SchivaTO - Technical Report

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Contents

1 Introduction

SchivaTO is a project developed by Vincenzo Petrolo and Alfredo Paolino.
The project goal is to design a versatile module able to detect obstacles and communicate the sensed data to the outside. The device has been designed taking into account the following use-case scenarios:

- Robot vacuum cleaner
- Parking sensor
- Robotic arm

2 General overview

SchivaTO is thought to work as a slave and, for the sake of flexibility, it provides data both through a PIN connected to the microcontroller and through a Bluetooth communication channel. The module is self-powered by a LiPo battery which can be charged up through the USB-A connector present on the board. On top of that, the module provides also a JTAG interface in order to be programmed and a switch to power ON/OFF the circuit. Finally, the sensing is done through an IR emitter (LED) and an IR receiver. Two potentiometers have been mounted to let the user regulate both the scanning frequency and the detection distance.

3 Design Flow

The following steps have been followed to deploy a complete version of our project:

- Choose name and scope
- Decide project specifications
- Select a complete set of components
- Design schematic diagrams in OrCAD Capture CIS
- Draw footprints in OrCAD PCB Editor
- Place and route of PCB in OrCAD PCB Editor

4 Name and Logo

The chosen name for this project is SchivaTO, which in Italian means 'avoided'. Being designed in Torino, we decided to highlight the letters TO in the name. The chosen logo, designed by us, represent one of the typical use-cases where SchivaTO could be used.

SchivaTO logo

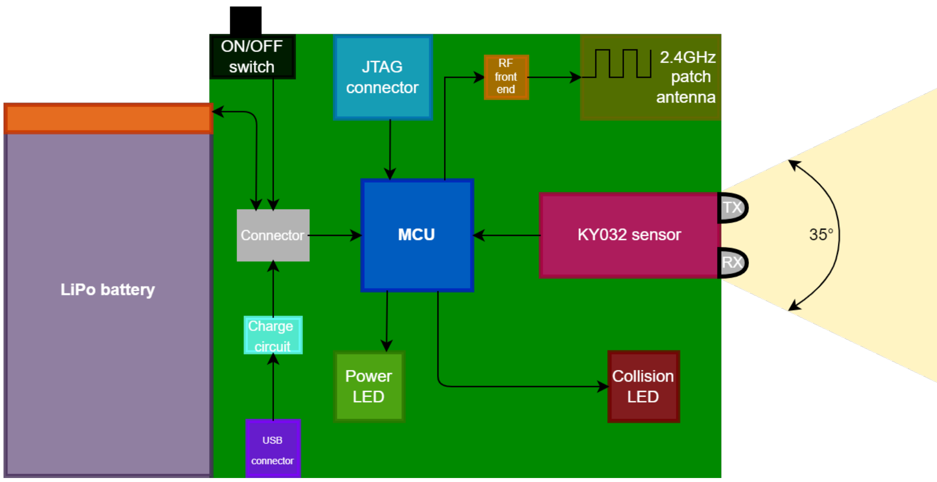
5 Device Specification

SchivaTO was designed around three key points:

- ease of use
- flexiblity
- low power consumption

After the regulation of the two potentiometers, a programmed schivaTO can be instantly plugged in a system and be fully operational for quite a long time if fully charged.

6 Block Diagram



Block Diagram of SchivaTO

As it can be observed in the above picture, the device is equipped with many components:

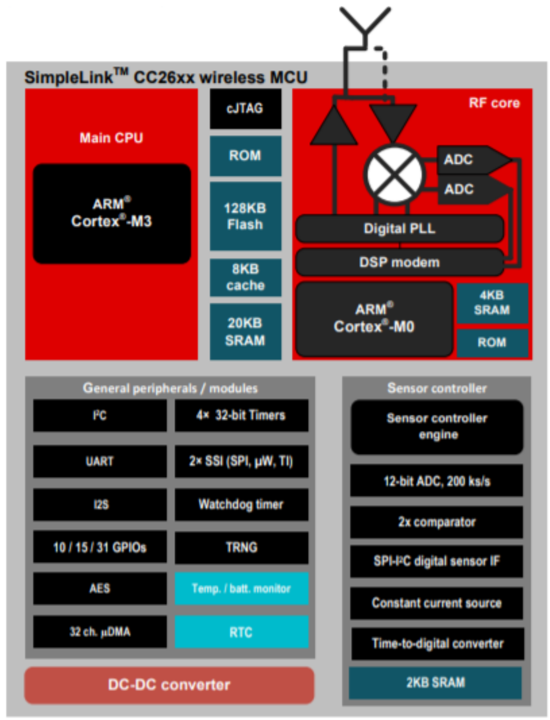
- **μC:** It is the "heart" of our device. Alongside the μC a significant number of bypass capacitors together with 2 external quartzes have been placed
- **2.4GHz antenna:** A patch antenna has been placed to permit Bluetooth communication. Beeing a critical signal, the connection starts from the antenna feed and goes to the μC through a direct straight line
- **KY-032 Obstacle avoidance sensor:** Its implementation is basically done through an IR emitter and an IR receiver. Two potentiometers are part of the sensor alongside with a timer module. The whole sensor can be bought as a COTS module, but we decided to reproduce it directly on the board in order to decrease the costs and to ensure mechanical stability
- **LiPo rechargable battery:** It is the power source of the whole circuit, connected to it through a battery connector
- **JTAG connector:** It is the connection of the circuit to the external world, used to program and teswt the μC
- **USB connector:** The Type-A USB connector is used to recharge the LiPo battery
- **Charge circuit:** It is used to adapt the voltage from the USB connector to the LiPo battery
- **LEDs:** In green and red, are both used to notify the correct functionality of the circuit. The red one notifies the presence of an obstacle, while the green ones notify both the battery's state of charge and the powering ON of the circuit
- **ON/OFF switch:** It is used to power ON and OFF the circuit

7 Electronic Components

SchivaTO module is divided into three main sections:

- Microcontroller
- Power Management
- Peripherals

7.1 Micro-controller



CC2640RSM block diagram

The microcontroller is a 32-bit ARM Cortex M3 CC2640RSM running at 48 MHz. It is a widespread microcontroller used in embedded domain and it is provided with plenty of peripherals as well as an RF front-end for low active bluetooth applications. The choice of this microcontroller among others is mainly due to its power requirements which in turn are very low.
In order to make the microcontroller work properly, it also needs two crystal oscillators as well as several bypass capacitors to cope with the spikes of current during operation. Being a standard, we decided to use EIA size 0603 for the package dimension of all our generic components (resistors, capacitors and inductors). Taking into account both the ease of soldering and the opportunity to route a small track between the pads, this choice seemed the best compared to smaller packages.
Furthermore, the microcontroller provides 10 General Purpose Input/Output (GPIO) pins half of which are for digital signals whereas the others are for analog ones. To program and tesst it, we connected the micorcontreller to the external world by mean of a JTAG inteface.

- **CC2640RSM:** Micro-controller
- **IQXC-26:** 48MHz quartz oscillator with 4 pads
- **IQXC-90:** 32KHz quartz oscillator with 2 pads

7.2 Power Management

The power management section is in charge of providing power to the microcontroller and peripheral sections. It can be further divided into two subsections which are one dedicated to battery charging and one for the linear voltage regulator.
The circuit is in fact powered by a LiPo battery which can in turn be charged by mean of an external USB type-A connector coupled to a MAX1555 integrated device.
Therefore, a Single Pole Double Throw (SPDT) switch have been introduced to let the user switch ON or OFF the circuit from the power supply.
On top of that, a low dropout regulator is preferred with respect to a switching regulator in order to have a simpler integrated device and at the same time avoid introducing noise from the switching process.
Finally, two LEDs have been introduced, as already said, to notify the state of the circuit to the user. In order to decrease the power consumption and subsequently increase the battery life, the chosen LEDs are driven by a very low current ($\sim 2mA$).

- **A1HSW6:** Type-A USB connector
- **AA3021LZGSK:** Charge LED, Power LED
- **MAX 1555:** Li+ battery charger
- **JST-XH2P-ST:** Battery connector
- **SPDT SS3-H:** ON/OFF switch
- **TLV70212DBVR:** Low-dropout (LDO) linear regulator

7.3 Peripherals

The most important peripherals in schivaTO board are certainly the patch antenna, which has a characteristic impedance of 50Ω, and the obstacle avoidance sensor. The latter is built using an IR-receiver with 45° angle directivity whose output pin can be directly tied to the microprocessor, an IR-transmitter and two potentiometers.
Furthermore, a timer is needed to regulate the pulsing frequency (which should always be kept around 38 kHz) of the infrared transmitter LED.
Finally, the already mentioned JTAG interface is used both to program the micro-controller and receive/send information from/to the outside.

- **FTSH-105-01-L-D:** JTAG connector
- **NE555DR:** Precision timing circuit capable of producing accurate time delays
- **AA3528LSECKT:** Sensing LED
- **3362H-1-103:** Frequency potentiometer
- **3362H-1-502:** Intensity potentiometer. By regulating it, it is possbile to change the sensing distance from 2cm to 40cm.
- **IR333A:** Infrared LED
- **HS0038B3VM:** Miniaturized infrared receiver

8 Datasheets

In this section, the links to the datasheet of the selected components are given as reference.

8.1 Micro-controller

The components present in the microcontroller sheet are:

- IQXC-90
- IQXC-26
- CC264RSM
- BLM18HE152SN1

8.2 Power Management

The components present in the power management sheet are:

- USB A1HSW6
- AA3021LZGSK
- MAXIM1555
- SS3-H
- TLV70212DBVR
- LiPo LP-402025-IS-3

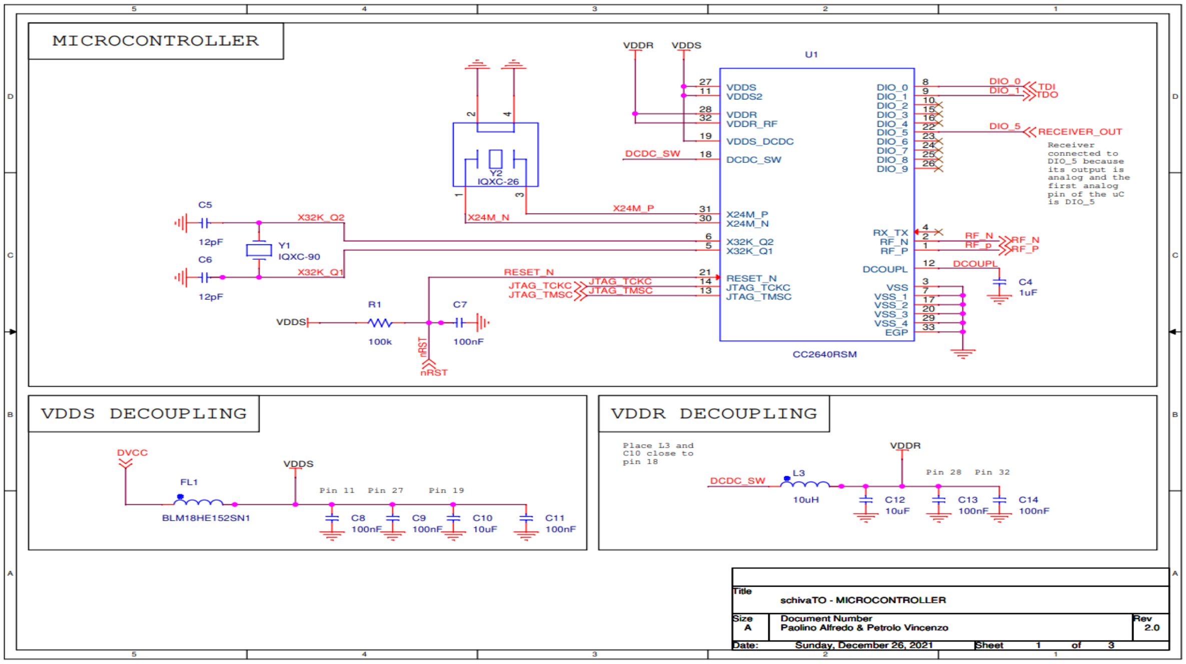
8.3 Peripherals

The components present in the peripherals sheet are:

- AA3528LSECKT/J3
- HS0038B3VM
- 3362H-1-502
- IR333-A
- NE555DR
- 3362H-1-103
- FTSH-105-01-L-D
- Patch Antenna specifications

9 Schematic

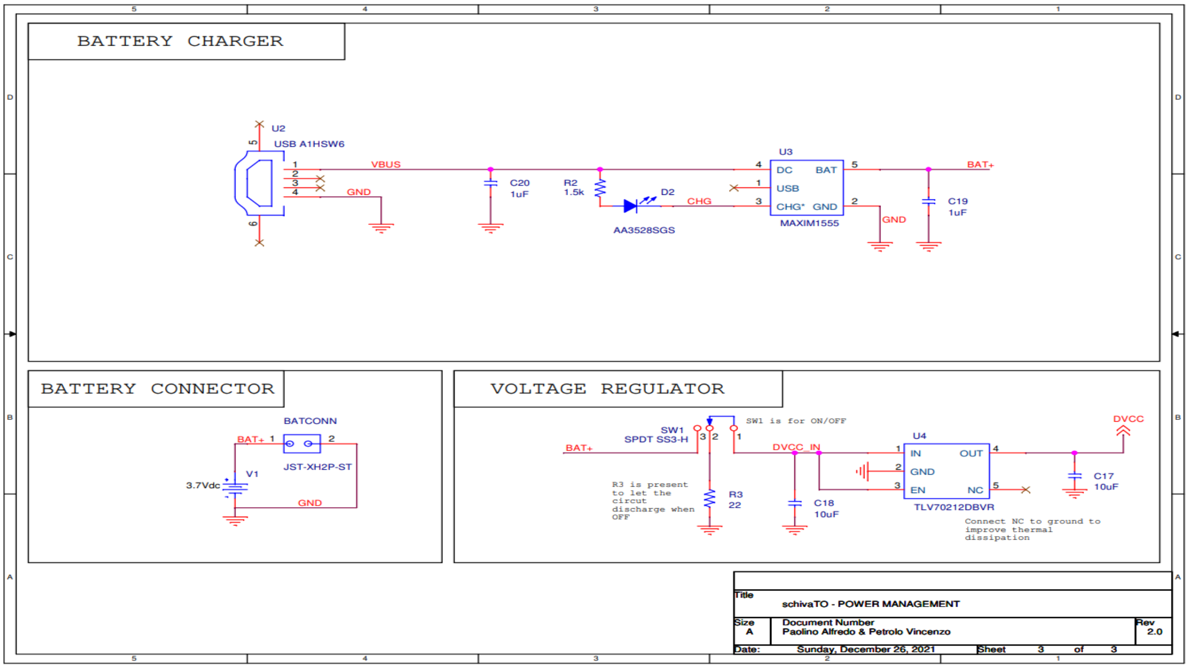
9.1 Micro-controller



Micro-controller schematic

The microcontroller related sheet describes how the CC2640 is tied in order to be properly working. As the need for more current arise, a number of bypass capacitors have been introduced to tackle this problem during operation.
Furthermore, the crystal oscillator Y2 is not tied to any capacitor since they are already mounted inside the integrated circuit of the microcontroller.
Although many GPIO pins are free, the first analog pin (DIO 5) was tied to the IR receiver output whereas the first two digital pins (DIO 0 and DIO 1) are used for JTAG communication during programming phase and for I2C communication during operational phase.
Thanks to this two pins schivaTO can be plugged into a larger system which supports I2C protocol i.e. a parking system for a car using several replicas of schivaTO all connected as slaves to the central system.
It is worth noticing that the values for bypass capacitors have been chosen accordingly to what is stated in the CC2640 datasheet. Furthermore, VDDR voltage is provided by the internal regulator present on the IC.
Eventually, microcontroller's unconnected pins can be used to accomodate possible future functionalities that will be added to schivaTO.

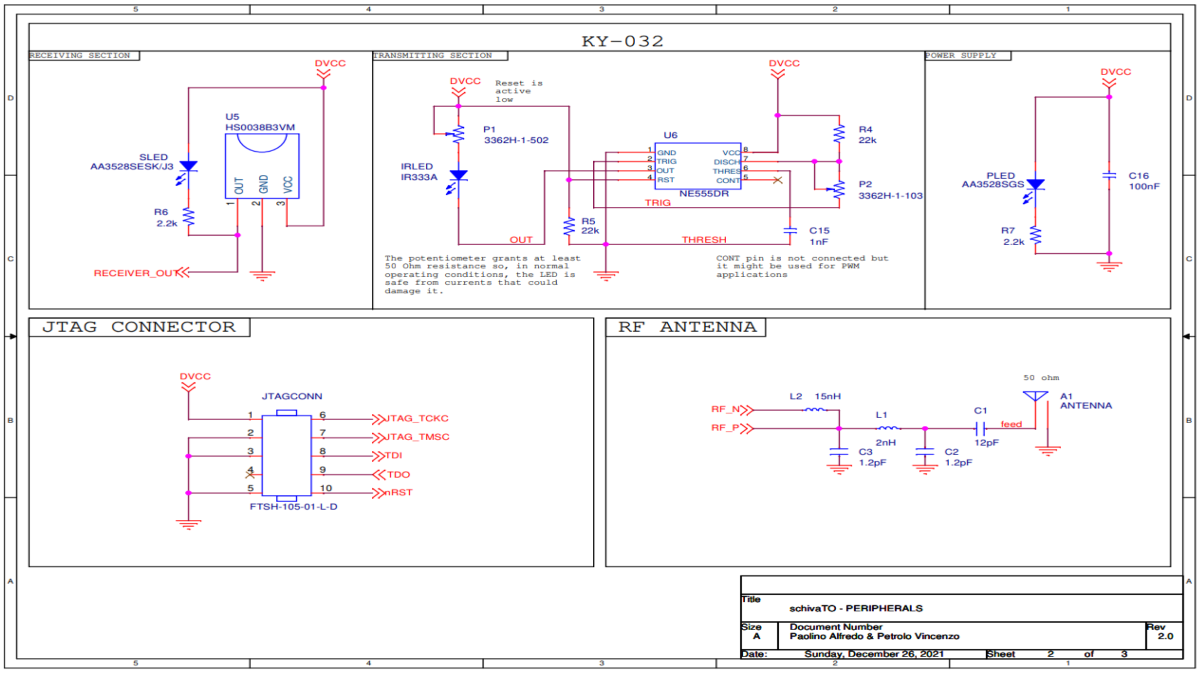
9.2 Power Management



Power management schematic

The sheet for power management shows how the charging circuit works and how the power is transformed before being provided to the circuit. The USB type-A has been chosen as it is commonly widespread. The data lines of the USB connector are left unconnected, while the power lines are fed into the MAX1555 which is in charge to provide power to the LiPo battery.
Thanks to an ON/OFF switch we can also give or remove power to schivaTO at will. In order to ensure a good behaviour of the circuit, a resistor has been placed in the middle of the ground line; in this way the circuit can fully discharge when switched OFF.
The TLV linear regulator is in charge of providing constant voltage to the circuit with low-dropout voltage. Pin 4 could be connected to ground to improve thermal dissipation but, dealing with very low voltages and currents, leaving it unconnected will not cause any problem.
There is another thing which is worth noticing: a resistor has been placed before the power LED to protect it from currents that would burn it.

9.3 Peripherals



Peripherals schematic

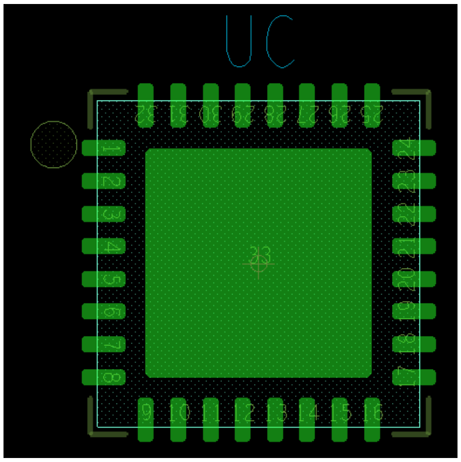
In the peripheral sheet the obstacle sensor can be observed. It is worth noticing that the KY-032 is directly built on the PCB and not used as an external sensor.
In the receiver section of the sensor it is present a LED which is in charge of signaling the presence of an obstacle; this LED is merely useful for debugging the hardware. The sensor is supplied by DC voltage coming out from the linear regulator and a small amount of it is consumed by a small LED in charge of signaling if the sensor is working.
The IR transmitter section is dominated by the NE555 timer, which is used in astable operation, while the two potentiometers P1 and P2 are used to adjust the sensing distance and the pulsing frequnce respectively.
Thanks to the datasheet of the NE555 some useful formulas can be found, especially the one used to compute the frequency and place it around 38 kHz.

$$f = \frac{1.44}{(R_4 + 2 \times P_2) \times C_{15}}$$

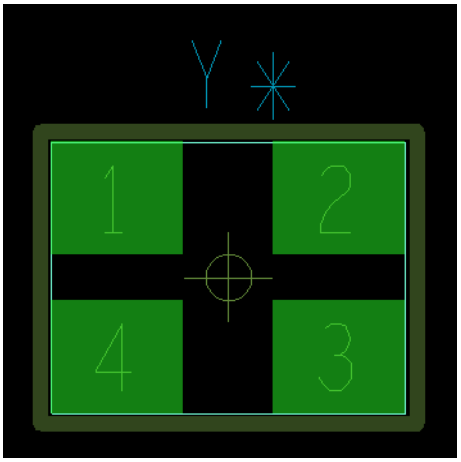
this equation can be easily solved in P_2 by superimposing $f = 38$ kHz and the result is that $P_2 = 7950\Omega$.
About the antenna and the JTAG connector we have already spent enough words in previous sections.

10 Footprints

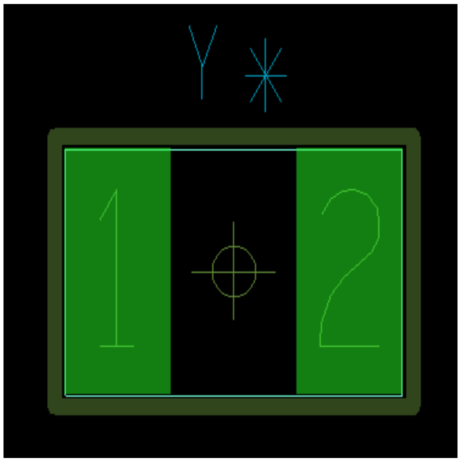
10.1 Micro-controller



CC2640

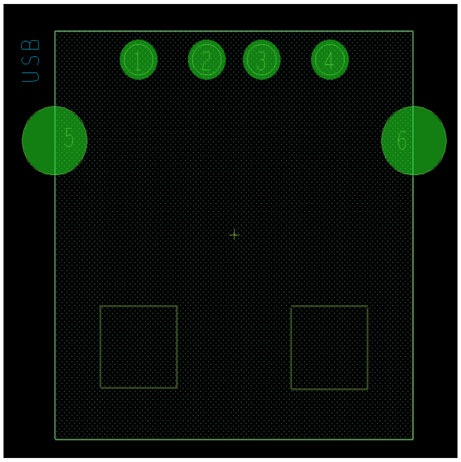


IQXC-26

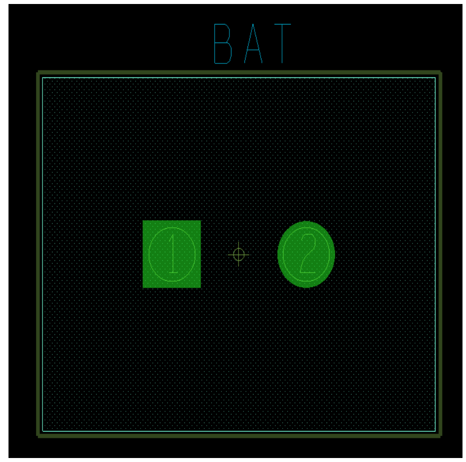


IQXC-90

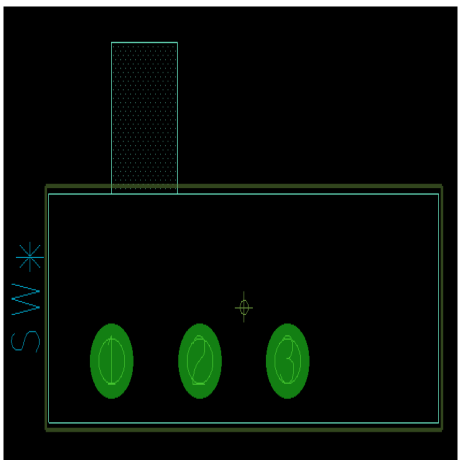
10.2 Power Management



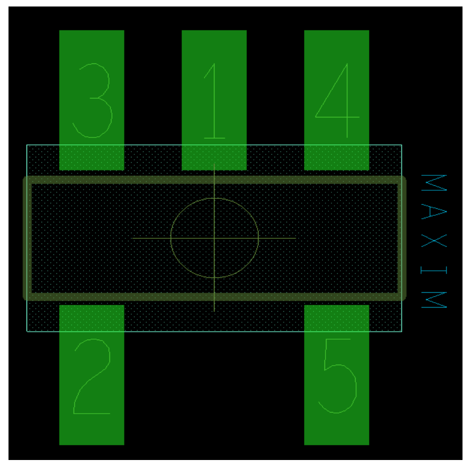
A1HSW6



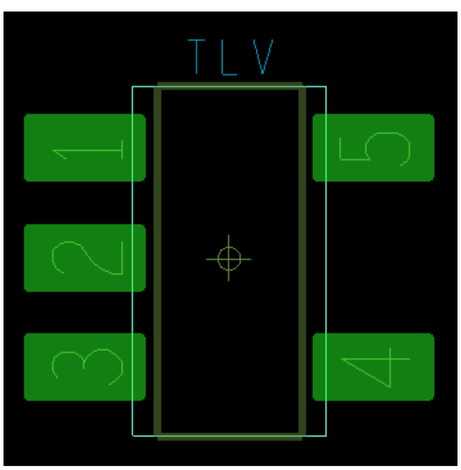
JST-XH2P-ST



SPDT SS3-H

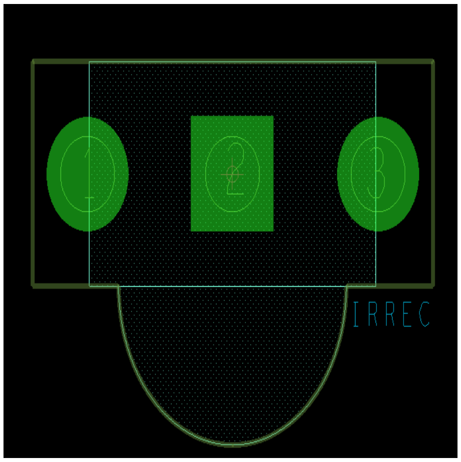


MAX1555

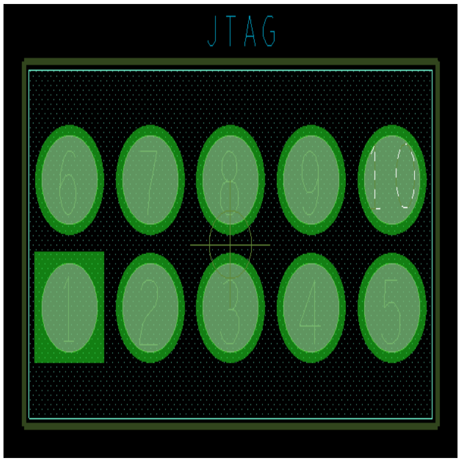


TLV70212DBVR

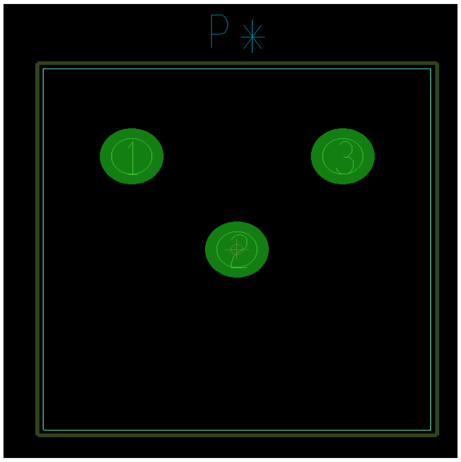
10.3 Peripherals



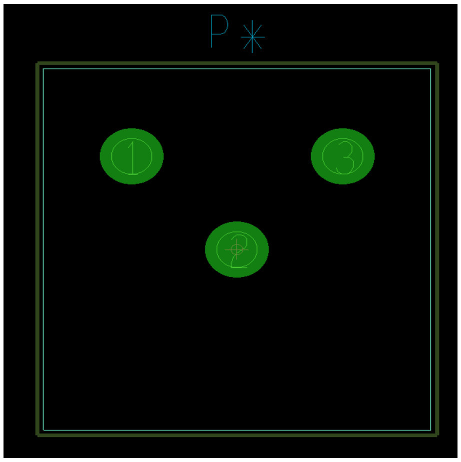
HS0038B3VM



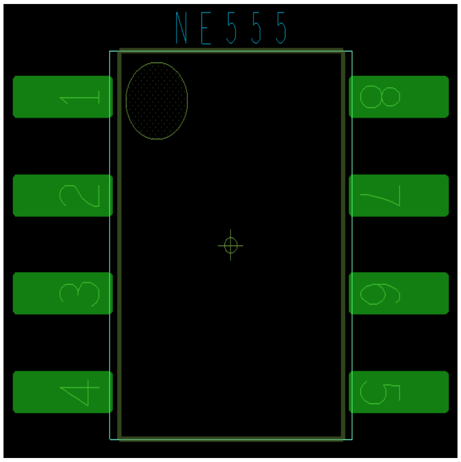
FTSH-105-01-L-D



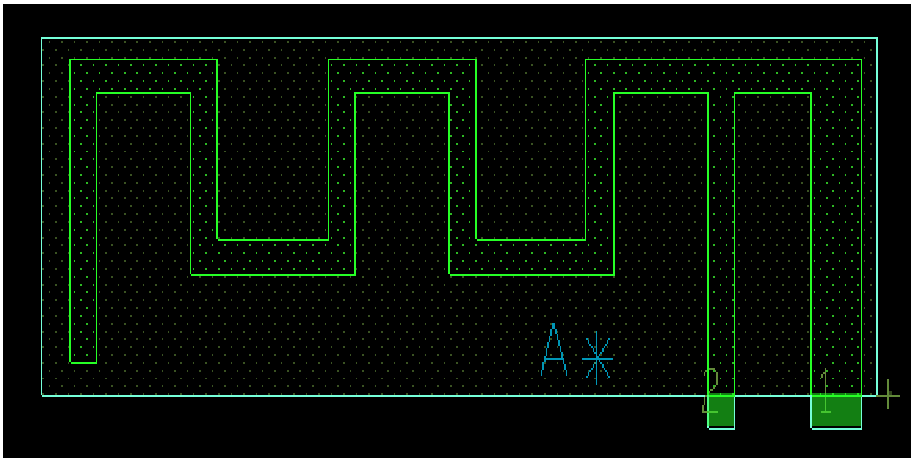
3362H-1-502



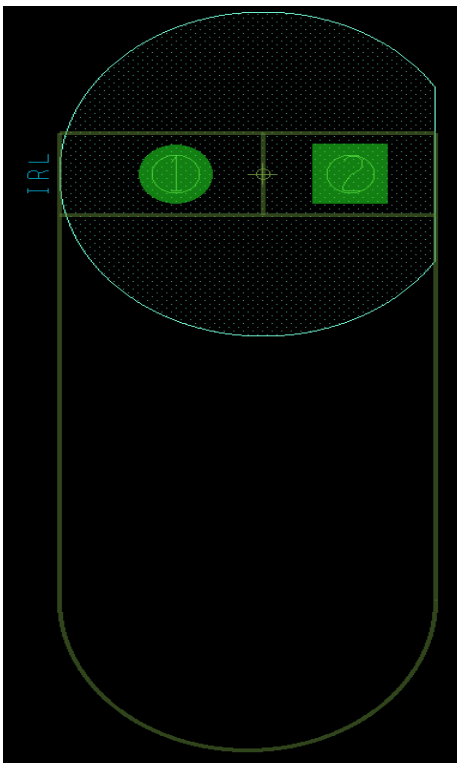
3362H-1-103



NE555DR

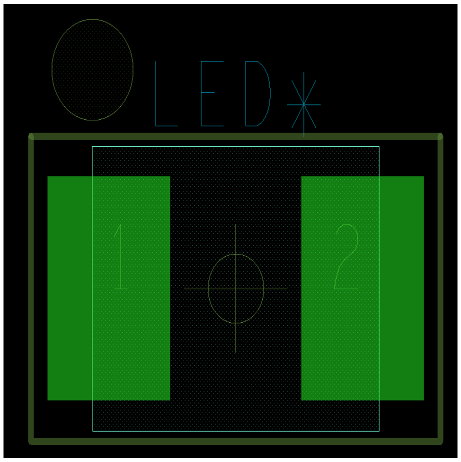


Antenna

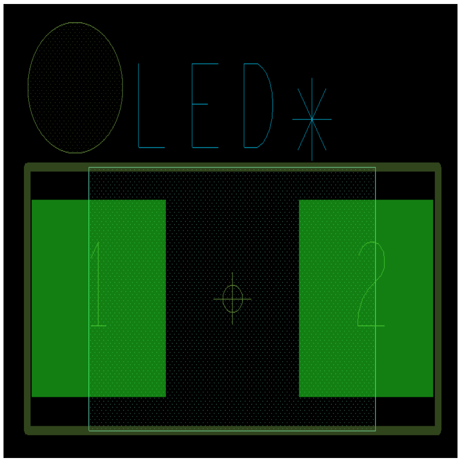


IR333A

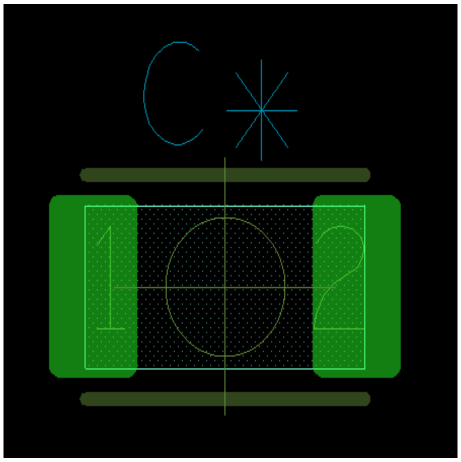
10.4 Generic Components



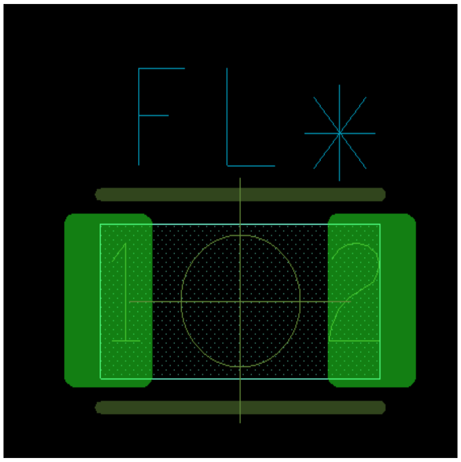
AA3528LSECKT



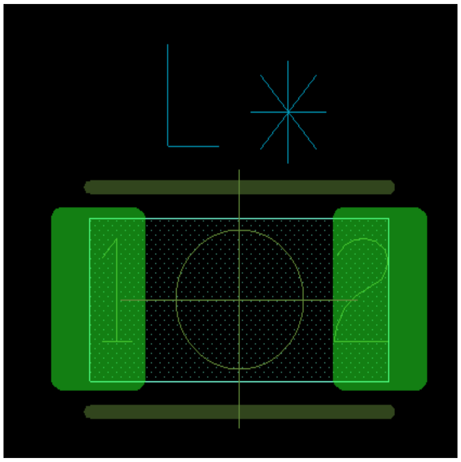
AA3021LZGSK



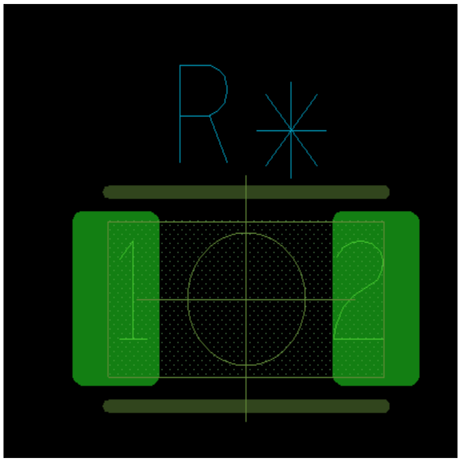
Capacitors



Ferrite

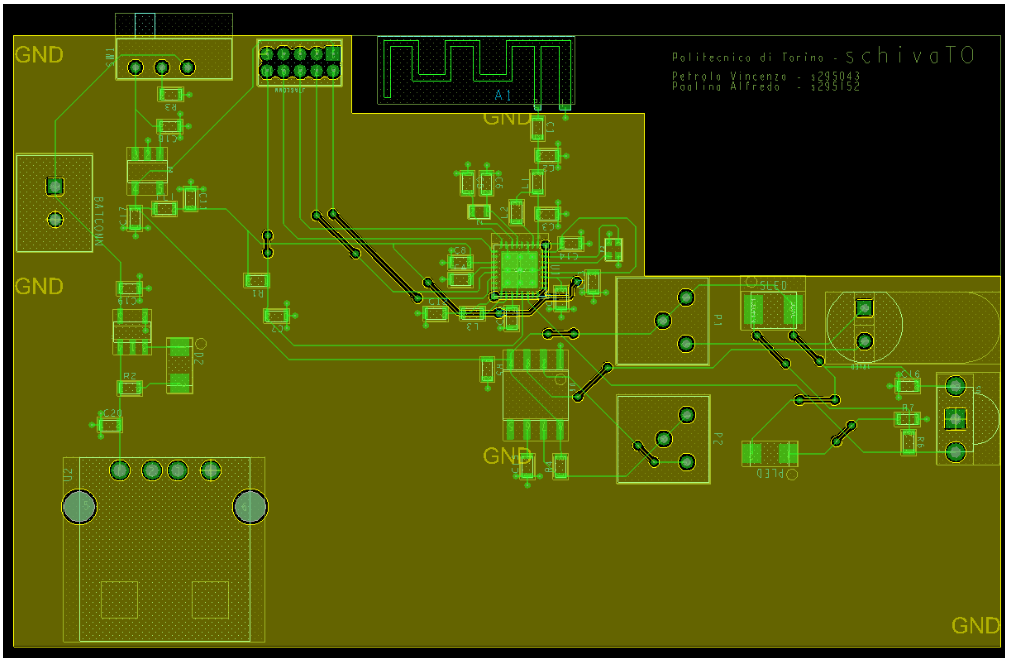


Inductances



Resistances

11 PCB Layout

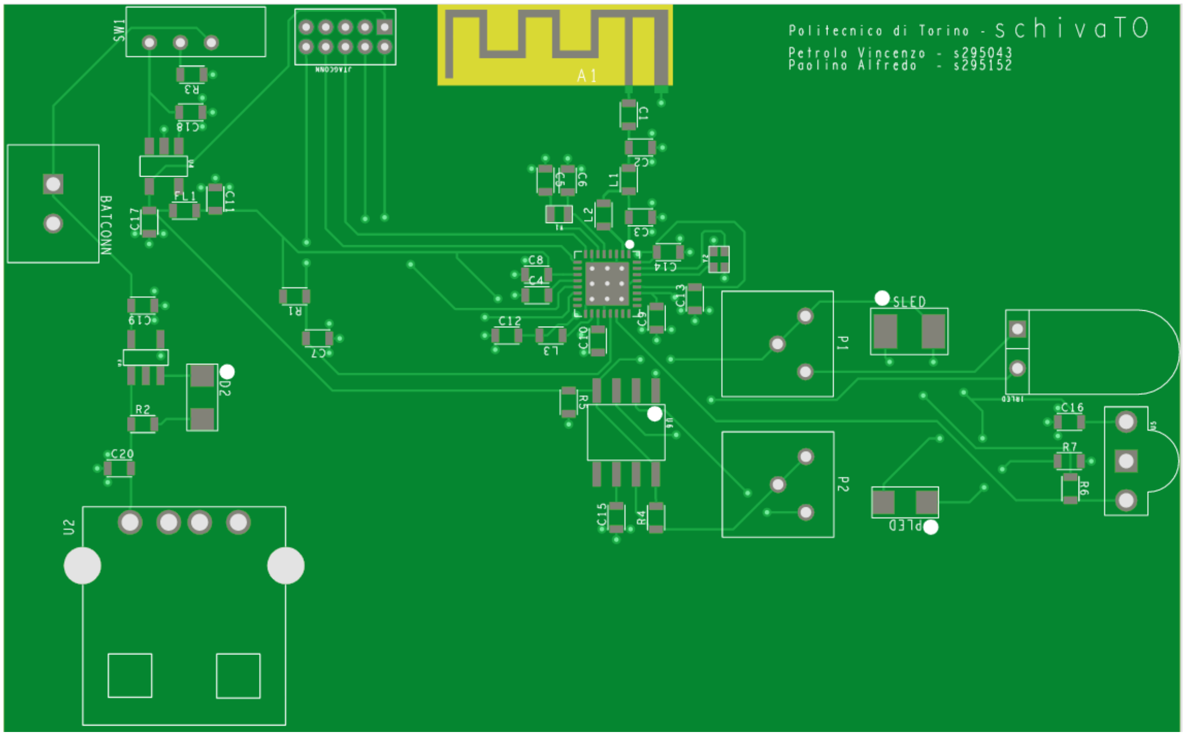


Cadence Allegro view of the board

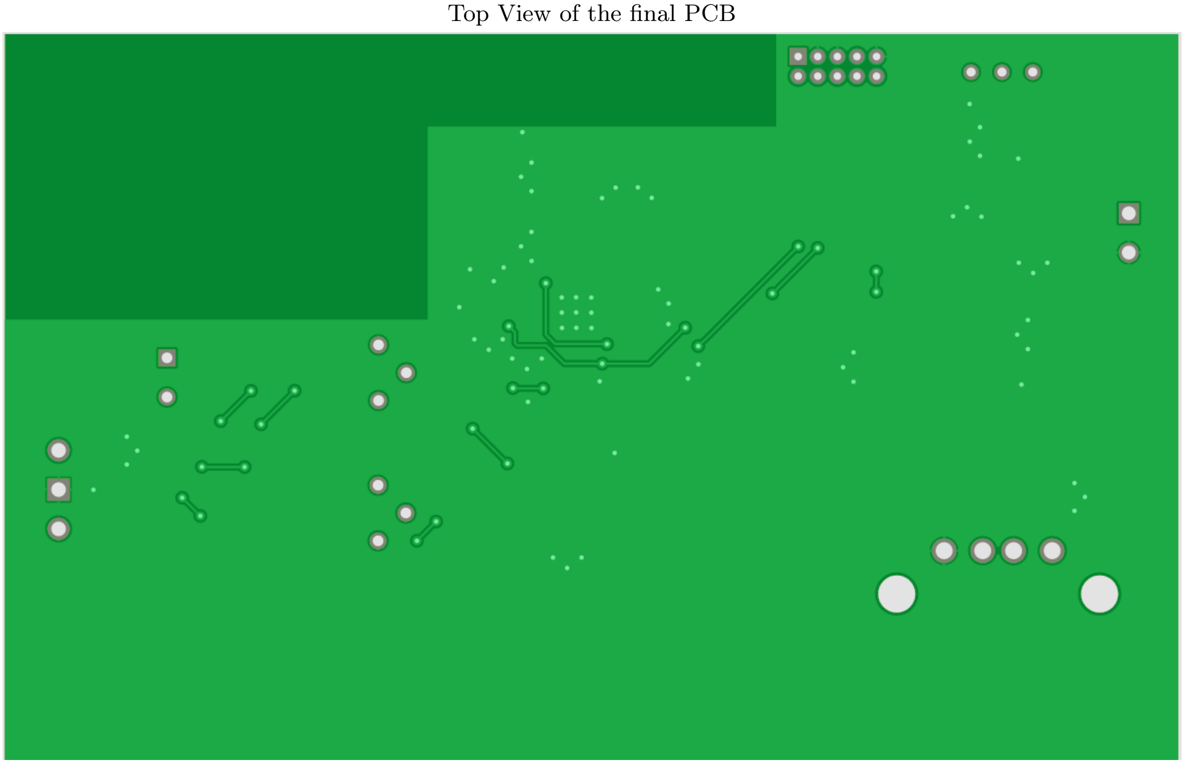
After the creation of the footprints, the design of the final PCB was performed. Since the antenna feed line is of paramount importance, the design begins by placing the antenna and then the microcontroller in order to route a straight trace between the two. Thereafter, the components forming the obstacle avoidance sensor are placed in order to respect what was described in the block diagram above. Afterwards, all the bypass capacitors are placed as suggested in the datasheet of the microcontroller. After that, the components involved in the power management and supply for schivaTO are layed down and placed to facilitate the routing process. Lastly, the bulkier mechanical components are placed in such a way that it is easy to access and use them. Once all the components have been placed, the ground plane is created in order not to shield (the GND plane is the yellow layer in the picture). After the placing of the GND plane, Allegro automatically connects to ground all the through hole padstacks which needed a connection to it. Hereafter, the routing stage begins and, as mentioned above, the antenna is the first component to be connected to the microcontroller through a straight trace etched on the top layer of the board. The routing process is carried out following some rules, in particular:

- Avoid creating long vertical cut on the ground plane. Thanks to this, the flow of the current which, in our case, happens to be from left to right is not interfered.
- Avoid creating right angles during the route of a trace, the maximum imposed was 45°.
- Add as many VIAs to ground in bypass capacitors where possible.

It is worth noticing that all the high frequency lines should follow a straight path in order to ensure a reliable transmission, but this is not the case for the JTAG connector because it is used only once when programming the board and thus is not critical. Furthermore, the trace width (0.1530 mm) was chosen in order to cope with the requirements from PCBway manufacturer standards and to keep the price low. On top of that, all the VIAs connection are tented, thanks to this we can rely on a thin layer of soldermask that protects the plated hole from external agents which could damage the connections. Eventually, the gerbers for each layer of the board are carefully divided into each section to provide a way of visual inspecting the board for errors. Once the layers are set up, the artwork is exported alongside with drill and route files. The .zip file is loaded into a DFMnow program to check if everything is correct. The last action to perform is to load the gerbers packed in a .zip file to eurocircuits website in order to receive a full analysis of the board. Once uploaded the gerbers on eurocircuits, it is performed the analysis to detect the technology needed to manifacture the circuit which in our case turns out to be 6C as we needed in order to keep prices low. In the picture are presented the previews (both top and bottom) for our final PCB.



Top View of the final PCB



Bottom View of the final PCB

Eurocircuits previews

12 Power Consumption

The power consumption is esteemed by taking the sum of all the major components present on the board.

Component	Power Consumption
NE555DR	740 mW
3362H-1-502	500 mW
3362H-1-103	500 mW
IR-led	150 mW
HS0038B3VM	18 mW
MAXIM1555	727 mW
AA3021LZGSK	102 mW
AA3528LSECKT/J3	140 mW
CC2640	10 mW
Total	2.9W

The capacity provided by the LiPo battery is 150 mAh. Therefore, to calculate how long the battery lasts we use the formula:

$$Batterylife = \frac{BatteryCapacity}{Loadcurrent}$$

where the load current is computed by taking:

$$I_L = \frac{Power}{V_L}$$

As a result, the battery life is esteemed to last around 7 days without recharging.

13 Bill of Materials and Cost Estimate

Considering a 1000 units production batch, the complete bill of materials is:

Item	Quantity	Reference	Part/Value	Unitary cost
1	1	A1	ANTENNA	0.00€
2	1	BATCONN	JST-XH2P-ST	0.15€
3	3	C1,C5,C6	12pF	0.80€
4	2	C2,C3	1.2pF	0.20€
5	3	C4,C19,C20	1uF	0.05€
6	7	C7,C8,C9,C11,C13,C14,C16	100nF	0.10€
7	4	C10,C12,C17,C18	10uF	0.15€
8	1	C15	1nF	0.15€
9	2	D2,PLED	AA3021LZGSK	0.15€
10	1	L1	BLM18HE152SN1	0.05€
11	1	IRLED	IR333A	0.10€
12	1	JTAGCONN	FTSH-105-01-L-D	1.15€
13	1	L1	2nH	0.05€
14	1	L2	15nH	0.05€
15	1	L3	10uH	0.05€
16	1	P1	3362H-1-502	1.15€
17	1	P2	3362H-1-103	1.15€
18	1	R1	100k	0.05€
19	1	R2	1.5k	0.05€
20	1	R3	22	0.05€
21	2	R4,R5	22k	0.05€
22	2	R6,R7	2.2k	0.05€
23	1	SLED	AA3528LSECKT/J3	0.15€
24	2	SW1,SW2	SPDT SS3-H	0.70€
25	1	U1	CC2640RSM	2.40€
26	1	U2 USB	A1HSW6	0.25€
27	1	U3	MAXIM1555	1.10€
28	1	U4	TLV70212DBVR	0.20€
29	1	U5	HS0038B3VM	0.40€
30	1	U6	NE555DR	0.10€
31	1	Y1	IQXC-90	1.00€
32	1	Y2	IQXC-26	0.45€

Others	Unitary cost
LiPo battery LP-402025-IS-3	9.00€
PCB	1.55€
Shppings	Negligible
Manufacturing	Negligible

Taking into account the costs of components, PCB, manufacturing process and shipping, we get a total of:

Total	27€/unit

13.1 Market Analysis

After an accurate research, we can assert that our device can compete with all other devices found on the market. To give an example, we report here some products with similar characteristics and their respective prices.

Tfmini LiDAR Module Obstacle Avoider : 47€

ZLL SG906 Laser Obstacle Avoider : 37€