Bluetooth Controlled Mobile Robot

Requirement and implementation specification and test plan

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1. Introduction

1.1. Purpose

The purpose of this documentation is to provide the specification of the device; what are the required features, how they are implemented, and how the functionality is tested.

The requirement specification defines the required functionality of the device, and all the preliminary information and calculations of required functional ranges.

The technical specification lists the parts chosen for the implementation of the device.

The test plan defines the plan how the functionality of the device can be verified.

1.2. Scope

Requirement specification covers the physical, functional and electrical requirements for the device.

Technical specification covers the choice of components and the reasoning behind the choices made.

Test plan covers the unit tests used for verifying the functionality of individual components.

1.3. Division of labor

There is no preliminary plan on division of labor, both students participate equally in every phase of the project.

1.4. Acronyms and Abbreviations

IMU - Inertial Measurement Unit

DOF – Degrees of Freedom

LED – Light Emitting Diode

UI – User Interface

MCU – Microcontroller Unit

CPT – Counts per Turn

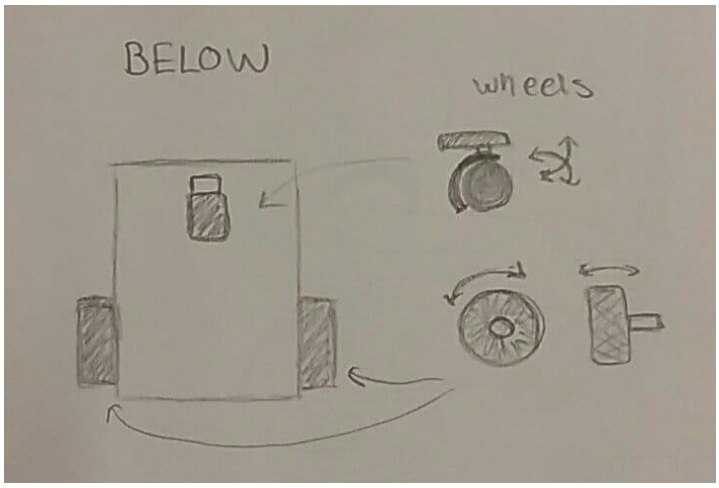
GND – Ground line

VCC – Operating voltage

1.5. General idea

The purpose of this project is to create a Bluetooth controlled mobile robot, which has sensors for detecting obstacles ahead of it and informs the user with a buzzer when it's getting too close to an obstacle.

The robot has two wheels it uses to move. The movement is controlled via Bluetooth, and IMU's and rotary encoders are utilized in the movement control. If the sensors on robot detect an obstacle ahead of it, a buzzer outputs a warning sound.



Picture 1. Illustration of the robot's wheels

The robot will also have LED: s for functionality verification, I.e., a LED that is on when the Bluetooth connection is alive.

2. Requirement specification

2.1. Functional requirements

2.1.1. General requirements

The general requirements are related to the components of the device.

Req-2.1.1	The device must have two controllable wheels (Wheel R, Wheel L) and one balancing wheel (Wheel B).
Req-2.1.2	The device must have two motors (Motor R, Motor L).
Req-2.1.3	The device must have an obstacle sensor (Sensor F)
Req-2.1.4	The device must have a buzzer for noise making (The Buzzer).
Req-2.1.5	The device must have an ON/OFF button/switch (Button P).
Req-2.1.6	The device must have a reset button (Button R).
Req-2.1.7	The device must detect 3-dimensional acceleration (resolution 0.1 G min).
Req-2.1.8	The device must detect 3-dimensional orientation (resolution 1 degree min).
Req-2.1.9	The device must be able to produce at least one kind of sound. (2.4kHz, single tone, Indicator)
Req-2.1.10	The device must have at least two LEDs (LED BT, LED P).
Req-2.1.11	The device must have two rotary encoders for measuring distance traveled.
Req-2.1.12	The device must have a H-bridge capable of controlling two motors (for allowing the motors to run backwards or forwards).
Req-2.1.13	The device must have a Bluetooth connectivity. Device must have at least 10 m range for the Bluetooth connectivity. 2.4 GHz is the bandwidth.
Req-2.1.14	LED BT must show activity of Bluetooth by turning it on when data is sent or received.
Req-2.1.15	The device must have a microcontroller unit.
Req-2.1.16	LED P must follow the power status and be on when the device is running.
Req-2.1.17	The buzzer must play a sound when there is something too close (15 cm) in the direction the robot is currently moving.
Req-2.1.18	The device must be functional for indoor usage.

2.1.2. Control requirements

This section specifies the requirements for the control of the device.

Req-2.2.1	A simple UI must be implemented for controlling the device.
Req-2.2.2	The device must be able to control the direction of the wheel movement (back/forth).
Req-2.2.3	The device recognizes “FORWARD”, “BACKWARD”, “LEFT” and “RIGHT” commands that are delivered by the Bluetooth serial connection. The device must move to the direction commanded.

Req-2.2.4	The data from sensors must be sent to user when command “DATA” is sent via Bluetooth.

2.1.3. Electrical requirements

Req-2.3.1	Device must use 5 V operating voltage.
Req-2.3.2	The device must use a 9 V battery as a power source.
Req-2.3.3	The operating time must be at least an hour.

2.1.4. Mechanical requirements

Req-2.4.1	The device needs a frame that can fit all the components of the device.
Req-2.4.2	The device must be able to move, so the frame and casing must not interfere with the device’s movement.
Req-2.4.3	The balancing wheel must yaw freely.
Opt-2.4.4	The device should have a casing for better appearance.

2.1.5. Other requirements

Req-2.5.1	The total price of the components used should not exceed the budget of 100€.

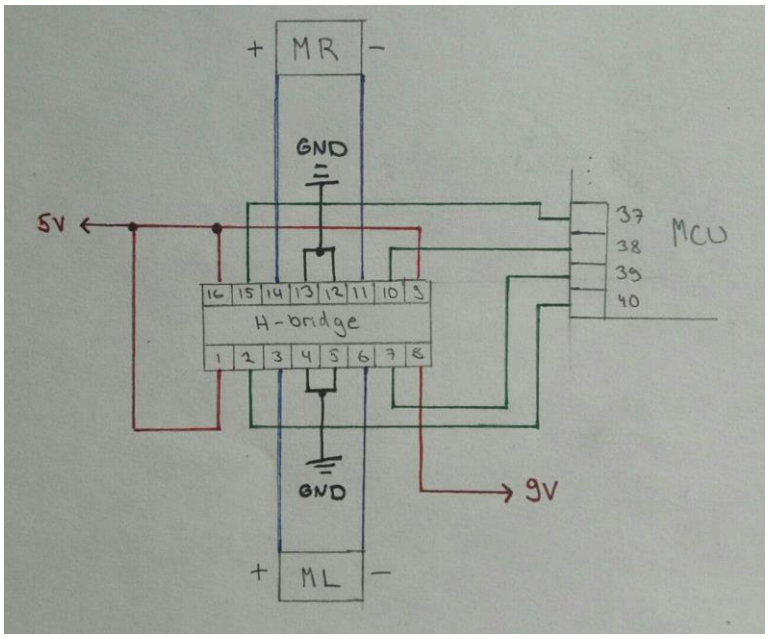
3. Technical specification

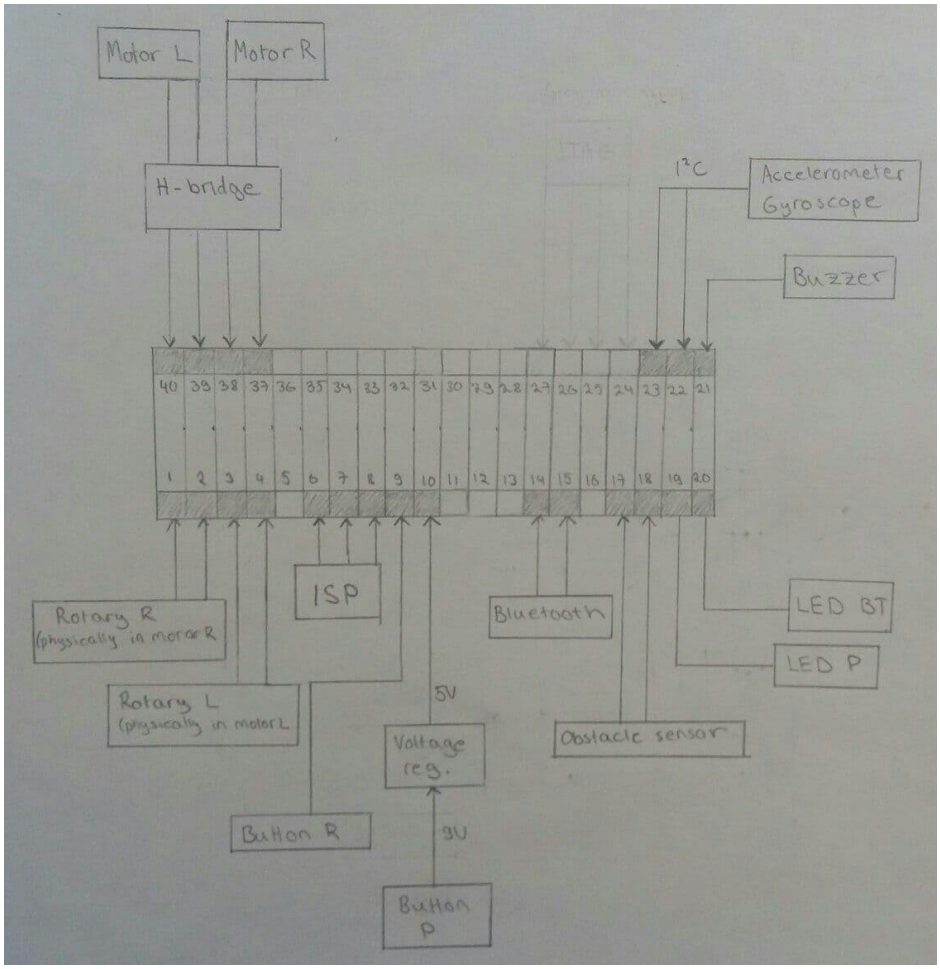
3.1. Hardware

3.1.1. Assumptions

A breadboard will be utilized in the process of developing the device.

3.1.2. Block Diagrams of the device


+ MR −
GND
5V
37
38
39
40
MCU
16 15 14 13 12 11 10 9
H-bridge
1 2 3 4 5 6 7 8
GND
9V
+ ML −


Motor L
Motor R
H-bridge
I²C
Accelerometer
Gyroscope
Buzzer
40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
ISP
Bluetooth
LED BT
LED P
Rotary R
(physically in motor R
Rotary L
(physically in motor L
5V
Voltage
reg.
Obstacle sensor
Button R
9V
Button
P

3.1.3. MCU

ATMEGA644P-20PU is chosen as the MCU of the device.

https://www.digikey.fi/product-detail/fi/microchip-technology/ATMEGA644P-20PU/ATMEGA644P-20PU-ND/1245866

3.1.4. Bluetooth module

JDY-31 Bluetooth module is chosen as the Bluetooth module. The operating distance is 30 meters, which fulfills Req-2.1.13. It uses the pins 14 and 15 of the MCU, utilizing the USART serial communication channel.

https://www.spelektroniikka.fi/p24050-bluetooth-moduuli-hc05-hc06-slave-yhteensopiva-fi.html

3.1.5. Buzzer (The Buzzer)

Buzzer CMI-1295IC-0585T was chosen for its simplicity, and because it fulfills Req-2.1.9.

https://www.digikey.fi/products/fi?keywords=%20CMI-1295IC-0585T

3.1.6. IMU

6 DOF Sensor-MPU6050 was chosen for the IMU, as it has both the accelerometer and gyroscope in it, and it fulfills both Req-2.1.7 and Req-2.1.8. It uses I^2C interface, and it's thus connected to the pins 22 and 23 of the MCU.

https://www.digikey.fi/product-detail/fi/dfrobot/SEN0142/1738-1070-ND/6588492

3.1.7. ISP interface

PGM-11801 Tiny AVR Programmer is used as the programming interface for the device. It utilizes ISP and is connected to pins 6-11 of MCU.

https://www.digikey.fi/product-detail/fi/sparkfun-electronics/PGM-11801/1568-1079-ND/5230948

3.1.8. Voltage regulator

https://www.digikey.fi/products/fi?keywords=LM7805CT-NOPB

LM7805CT/NOPB voltage regulator is used to produce 5 V operational voltage (Req-2.3.1) from 9V power source (Req-2.3.2). It is connected to pin 10 of the MCU.

As specified in the spec sheets of the voltage regulator, the regulator needs a 0.22µF input capacitor and a 0.1µF output capacitor for stability of the 5V signal.

3.1.8.2 Capacitors

The input capacitator:
https://www.spelektroniikka.fi/p10440-polko-polyesterikondensaattori-220-nf-63v-r-5-mm-fi.html
The output capacitor/noise reducer capacitors for motors:
https://www.spelektroniikka.fi/p10425-polko-polyesterikondensaattori-100-nf-250v-r-75-mm-fi.html

100uF capacitors for voltage dip prevention:
https://www.spelektroniikka.fi/p10911-pystyelko-100-uf-25v-105-c-fi.html

3.1.9. Obstacle sensor (Sensor F)

HC-SR04 Ultrasonic Sonar Distance Sensor is used for detecting obstacles ahead of the device (Req-2.1.3). The detection range is 2 cm – 400 cm. It is connected to pins 17 & 18 of the MCU.

https://www.digikey.fi/product-detail/fi/adafruit-industries-llc/3942/1528-2711-ND/9658069

3.1.10. Motors (Motor R, Motor L) + rotary encoders

Two DG01D---E motors with encoders were chosen for their low price, and because they have the rotary encoders integrated into them (Req-2.1.1 & Req-2.1.11).

https://www.digikey.fi/product-detail/fi/sparkfun-electronics/ROB-16413/1568-ROB-16413-ND/12178435

3.1.11. LEDs (LED BT, LED P)

The LEDs for debugging purposes (Req-2.1.10, Req-2.1.14 & Req-2.1.16).

https://www.spelektroniikka.fi/p1028-punainen-3-mm-led-diffusoitu-1kpl-fi.html

Also 85-ohm resistors are needed for LEDs: (5V-3.3V)/0.02A = 85 ohm

https://www.spelektroniikka.fi/p7145-metallikalvovastus-866-ohm-1-2-04-06w-fi.html

3.1.12. H-bridge

H-bridge for motor control.

https://www.digikey.fi/product-detail/fi/texas-instruments/SN754410NE/296-9911-5-ND/380180

Between motor driver pins and H-bridge pins (3,6,11,14), four 0.1µF capacitors are added for noise reduction. The 9V and 5V inputs of H-bridge also utilize 100µF capacitors for preventing voltage dips. The 5V input pins also utilize the voltage regulator's 0.1µF output capacitor. [1]

3.1.13. Buttons

3.1.13.1. Button P

Power switch for the device. Locks in position. (Req-2.1.5)

https://www.spelektroniikka.fi/p11380-painokytkin-1-x-on-off-lukkiutuva-pk3-vihrea-fi.html

3.1.13.2. Button R

The reset button for the device. Momentary (Req-2.1.6).

https://www.spelektroniikka.fi/p11403-painonappi-painike-ppn2-keltainen-1-x-off-on-mom-fi.html

3.1.14. Wheels

3.1.14.1. Wheels R and L

The wheels for the device were chosen for their cheap price, and universal connectivity.

https://www.digikey.fi/product-detail/fi/adafruit-industries-llc/4205/1528-2964-ND/10187734

3.1.14.2. Wheel B

This wheel is used for balancing the device (Req-2.1.1 & Req-2.4.3).

https://www.digikey.fi/product-detail/fi/adafruit-industries-llc/2942/1528-1557-ND/5823358

3.1.15. Other components

3.1.15.1. Pin headers

Some pin headers for connections on the board. Needed for motors and acceleration sensor.

For motors x 2 and ISP (3 x 2x3 needed)

https://www.spelektroniikka.fi/p17553-piikkirimavastake-2-x-10-rasteri-254-mm-fi.html

For obstacle sensor, Bluetooth module, IMU and 9V connector. (3 x 1x4 + 1x2)

https://www.spelektroniikka.fi/p17551-piikkirimavastake-1-x-20-rasteri-254-mm-fi.html

3.1.15.2. Battery connector

A connector is needed for battery.

https://www.spelektroniikka.fi/p17991-paristoneppari-suora-tavallinen-johdot-n-150-mm-fi.html

3.1.16. Component calculations

Link to BOM:
https://docs.google.com/spreadsheets/d/1CoyD148f1Mdu8gfJ7MREnOP38mR3pTKYltyKeFOfEoA/edit#gid=0

Part	Price (€)	Current (mA)	Voltage (V)	Power (mW)	Delivery time (weeks)
MCU	5,38	1	5	5	6
Bluetooth module	10,00	7,3	5	36,5	-
Buzzer	1,04	30	5	150	5
IMU	8,15	1	5	5	?
ISP	13,41	-	-	-	2
Voltage regulator	1,34	Estimated 200	9 -> 5 (4 drop)	Estimated 800	6
Ultrasonic sensor	3,25	15	5	75	2
2x Motor	9,80	Estimated 500	5	2500	2
2 x Button	2,40	-	-	-	-
2x Wheels (L&R)	3,22	-	-	-	2
Wheel B	1,61	-	-	-	2
2x LED	0,20	50	5 (2)	125	-
H-bridge	2,20			-	6
5x 0.1µF capacitors	1,25	-	-	-	-
1x 0.22µF capacitor	0,25	-	-	-	-
2x 100µF capacitors	0,5	-	-	-	-
Pin headers	1,90	-	-	-	-
Battery connector	0,30	-	-	-	-
2x x ohm Resistor	0,40	-	-	-	-
TOTAL:	66,6		-	Estimated 3696,5	Max 6 weeks

4. Testing plan

4.1. Basic hardware tests without power or ICs.

Test-ID	**Description**	**Result**
Test-1.1	There is no short cuts or bad soldering seen on the board.	
Test-1.2	GND and VCC lines are not short cut.	
Test-1.3	GND is connected to GND pins of IC sockets.	

Test-1.4	VCC is connected to VCC pins of IC sockets.	
Test-1.5	Data pins of Bluetooth module are connected to corresponding data pins of the MCU.	
Test-1.6	Bluetooth data pins are not connected to GND or VCC.	
Test-1.7	The Buzzer is contacted to GND and correct pin of MCU.	
Test-1.8	The data pins of IMU (accelerometer/gyroscope) are connected to the corresponding data pins of the MCU.	
Test-1.9	The data pins of IMU are not connected to GND or VCC.	
Test-1.10	The data pins of ISP are connected to corresponding data pins of the MCU.	
Test-1.11	ISP data pins are not connected to GND or VCC.	
Test-1.12	Voltage regulator is connected to Button P, GND and correct pin of the MCU.	
Test-1.12	Data pins of Sensor F are connected to corresponding data pins of the MCU, GND pin to GND and VCC pin to VCC.	
Test-1.13	The motor poles are connected to the corresponding pins of the H-bridge.	
Test-1.14	The H-bridge is connected to GND, VCC and 9V. The data pins of the H-bridge are connected to corresponding data pins of the MCU.	
Test-1.15	The data pins of rotary encoders are connected to the corresponding pins of the MCU, GND pin to GND and VCC pin to VCC.	
Test-1.16	Button P is connected to the power source and voltage regulator.	
Test-1.17	Button R is connected to GND and reset pin of the MCU.	
Test-1.18	The LEDs are connected to correct pins of the MCU and GND.	

4.2. Bacic hardware tests with power, but without ICs.

Test-ID	**Description**	**Result**
Test-2.1	The voltage between GND and VCC is 5V with a tolerance of 0.2 V.	
Test-2.2	When powering the device is powered up, the current consumption does not exceed 500 mA.	
Test-2.3	Any of the components do not heat up at an alarming rate.	

4.3. Basic hardware tests with ICs connected, but without power.

Test-ID	**Description**	**Result**
Test-3.1	The GND and VCC lines are not short cut.	

4.4. Basic hardware tests with power and ICs.

Test-ID	Description	Result
Test-4.1	When powering the device is powered up, the current consumption does not exceed 500 mA.	
Test-4.2	Any of the components do not heat up at an alarming rate.	

4.5. Unit tests

Test-5.1	**MCU is operational.**
Tools	Device with MCU attached.
Steps	Turn the device's power on.
Acceptable result	
Result	

Test-5.2	**Bluetooth module is operational.**
Tools	Device with MCU and Bluetooth module attached. A computer with Bluetooth connectivity. Terminal application.
Steps	Turn the device on. Wait for Bluetooth connection between the device and the. Send command X to the device via the terminal.
Acceptable result	Device must send back: X
Result	

Test-5.3	**The Buzzer is operational.**
Tools	Device with MCU and buzzer attached.
Steps	Enable The Buzzer test from source code. Flash new software to the device. Switch device power on. After test flash the original software back to the device.
Acceptable result	The buzzer makes a sound.
Result	
Test-5.4	**Acceleration detector is operational.**
Tools	Device with MCU, buzzer and acceleration attached.
Steps	Enable acceleration detector test from source code. Flash new software to the device. Switch device power on. Hold the device in a normal position (upside up), then turn it upside down. Alternate between the two positions. After test flash the original software back to the device.
Acceptable result	When the device is upside up the buzzer is silent, and when the device is upside down, the buzzer makes sound.
Result	
Test-5.5	**Obstacle sensor is operational.**
Tools	Device with MCU, buzzer and obstacle sensor attached.
Steps	Enable obstacle sensor test from source code. Flash new software to the device. Keep the area in front of the sensor free. Switch device power on. Put an obstacle in front of

	the sensor. Remove the obstacle. After test flash the original software back to the device.
Acceptable result	The buzzer makes a sound whenever there is something in front of the sensor.
Result	
Test-5.6	**Motors are operational.**
Tools	Device with MCU and both motors with wheels attached.
Steps	Enable motors test from source code. Flash new software to the device. Switch device power on. Observe motors' movements. After test flash the original software back to the device.
Acceptable result	After 1 second of delay, the right motor will first spin 3 seconds forward, then 3 seconds backward, after 1 second of delay, perform the same routine to left motor.
Result	
Test-5.7	**LEDs are operational.**
Tools	Device with MCU and both LEDs attached.
Steps	Enable LED test from source code. Flash new software to the device. Switch device power on. After test flash the original software back to the device.
Acceptable result	The LEDs blink simultaneously multiple times, then they start blinking one after other for some time, and then they go back to simultaneous blinking and repeats this behavior.
Result	
Test-5.8	**Button R is operational.**
Tools	Device with MCU, button R and LED P attached.
Steps	Enable Button R test from source code. Switch device power on. Press button R when more than 1 second is passed after switching power on (LED P should be on). After test flash the original software back to the device.
Acceptable result	The LED P should turn on after 1 second of Switching the power on. When the button R is pressed the LED P is turned off. After 1 second of the button press, the LED P is turned back on.
Result	
Test-5.9	**Button P is operational.**
Tools	Device with MCU attached. Voltage meter.
Steps	Turn the device off if it is not already. Measure the voltage between pins XX and XX. Push the Button P. Measure the voltage between pins XX and XX.
Acceptable result	The first voltage measurement between pins XX and XX is 0V with tolerance of 0V. The second voltage measurement between pins XX and XX is 5V with tolerance of 0.2V.
Result	

Test-5.10	**Battery is operational.**
Tools	Device with MCU attached. Voltage meter.
Steps	Switch device power on. Measure the voltage from pins XX and XX, and the voltage in pins.
Acceptable result	The voltage measured between the XX and XX pins is 5V (with tolerance of 0.2 V), and the voltage measured from the battery in pins is 8.5 V (with tolerance of 0.5 V).
Result	

Test-5.11	**Wheels are usable.**
Tools	Device with wheels R and L attached to the motors, and B attached to the base.
Steps	Move the robot along flat surface with hand, also move it backwards, and try turning left and right.
Acceptable result	The wheels turn both forward and backward, and the robot will move left or right with ease.
Result	

4.6. System tests

4.6.1. General functionality tests

Test ID	**Requirement**	**Description**	**Result**
Test-7.1.1	Req-2.1.1	Locate Wheel R, Wheel L and Wheel B. The test is passed if all the wheels are found in following places: Wheel R is connected to the right motor's shaft. Wheel L is connected to the left motor's shaft. Wheel B is connected to the front of the base and is centered.	
Test-7.1.2	Req-2.1.2	Locate Motor R and Motor M. The test is passed if the Motor R is found connected to the right of the base and the Motor L is connected to the left of the base.	
Test-7.1.3	Req-2.1.3	Locate the Sensor F. The test is passed if the Sensor F is found at the front of Robot.	
Test-7.1.4	Req-2.1.4	Find The Buzzer. The test is passed if The Buzzer is found.	
Test-7.1.5	Req-2.1.5	Find Button P. The test is passed if the Button P is found.	
Test-7.1.6	Req-2.1.6	Find Button R. The test is passed if the Button R is found.	
Test-7.1.7	Req-2.1.7	While device turned on and Bluetooth is connected to a computer with terminal, move the device. The test is passed if there is 3-dimensional acceleration information seen on the terminal window.	
Test-7.1.8	Req-2.1.8	While the device is turned on and Bluetooth is connected to a computer with terminal, move the device. The test is passed if there is 3-dimensional orientation information seen on the terminal window.	

Test-7.1.9	Req-2.1.9	While the device is turned on, put the device near a wall facing it. The test is passed if the buzzer makes a sound.	
Test-7.1.10	Req-2.1.10	Find LED BT and LED P. The test is passed if both LEDs are found.	
Test-7.1.11	Req-2.1.11	While the device is turned on and Bluetooth is connected to a computer with a terminal open, move the device with rotating its motors with any move command. The test is passed if the encoder information is seen in the terminal.	
Test-7.1.12	Req-2.1.12	Locate the H-bridges. The test is passed if the H-bridges are found.	
Test-7.1.13	Req-2.1.13	Connect the device to a computer with Bluetooth. The test is passed if the device is connected to the computer, and the connection is not lost in a 10m radius from the computer.	
Test-7.1.14	Req-2.1.14	With turned on device connected to a computer with Bluetooth, send and/or receive commands/data to/from the device. The test is passed if LED BT is turned on when data is sent or received via Bluetooth connection.	
Test-7.1.15	Req-2.1.15	Locate the MCU. The test is passed if the MCU is found.	
Test-7.1.16	Req-2.1.16	Turn on the device. The test is passed if LED P is turned on the whole time the device is on.	
Test-7.1.17	Req-2.1.17	While the device is turned on, put the device near (15 cm or closer) a wall facing it. The test is passed if the buzzer makes a sound.	
Test-7.1.18	Req-2.1.18	Do all the tests above while indoors. The test is passed if the device functions indoors and none of the parts malfunction.	

4.6.2. Control functionality tests

Test ID	Requirement	Description	Result
Test-7.2.1	Req-2.2.1	Locate the simple UI from a computer that is connected to the device with Bluetooth. The test is passed if there is a simple UI for controlling the device implemented.	
Test-7.2.2	Req-2.2.2	Send “FORWARD”, “BACKWARD”, “RIGHT” and “LEFT” commands with a terminal from a computer with a Bluetooth connection to the device. The test is passed if the wheels move to the direction specified with the commands given.	
Test-7.2.3	Req-2.2.3	Send “RIGHT”, “LEFT”, “FORWARD” and “BACKWARD” commands with a terminal from a computer with a Bluetooth connection to the device. The test is passed if each command is echoed back to the terminal.	
Test-7.2.4	Req-2.2.4	Send “DATA” command via a terminal in computer that is connected to the device with Bluetooth. The test is passed if the data from sensors is received from the device to the computer.	

4.6.3. Electrical functionality tests

Test ID	Requirement	Description	Result
Test-7.3.1	Req-2.3.1	Measure the operating voltage. The test is passed if the operating voltage is 5V.	
Test-7.3.2	Req-2.3.2	Find a 9V battery as a power source. The test is passed if a 9v battery is found as a power source.	
Test-7.3.3	Req-2.3.3	Operate the device for 1 hour with a full battery. The test is passed if the device has not run out of power after 1 hour.	

4.6.4. Mechanical functionality tests

Test ID	Requirement	Description	Result

Test-7.4.1	Req-2.4.1	Locate and inspect a frame of the device. The test is passed if a frame is found, and it can fit all the components of the device.	
Test-7.4.2	Req-2.4.2	Move the device left, right, back and forth. The test is passed if the frame does not interfere with the movement of the device (Blocking wheels, hitting grounds, etc.).	
Test-7.4.3	Req-2.4.3	Yaw the balancing wheel 360 degrees and then 360 to the other direction. The test is passed if the wheel can yaw the whole way and there are no point or direction where the wheel moves slower or gets stuck.	
Opt-Test-7.4.4	Opt-2.4.4	Find a casing. The test is passed if there is a casing to be found.	

4.6.5. Other tests

Test ID	**Requirement**	**Description**	**Result**
Test-7.5.1	Req-2.5.1	Calculate the price of all the components used in the device. The test is passed if the component price total does not exceed 100€.	

References

[1] https://www.robotshop.com/community/forum/t/capacitors/8898