input Signal: 10 microseconds TTL pulse;
- Dimension: 45 x 20 x 15 millimeters.

Sensor Pinout

In Fig. 1.3 is described the sensor pinout and each pin works as follows [2]:

1.1. Hardware specification

1. is the power supply for HC-SR04 Ultrasonic distance sensor which we connect to a 5V supply (for example, 5V pin on Raspberry);
2. pin that is used to trigger the ultrasonic sound pulses;
3. pin that produces a pulse when the reflected signal is received. The length of the pulse is proportional to the time it took for the transmitted signal to be detected.
4. pin that should be connected to the ground (for example, GND pin of the Raspberry).

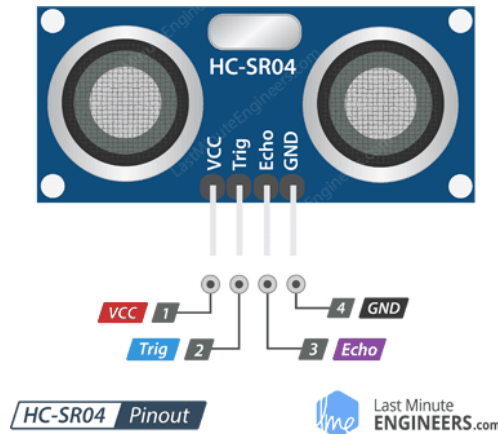


Figure 1.3.: HC-SR04 Pinout (withdrawn from [2])

For this project it will be used three sensors, one placed on the bottom, another on the middle and another one on the top of the machine. With this setup, it can be avoided some perturbations like an animal walking in front of the machine (only the bottom sensor will detect). The disposition of the middle and top sensors can't be too high, because of short people, for example.

1.1.4. Fragrance Diffusion Actuator

The chosen fragrance diffusion actuator is in Fig. 1.4 and has the following specifications [3]:

It has an operating voltage of 5V DC and an operating current of 300 mA. The operating power is 2 Watt. It has a fixed frequency single-chip microcomputer with a frequency of 108 KHz. The dimensions of the board of the module are 35 * 20 * 17 millimeters. It has a strong versatility, large amount of fog, stable performance, the chip has an automatic timing shutdown function (4 hours of continuous work will automatically shut down protection, to turn on again, press the power on again). The 5V USB power supply mode, can be powered by MICRO charging cable. The net diameter of the atomized steel sheet is 16 millimeters, the outer diameter of the silicone ring is 20 millimeters, and the wire length is 8 centimeters.

1.1. Hardware specification



Figure 1.4.: Fragrance module (withdrawn from [3])

1.1.5. Camera

The camera to use in this project needs to be compatible with the board in use, in this case, the Raspberry Pi. Thus the camera module that is used is the **Raspberry Pi Camera Module V2** (Fig. 1.5).

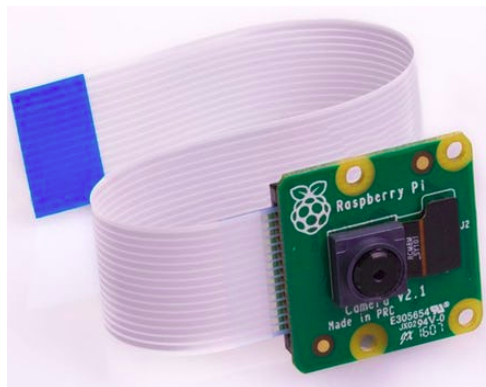


Figure 1.5.: Camera module (withdrawn from [4])

This camera module has a **Sony IMX219 8-megapixel sensor** and can be used to take high-definition video, as well as stills photographs. It supports 1080p30, 720p60 and VGA90 video modes, as well as still capture. It attaches via a 15 centimeters ribbon cable to the CSI port on the Raspberry Pi. The camera works with all models of Raspberry Pi 1, 2, 3 and 4. It can be accessed through the MMAL and V4L APIs, and there are numerous third-party libraries built for it, including the Picamera Python library. [4].

1.1.6. LCD Display

In Fig. 1.6 is the display that is used in this project. One advantage on this display is that it has **audio drivers**, which means that it is only necessary to plug a speaker and the board can handle the rest. It is also important to refer that the display isn't touch because there is no need to it and also this was the chosen one because it was the bigger and best on market considering quality and price.

As it can be seen, the display has **10.1 inches** and it is supplied with **5V DC** and with a current of **2 A** via a micro USB port. Fig. 1.7 show all the interfaces that the board module of the display provides. That was also one more reason for the choice of this display: it has an **HDMI interface** to connect to the Raspberry, the **50Pin TTL Screen Interface** that will connect to the display and two options to plug audio - the **Speaker Interface** and the **3.5mm audio interface**.



Figure 1.6.: Display (withdrawn from [5])

It can also be seen in this figure that the display has also a remote and a board to handle the remote controls, but in this implementation, it will probably not be in use.

1.1.7. Speakers

When playing video ads, it is not only necessary a display, but also a speaker to playback the sound of the ads. As it can be seen in Fig. 1.7, the screen board has two different interfaces of audio: the speaker interface and the audio interface. For this project it will be used speakers that uses the speaker interface, because that type of speakers with that interface are passive speakers and don't need a DC power supply, which is an advantage [6].

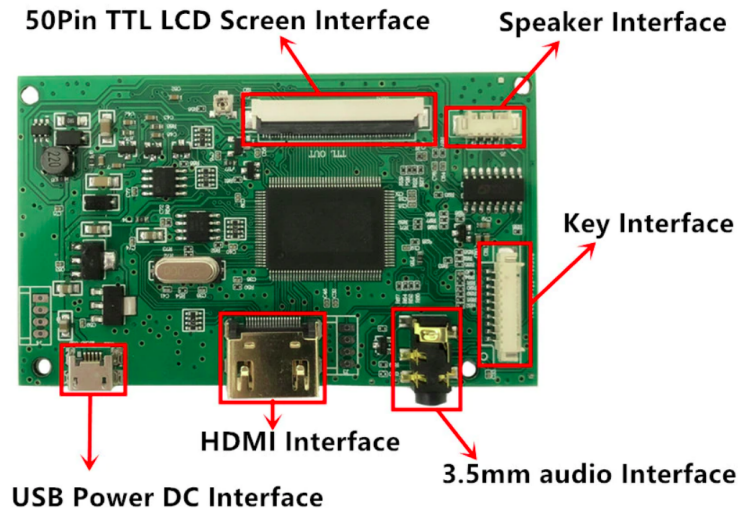


Figure 1.7.: Display Interfaces (withdrawn from [5])

Thus, the speakers that will be used have an impedance of 8 Ohm and a power of 5 Watts and are displayed on Fig 1.8.



Figure 1.8.: Speakers (withdrawn from [7])

1.1.8. Power Supply

The MDO Local System (MDO-L) will be a plugged in system, so it will be needed a plugged in power supply to supply all the components of the system. In total, the power consumption will not overtake 20 Watts and all the supplies necessary are plugged by USB (Raspberry Pi, Fragrance Diffusion Actuator, and screen). So, it will be used the power supply in Fig. 1.9, that has 4 outputs of 5 V DC and 2.4 A DC each.

1.1. Hardware specification



Figure 1.9.: Power Supply (withdrawn from [8])

1.1.9. On/Off button

In this context, an On/Off button can be useful to power On/Off the MDO-L. However, this feature is not that necessary, so, this prototype will be only powered through the power supply previously talked in section 1.1.8 and will be always on until the power supply be unplugged, powering off the machine.

1.1.10. Total HW cost

The total HW cost can now be precisely calculated, once that all the hardware is now specified on table 1.1, yielding about 175 EUR.

Table 1.1.: Total spending on Hardware

Item	Quantity	Price (€)
Raspberry Pi 4B	1	70.00
Ultrasonic Sensor HC-SR04	3	11.70
Fragrance Diffusion Actuator	1	3.23
Raspberry Pi Camera V2	1	20.00
LCD Display	1	51.95
Speakers	1	3.00
Power Supply	1	13.50
Total		173.38

1.2. Hardware interfaces definition

After specifying the HW, it is important to define its interfaces. Firstly, it is necessary to have basic know-how of the main board's pinout. In Fig. 1.10 is represented the pinout of the Raspberry Pi.

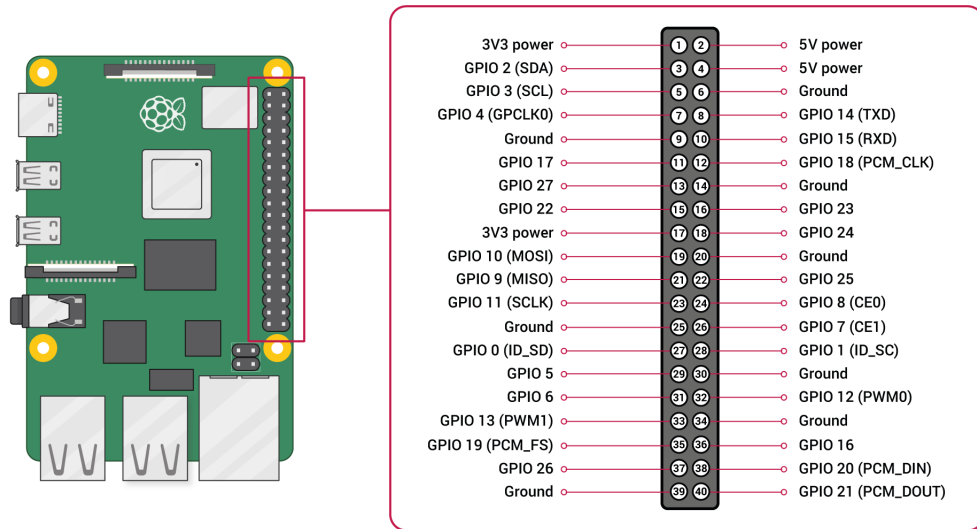


Figure 1.10.: Power Supply (withdrawn from [9])

1.2.1. Peripherals Mapping

After have a basic know-how of the Raspberry's pinout, it is now possible to map all the HW components. As it can be seen in Fig. 1.11, only two types of peripherals need to be mapped in the Raspberry: the ultrasonic sensor and the fragrance diffusion actuator.

Firstly, the ultrasonic sensors can have three of their four pins in common: the **Vcc**, the **GND** and the **Trig**. The first two are for obvious reasons: they can be powered for the same source, so they are connected to the pin 2 (5V power) and pin 9 (Ground), respectively. The last one is because the trigger only triggers the sensors to start the acquisition, so, they can all start at the same time and have the same trigger source, so, they are all connected to the pin 11 (GPIO 17). Then, each one of them need a specific pin to connect to its **Echo** in order to make the distance read, so, the pins that are chosen are pin 15 (GPIO 22), pin 16 (GPIO 23) and pin 18 (GPIO 24).

Lastly, the fragrance diffusion actuator. Although this one is powered up by Micro-USB, it is necessary to activate or deactivate the diffusion and this is only possible with a **Metal Oxide Semiconductor Field-Effect**

1.2. Hardware interfaces definition

Transistor (MOSFET), activating its gate. The gate is connected to the pin 36 (GPIO 16) and this is the pin responsible to activate or deactivate the fragrance diffusion.

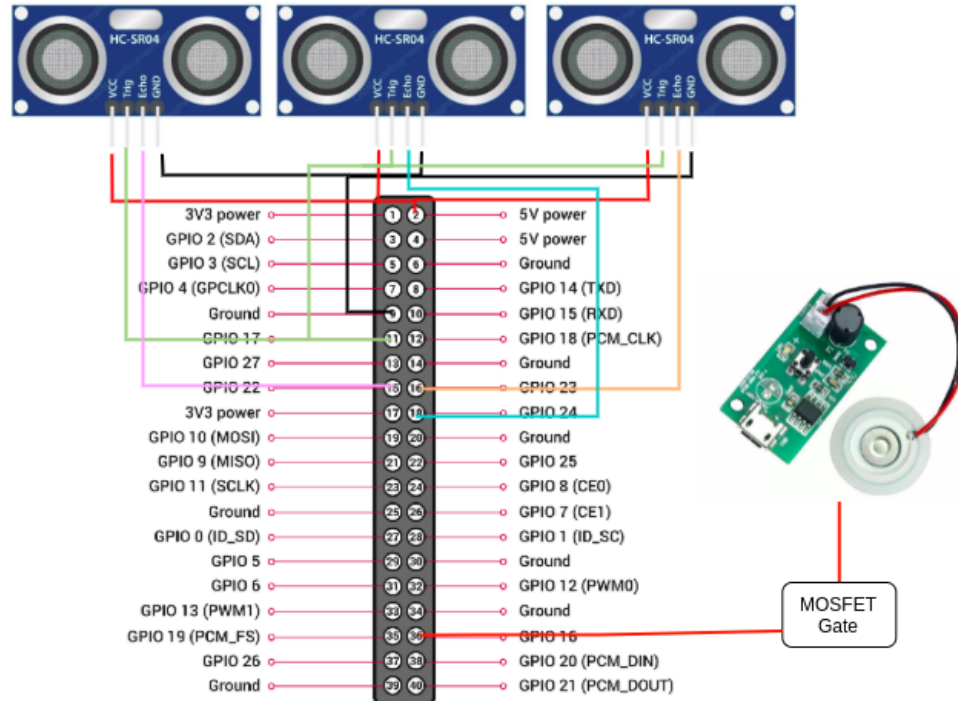


Figure 1.11.: Peripheral Mapping

To turn things more clear, Table 1.2 shows all the pin mapping in a more clear way.

1.2.2. Test Cases

In order to verify if all the hardware is in good conditions, are made some test cases to each component. In Table 1.3 are displayed all the test cases to be done in all pieces of HW. Basically, all tests are functional tests and need to be done to know if some component may be damaged or also could not be in the error range provided by the manufacturer.

1.2.3. PCB Design

As it can be seen in Fig: 1.11, it is a little bit complex and messy to look and conceive a circuit with all those connections, and since many connections are in common, it is an advantage to design a PCB to make things more simpler.

1.3. Software specification

Table 1.2.: Pin Mapping

Pin Mapping		
Controller Pin	Interface Device Pin	Function
Pin 2 (5V)	Ultrasonic Sensors (Vcc)	Supply 5V to the sensors
Pin 9 (Ground)	Ultrasonic Sensors (GND)	Close the supply connection
Pin 11 (GPIO 17)	Ultrasonic Sensors (Trig)	Make pulses to the Trigger's sensors in order to start the distance acquisition
Pin 15 (GPIO 22)	Ultrasonic Sensor 1 (Echo)	Handle the Echo Pin of the first sensor in order to measure the distance
Pin 16 (GPIO 23)	Ultrasonic Sensor 2 (Echo)	Handle the Echo Pin of the second sensor in order to measure the distance
Pin 18 (GPIO 24)	Ultrasonic Sensor 3 (Echo)	Handle the Echo Pin of the third sensor in order to measure the distance
Pin 36 (GPIO 16)	MOSFET's Gate	Toggle the gate of the MOSFET in order to turn On/Off the diffusion actuator

For the design of this PCB it was used the software **PADS**, developed by Mentor Graphics. In Fig. 1.12 is the logic of the connections to the PCB, this part was made on **PADS Logic** and basically is joining everything that is common to the sensors to then connect to the raspberry Pi, then there's a pin for every Trigger of every sensor and finally a pin for the gate of the MOSFET and two pins for its supply.

When the logic is done, it is moved to the layout on **PADS Layout** where all the components are placed and connected through tracks. In Fig 1.13 is the final layout of the PCB. Note that there are two tracks that are more wide, this is because they are the tracks that supply the MOSFET and this one need more current, which means wider tracks.

Connectors J1, J2 and J3 are for the sensors, connector J4 is for the GPIO of the Raspberry Pi, connector J5 supplies the sensors and connector J6 supplies the MOSFET Q1.

It is to note that the final size of the PCB is 2400 * 2200 mils. Converting this to centimeters gives a dimension of approximately 6.1 * 5.6 centimeters.

1.3. Software specification

Next, the SW responsible for system operation is specified for all subsystems — **MDO Remote Client (MDO-RC)**, **MDO Remote Server (MDO-RS)**, and **MDO Local System (MDO-L)**. All these subsystems are event-driven (asynchronous), and they can be more easily specified using state-machine diagrams, previously illustrated in the analysis phase (Section ??). Also in the analysis phase, the use case diagrams helped to identify the main features required for the system and the respective sequence diagrams helped

1.3. Software specification

Table 1.3.: Hardware Test Cases

HW Component	Type of test	Description	Expected Result
Ultrasonic Sensor	Functional	One will connect the ultrasonic sensor to the Raspberry Pi. Then, an object will be approximated to the sensor from several distances with the corresponding distance being measured with a measuring tape.	If the distance measured by the sensor and the measuring device are within the error margin provided by the manufacturer, the device is compliant.
Camera	Functional	One will connect the camera to the Raspberry Pi and then will try to make image acquisition in real time, take pictures and also try to take some gifs and videos.	If the quality of the image and the image acquisition are in good quality according to the manufacturer's information, then the device is in good conditions of use.
Fragrance Diffusion Actuator	Functional	One will connect a MOSFET to the fragrance diffusion and connect its gate to the Raspberry Pi. Then, one will trigger the MOSFET's gate and watch the actuator's behavior.	If the diffusion actuator diffuses in good state the fragrance and also if the MOSFET doesn't overheat, then the set of HW is in good conditions of use.
Power Supply	Functional	One will connect the three components (LCD, Fragrance Diffusion Actuator and Raspberry Pi) to the power supply and see their behavior.	If all components work properly, then this piece of HW is in good conditions of use.
Speakers	Functional	One will connect the Speakers to the LCD board and try to run a video with sound in order to verify the sound provided by the speakers.	If the sound output matches the manufacturer's characteristics of the product, then this set of HW is compliant.
LCD Display	Functional	One will connect the LCD board through HDMI to the Raspberry Pi, the LCD Display to its board and supply the board and then try to send some images and videos to the LCD Display.	If the images and videos are displayed in good quality and are in match with the manufacturer's information, then this set of HW is in good conditions of use.

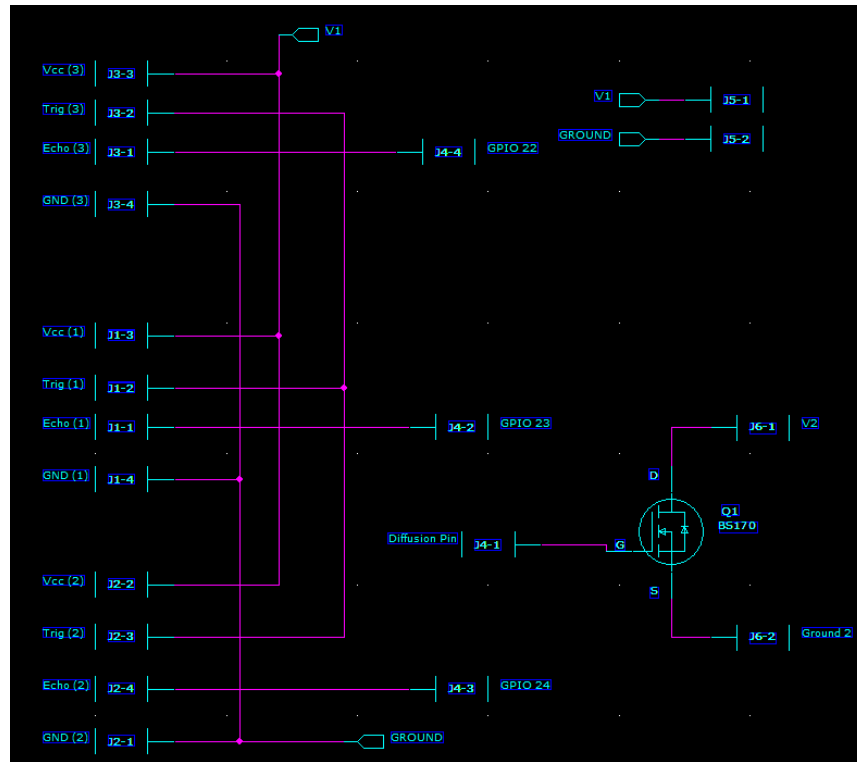


Figure 1.12.: PCB logic

to clarify the intervening objects and the interaction among them.

In this section, the analysis phase information is used to derive the static architecture of the system – classes diagram – and to specify algorithms for its implementation through flowcharts, keeping in mind that the several subsystems operate multiple tasks concurrently, thus requiring the tasks' specification and its priorities. The data frame formats are specified for communication between the different modules. The Entities-Relationships diagram (ERD) are depicted to design the required databases and the User Interface (UI) mock-ups are recalled. The test cases for each subsystem are listed, defining its operation and the expected result. The Commercial off-the-shelf (COTS) SW and the third-party libraries are identified and a mapping between class topics and the foreseeable implementation is presented for clarification. Finally, the SW tools are listed.

1.3.1. Software architecture

The system's SW architecture was devised using Unified Modeling Language (UML) component diagrams for Remote Client (Fig. 1.14), Remote Server (Fig. 1.15), and Local System (Fig. 1.16). Each component diagram illustrates all SW components for the system in analysis and the interaction between them, and its

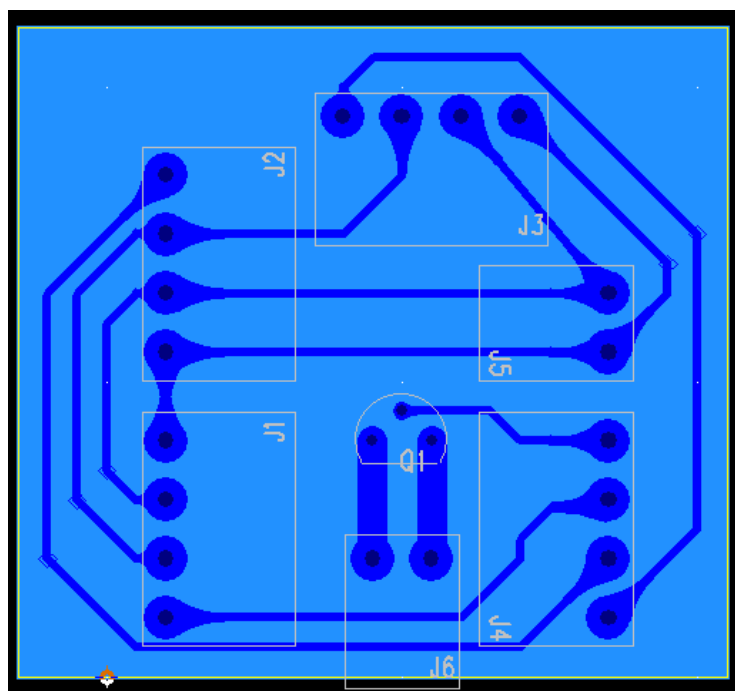


Figure 1.13.: PCB layout

interfaces with external subsystems.

Remote Client

Fig. 1.14 depicts the Remote Client SW architecture, encapsulated in the package MDO-RC: AppManager, and is comprised of the following artifacts:

- User Interface package: contains the UI and UI Engine. It is responsible for providing user feedback and capturing UI events which drive the Remote Client's logic.
- Comm Manager package: manages incoming and outgoing connections to the Remote Server (package MDO-RS: App Manager), periodically checking the connection status by pinging the Remote Server. All connections consist of Transmission Control Protocol/Internet Protocol (TCP/IP) sockets.
- DB Manager package: manages the queries and the associated responses by building or parsing them, respectively.
- Remote Controller package: contains the Cmd Parser, which parses the command responses received from the Remote Server when the Admin is performing remote control of the Local System.
- RC Rx Parser component: high-level parser which filters between db responses and cmd responses for appropriate dispatching.

1.3. Software specification

- TCP/IP Tx socket: outgoing connection node, through which tx frames are sent to the Remote Server.
- TCP/IP Rx socket: incoming connection node, through which rx frames are received from the Remote Server.

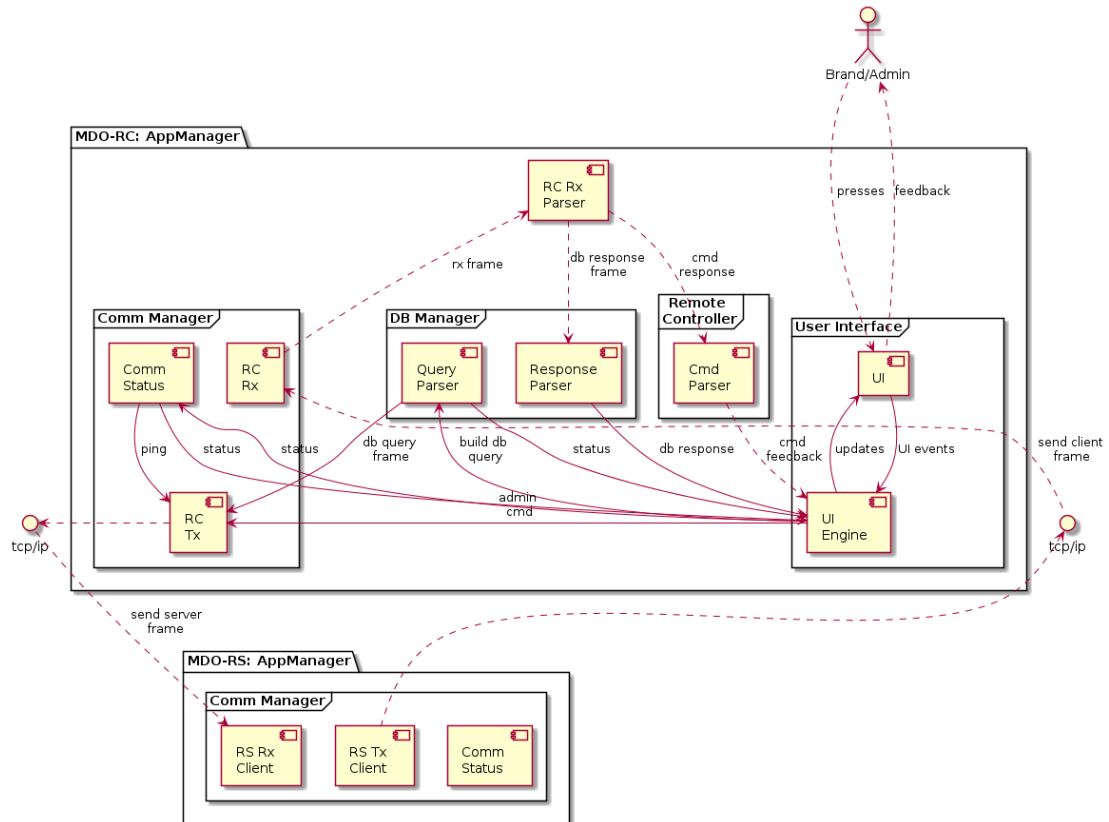


Figure 1.14.: SW architecture: component diagram — Remote Client

Remote Server

Fig. 1.15 depicts the Remote Server SW architecture, encapsulated in the package **MDO-RS: AppManager**. It interacts with the Remote Client (package **MDO-RC: AppManager**), with the Local System (package **MDO-L: AppManager**), and with the Database (DB) server (**MDO-RS: DB Server**). The database management is done using client-server architecture, with **MDO-RS: AppManager** containing the DB client and **MDO-RS: DB Server** the server.

The **MDO-RS: AppManager** package is comprised of the following artifacts:

- Command-Line Interface package: contains the **Command Line Interface (CLI)**, the **CLI Engine**, and the **CLI Parser**. It provides the server external interface for clients to perform requests, capturing

1.3. Software specification

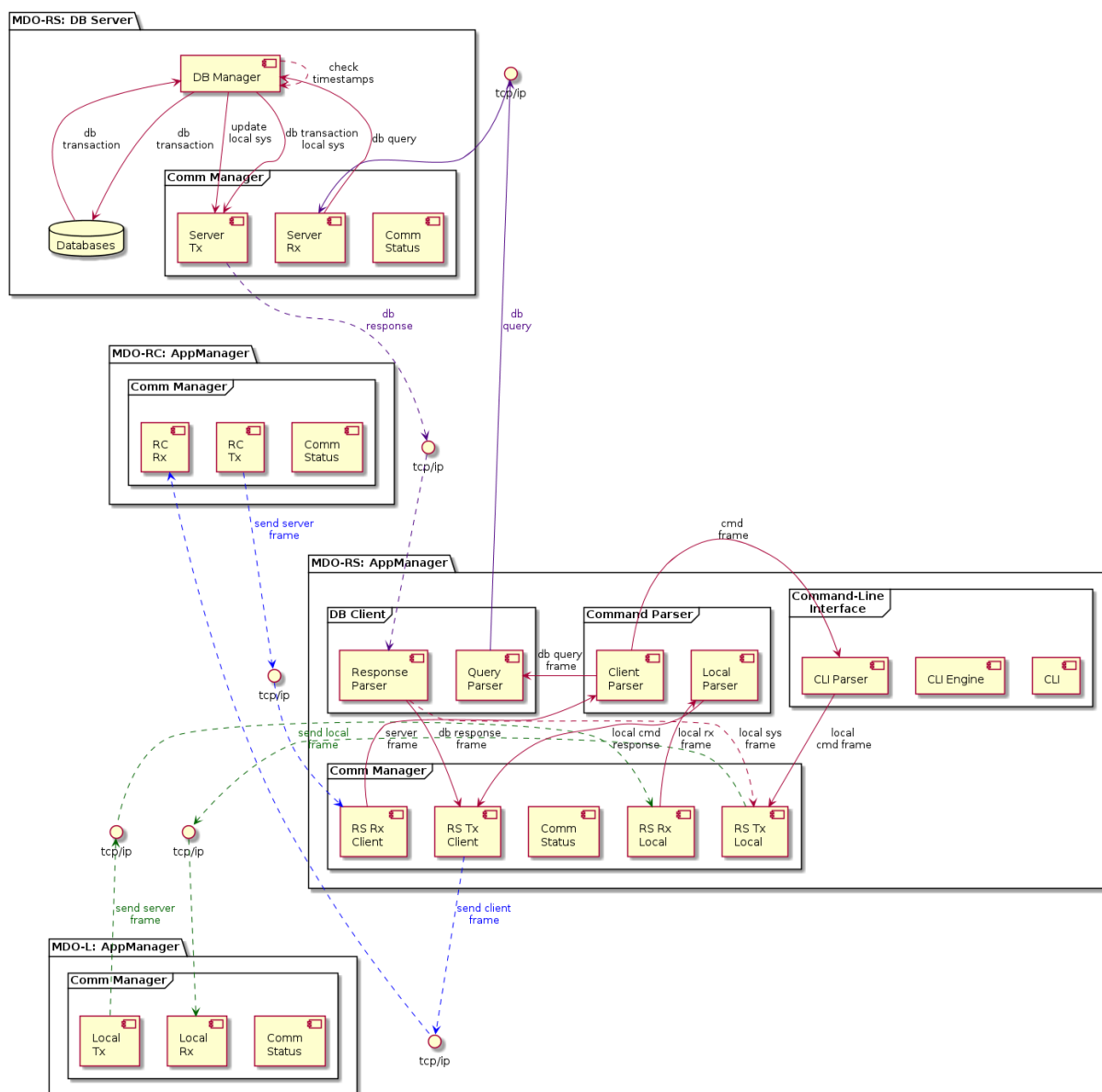


Figure 1.15.: SW architecture: component diagram — Remote Server

the events which drive the Remote Server's logic.

- **Comm Manager package:** manages incoming and outgoing connections to the Remote Client (package MDO-RC: App Manager), and each Local System (package MDO-L: AppManager) it needs to interact. It periodically checks all connections statuses. All connections consist of TCP/IP sockets.
- **DB Client package:** manages the queries and the associated responses by building or parsing them, respectively. It performs the requests for DB server with the solicited queries.
- **Command Parser package:** contains the Client Parser, and the Local Parser to parse and handle

frames received from the **Remote Client** or **Local System**, respectively, forwarding it for appropriate dispatching.

- TCP/IP sockets: incoming/outgoing connection nodes, through which incoming or outgoing traffic flows for the **Remote Client**, the **Local System** and the **DB Server**.

The **MDO-RS: DB Server** package is comprised of the following artifacts:

- **Comm Manager package**: manages incoming and outgoing connections to the **DB Client** (in package **MDO-RS: App Manager**). It periodically checks all connections statuses. All connections consist of TCP/IP sockets.
- **DB Manager package**: handles the received queries, issuing transactions for the databases and returns its response. It is also responsible for periodically checking timestamps, and when there is a match, update the local system with the relevant information.
- **Databases**: contains the actual data stored.

Local System

Fig. 1.16 depicts the **Local System** SW architecture, encapsulated in the package **MDO-L: AppManager**.

It interacts with:

- **Remote Server** (package **MDO-RS: AppManager**): to retrieve updates on its operation or **Admin** commands
- **Twitter** (via its **Representation State Transfer (REST) Application Programming Interfaces (APIs)**): to share posts on it
- **transfer.sh** — an **Uniform Resource Locator (URL)** proxy server: to ease file transfer between the **Remote Server** and the **Local System**.

The **MDO-RS: AppManager** package is comprised of the following artifacts:

- **User Interface package**: contains the **UI**, the **UI Engine**, the **Gesture Recognition Engine**, and the **User Detection package**. The **UI** provides user feedback and **UI Engine** captures the events that drive the **Local System**'s logic. When a user approaches the **Local System**, the **Ultrasonic sensor device driver** captures this event and passes it to the user space where the **Ultrasonic sensor daemon** logs it, which, in turn, signals this event to the **UI Engine**. When the **User** performs gestures, the **Gesture Recognition Engine** requires a service to the **Gesture recognition component (Computer Vision Framework)** to recognize the gesture. Also, when the **User** is detected, the **UI Engine** requests the **Normal mode manager** to stop running, and requests **Face detection** to track people's faces in the camera.

ment, and social media management, in this case, **Twitter**.

- Normal Mode Manager package: manages the normal mode related tasks, namely, fragrance diffusion, video and audio outputs. The fragrance diffusion is requested to the device driver using a daemon to bridge user-space and kernel-space.
- App Parser package: manages the parsing for database queries and requested commands.
- TCP/IP sockets: incoming/outgoing connection nodes, through which incoming or outgoing traffic flows for the **Remote Server**, and the web services for **Twitter** and the **URL proxy server**.

1.3.2. Static architecture – Class diagrams

In this section the static architecture is derived from the SW architecture, i.e., the class diagrams are outlined, using the component diagrams as a starting point, for each subsystem.

Remote Client

Remote Server

Local System

1.4. Software interfaces definition

1.5. Start-up/shutdown process specification

1.6. Error handling specification

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Appendices

A. Project Planning – Gantt diagram

In Fig. [A.1](#) is illustrated the Gantt chart for the project, containing the tasks' descriptions.

