



ÉCOLE POLYTECHNIQUE  
FÉDÉRALE DE LAUSANNE

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BIOENG 390: Project in Biotechnology and Biosciences

# UNIVERSAL GRIPPER CONTROLLER DESIGN with VISUAL FEEDBACK

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### **Abstract**

This semester project aims to develop two new boards for the modular robot Roombots. These new boards are designed to be fully compatible with the other Roombots in terms of hardware and software. The first board we designed is the Spotlight Board which aims to control a spotlight mounted into the Roombots module to give a visual feedback to user. The second board we designed is Gripper Board which aims to control a universal gripper designed by Simon Hauser, research assistant at BioRob. After designing the boards, we developed their firmware and a simple text based Bluetooth user interface and we also created a simple graphics based Android user interface to ease the testing and the use of our boards.

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# 1. Introduction

## 1.1. Background

Roombots is a modular robots that can be configured in various shapes and can perform various actions. As it can be seen from the **figure 1** Roombots can be used for creating various structures.



*Figure 1* Roombots while creating various structures [1]

There are many electronic boards and mechanical structures in Roombots in order to provide these functions. As Roombots is modular, many other modules can be designed and added to these structures in order to provide new functionalities to Roombots. In this project we aimed to add two new functionalities to Roombots: Universal Gripping and Powerful Lightening.

## 1.2. Aim of the Project

In order to add Universal Gripping and Powerful Lightening functions to Roombots, two new controller boards need to be designed and implemented. The aim of the project is to design these boards which are compatible with the rest of the Roombots environment, in terms of electrical hardware and firmware, so the final product will be able to be placed into a Roombots module.

## 1.3. Coverage of the Project

Our project covers the schematic and PCB layout designs of the boards, firmware development and testing.

### 1.3.1. Spotlight Board

The Spotlight Board consists of 2 different boards, first one is the main board includes all control and communication and second one is the sub board called “Power-LED Board” includes the Power LED, color mixer and mechanical connections.

### 1.3.2. Gripper Board

The design and selection of the electro-mechanical components such as gripper membrane, air valves, air pump of the Universal Gripper are not in the scope of this project. This project only focused on designing the control board for the Universal Gripper and sub-electromechanical components.

## 1.4. Materials Used

### 1.4.1. Hardware

As a template for PCBs, design of the Roombots Communication Board used and then required changes made on it. The shape of the Communication Board is already compatible with the Roombots hemispheres, allowing us to place the new boards into the Roombots. Additionally Communication Board includes less specific components, so it is easier to make changes without affecting functionality.



*Figure 2* The Roombots Communication Board Design (left) and its placement into a Roombots hemisphere (right). There are two more slots available for the same shaped boards in each hemisphere

The main hardware components for both the Gripper Board and the Spotlight Board are the same as the rest of the Roombots environment. Microcontroller (*Microchip*

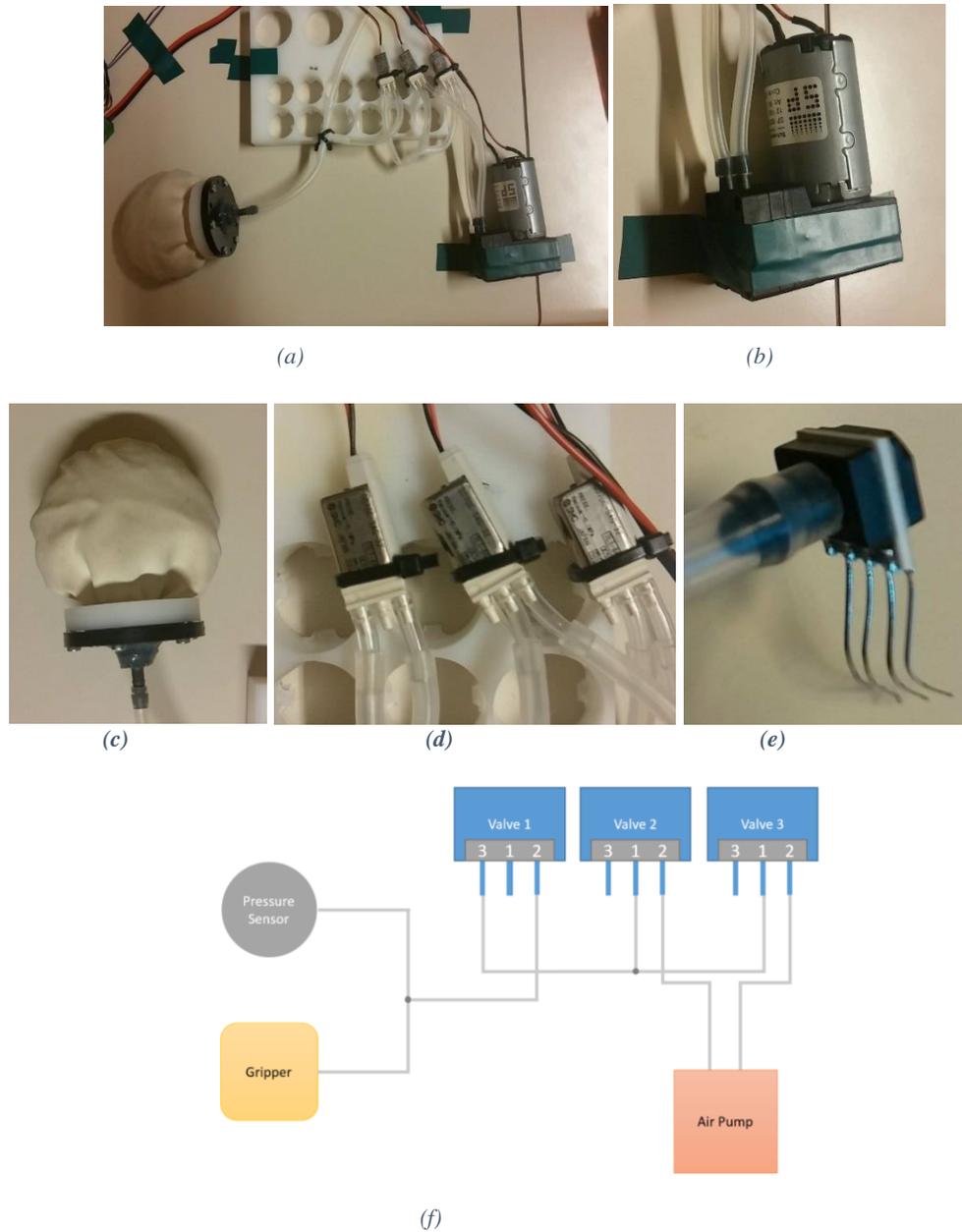
*dsPIC33FJ128MC802-I/MM* [2]), connectors, sub-electronic components and converter ICs are directly taken from the Communication Board.

#### 1.4.1.1. *Spotlight Board*

In order to control a powerful multichannel LED, several solutions can be used but power consumption should be taken into consideration at an early design stage. The brightness (amount of light emission) of LEDs is proportional to the current going through the component. In order to ensure safe and stable operation, constant current LED drivers can be used. There is a great range of ICs that can be found on the market but one of the design requirements is to have a current level from 100 mA to 500mA and also the ease of use, so *TL4242 Constant Current LED Driver* from Texas Instruments is selected to drive LED Spotlight at a constant current. [3] In order to have a good range of color multichannel LED's can be used, a first plan was to use a 3-channel LED but 3-channel LEDs are not efficient to give natural white color so a 4-channel LED is selected. Since it has been planned to use a 4-channel (RGBW) LED, 4 *TL4242*s are used in a single Spotlight Board. As LED *Cree X-Lamp MC-E* is selected, because this model can be found easily in the market and there is a great range of sub-products such as lenses or color mixers compatible with it. [4]

#### 1.4.1.2. *Gripper Board*

The design of the Gripper Board requires more specific components. First of all, a driver is needed to drive the air pump which controls the air coming from or going through to the system. Secondly, the system has three valves in order to control the direction of the air and the state between the gripper and the air pump, so some specific components are also needed to control the valves. In addition to these two mechanical components, a sensor to measure the pressure in the gripper is also needed. For this case sensor has already been chosen, so we just needed to include in the boards design. The universal Gripper and sub-electromechanical components can be seen in the **figure 3**.



**Figure 3** Universal Gripper and Sub-Electromechanical Components, (a) Complete System, (b) Air Pump, (c) Gripper, (d) Valves, (e) Pressure Sensor and (f) Block Diagram of the System with Air Flow Connections.

In order to control the air pump a generic and easy to use motor driver is selected: **L293D 4-Channel Driver**. [5] For controlling the valves P-channels MOSFETs are used since just the on-off switch control is needed. Previously selected pressure sensor is the **SSCSANN015PAAA5 Low Pressure Sensor** from Honeywell. [6]

#### 1.4.2. Software

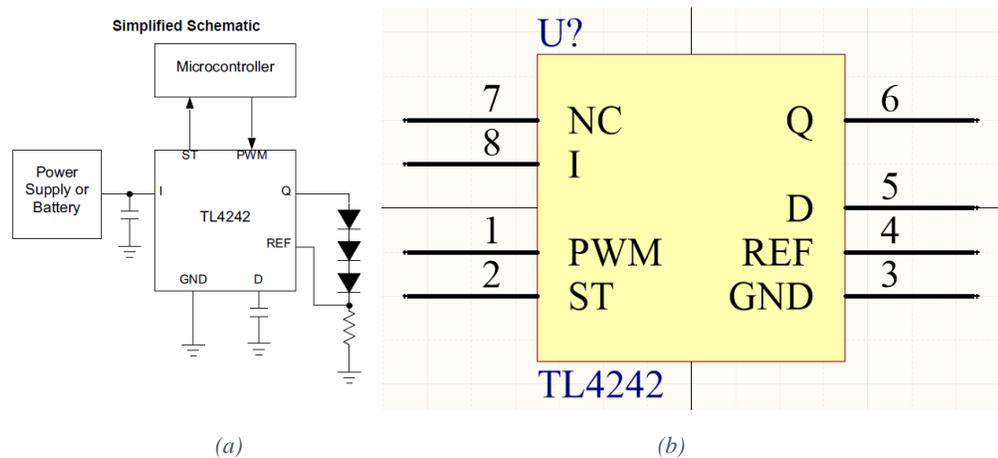
For the PCB design *Altium Designer* is used under EPFL student license. [7] For the firmware development *Microchip MPLAB X IDE* is used. [8] For the communication between computer and modules during testing, a Serial port terminal application called *Termite* is used. [9] For the Android user interface a Google Play Application called *Bluetooth Serial Controller* is used. [10] Except *Altium Designer* which is used under EPFL license, all software and application used in the project are free and can be downloaded and used by anybody with compatible devices and operating systems.

## 2. Spotlight Board

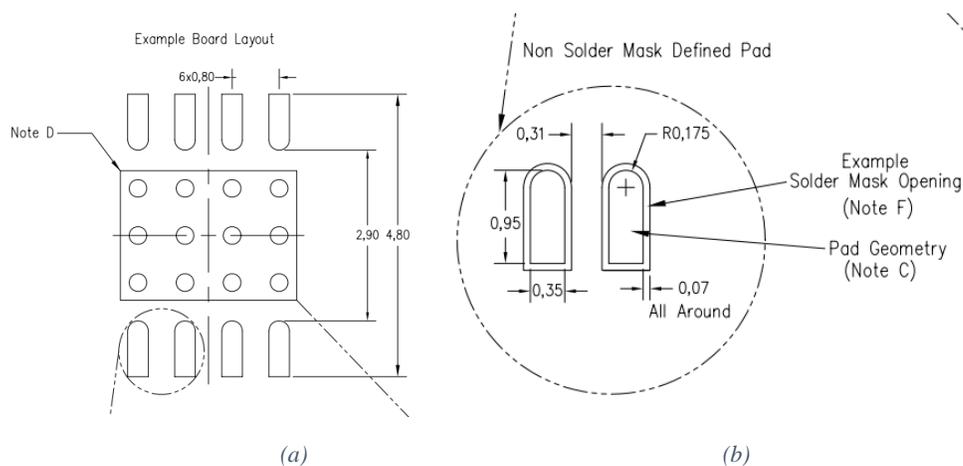
### 2.1. Hardware Design

#### 2.1.1. Board Specific Components

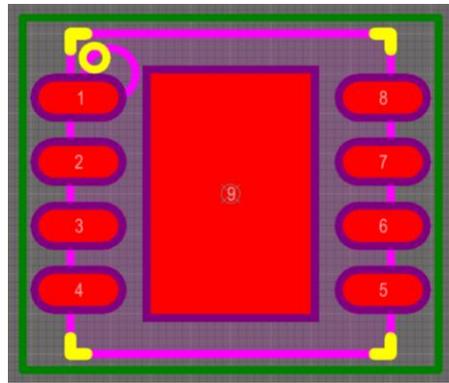
Before starting to design the Spotlight Board, the components which are not provided by the manufacturer nor included in the previous Roombots libraries should be added to the Altium Designer libraries. For the Spotlight Board the only specific component is the **TL4242 Constant Current LED Driver**. So, before the design of the Spotlight Board, schematic and PCB footprint libraries of the **TL4242 Constant Current LED Driver** are added, to Altium designer as a new integrated library by using *Altium Creating Components Tutorial* and *Component Wizard*. [11]



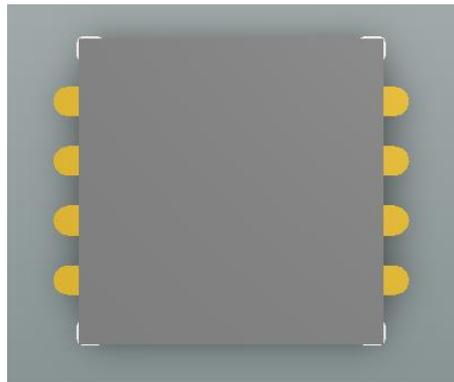
**Figure 4** TL4242 Constant Current LED Driver Schematic, (a) Simplified Schematic from datasheet, [3] (b) Schematic Implementation in Altium Designer.



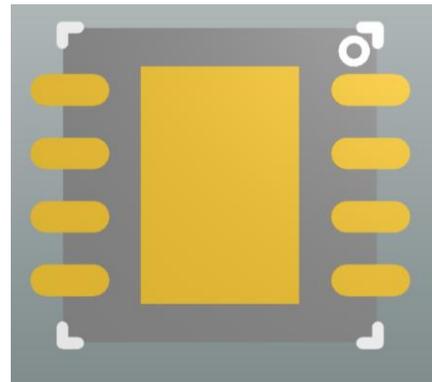
**Figure 5** TL4242 Constant Current LED Driver Recommended Layout from datasheet, [3] (a) General Layout (b) Pad Layout



(a)



(b1)



(b2)

**Figure 6** *TL4242 Constant Current LED Driver PCB Layout, Implemented in Altium Designer, (a) PCB Layout, (b) 3D view (b1) from top, (b2) from bottom*

### 2.1.2. Schematic

After all of the components are ready, schematic design of the Spotlight Board is implemented in the Altium designer. As the design of the Communication Board is used for reference; programming, communication and power supply are not changed in order to simplify the design process and protect the compatibility with the rest of the Roombots environment. Just minor changes are made on these parts in order have specific pins spared for the ***TL4242 LED Constant Current LED Drivers***.

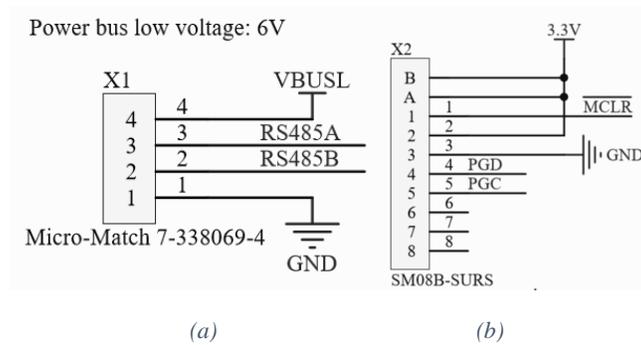


Figure 7 (a) Power and Communication Bus Connector, (b) Programming Connector

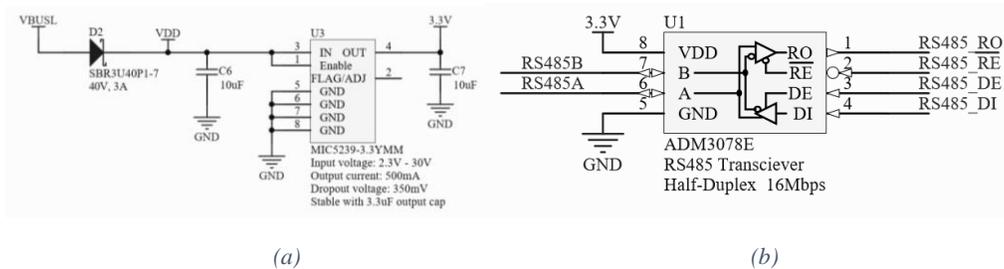


Figure 8 (a) Power Converter Circuit to Supply Main Power for the Microprocessor, (b) RS485 Transceiver for Communication

When the schematic is ready, we added the TL4242 Drivers and the connectors for the LEDs and supply voltage. The TL4242 circuits are taken from the example circuit from the datasheet.

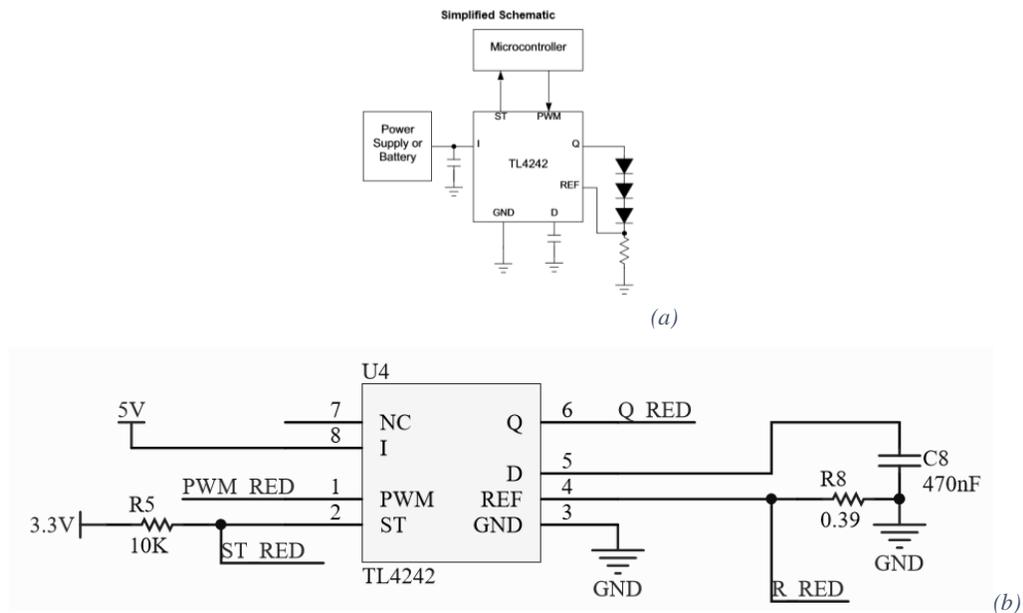
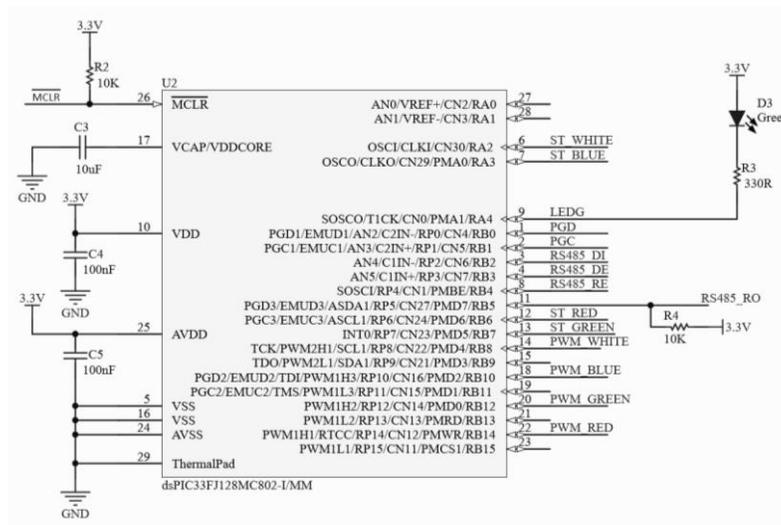


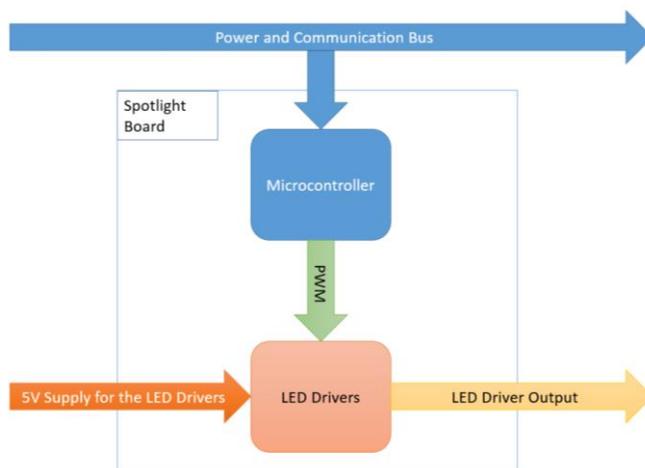
Figure 9 (a) TL4242 Example Circuit, and (b) TL4242 Implementation in the Spotlight Board Schematic

As it can be seen from the *figure 9* for each TL4242 Driver there is one PWM output and one digital input should be used from the microcontroller. Since the total number of TL4242s in the Spotlight Board design is 4, four independent PWM channels are needed in design. There are 3 PWM modules in the *dsPIC33FJ128MC802-I/MM*, first PWM module has 6 independent channels but it has only 3 duty cycle generators, as 4 different duty cycles are needed to control 4 LEDs independently, PWM1 output from second PWM module of the microcontroller is also used. [2]



*Figure 10* Microcontroller Circuit the Spotlight Board Schematic; RED, GREEN and BLUE LEDs are controlled with the first PWM module (PWM1H1, PWM1H2, PWM1H3) and WHITE LED controlled with the second PWM module (PWM2H1)

Complete design of the Spotlight Board Schematic can be found in the *Appendix*.



*Figure 11* Block Diagrams of Main Electrical Connections of the Spotlight Board

### 2.1.3. PCB Layout

PCB Layout of the Spotlight Board was implemented in Altium Designer by using the layout design which is synchronized to the schematic design. A two sided PCB was designed for the Spotlight Board.

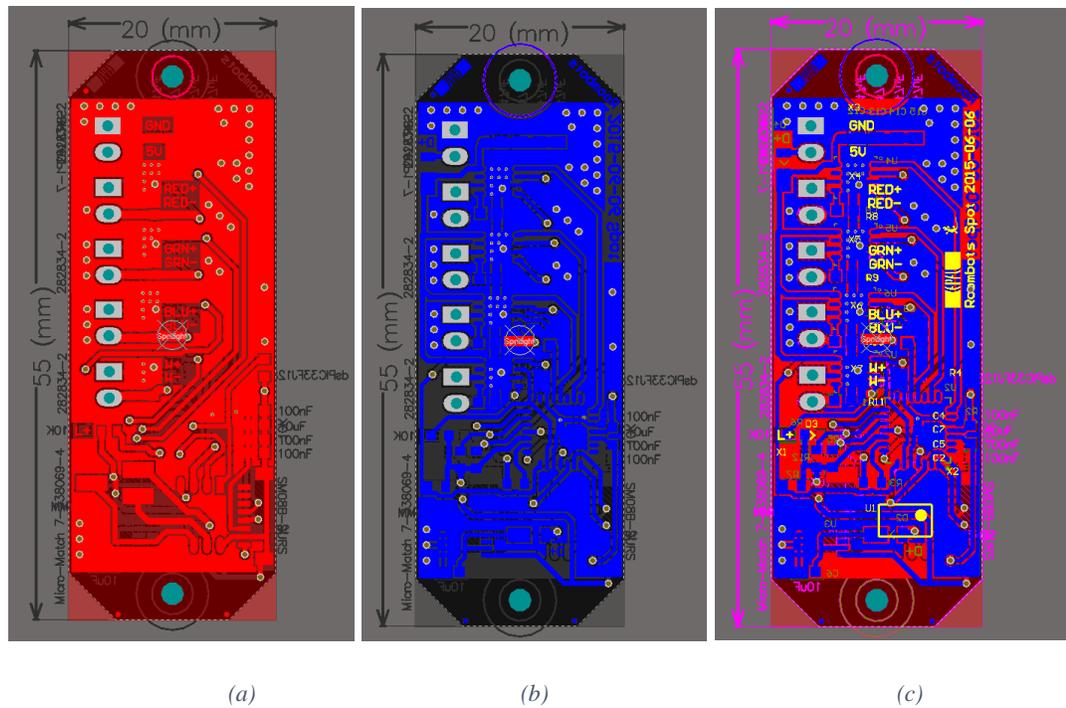


Figure 12 PCB Design of the Spotlight Board in 2D view, (a) single layer top side, (b) single layer bottom side, (c) multilayer

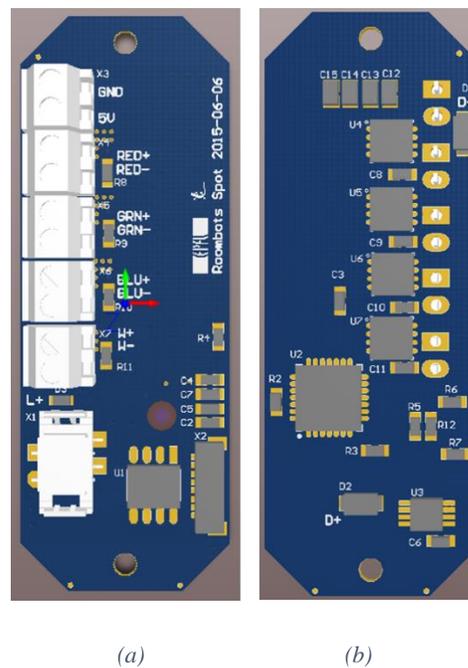
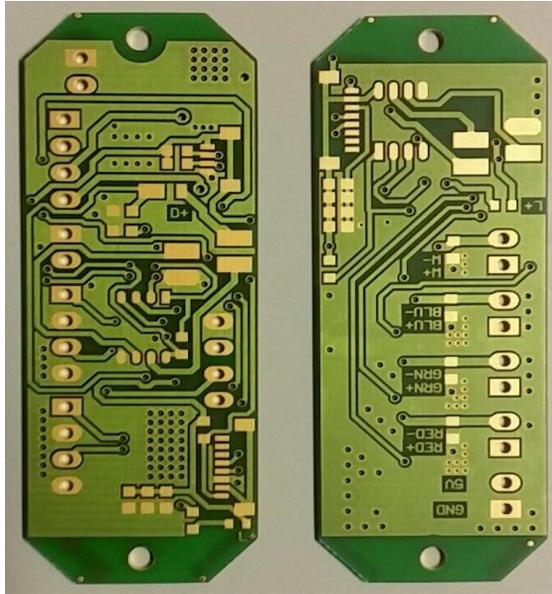


Figure 13 PCB Design of the Spotlight Board in 3D view, (a) top side, (b) bottom side

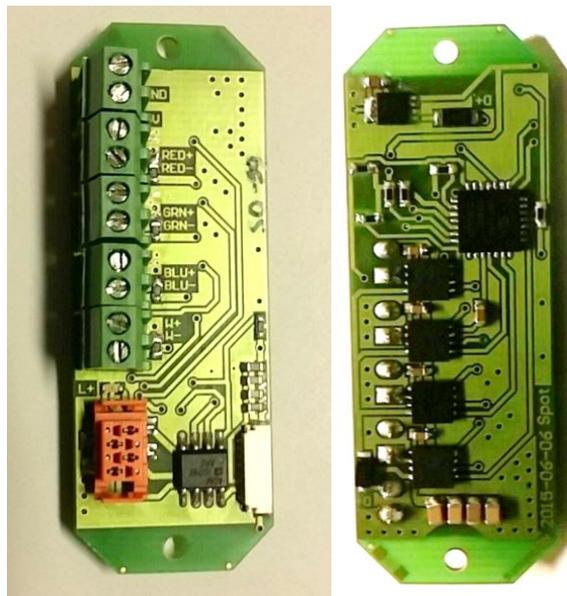
After the PCB design is ready and checked, we sent to the EPFL workshop for production. We then proceeded with the soldering of the prototype boards.



(a)

(b)

Figure 14 PCB of the Spotlight Board after production, (a) top side, (b) bottom side



(a)

(b)

Figure 15 PCB of the Spotlight Board after soldering, (a) top side, (b) bottom side

After soldering and connection tests, the Spotlight Board was ready for firmware development.

### 2.1.4. Power LED Board

As stated in the introduction, the Spotlight Board was designed to control a powerful LED Spotlight and for the LED, *Cree X-Lamp MC-E* was selected. Since this LED is coming as a single LED without any board or mechanical connections on it, a new board called Power LED Board was designed in order to place the Spotlight into the Roombots module. This board only contains the LED and connectors. Firstly we added a component library for the LED and then completed the board design. In addition to the LED, we also used a lens with a color mixer. A lens with a color mixer gives better results in terms of color quality and color uniformity becomes better.

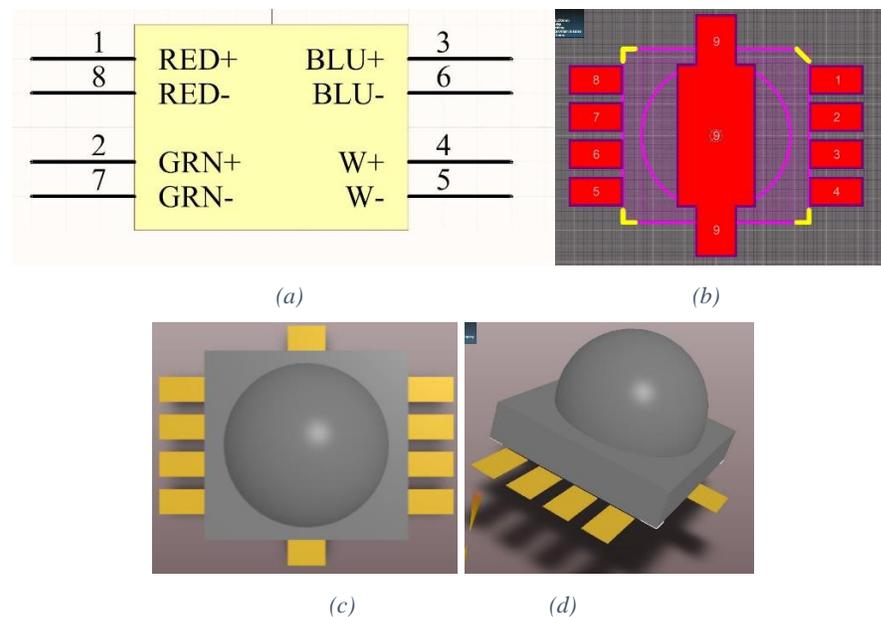


Figure 16 Cree XLAMP MC-E LED Design, (a) schematic, (b) PCB footprint in 2D view, (c-d) PCB footprint in 3D view

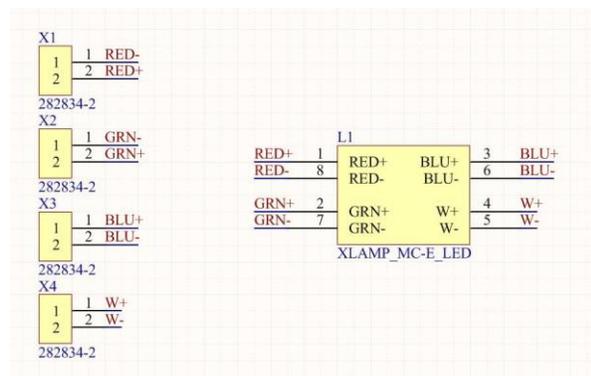


Figure 17 Schematic Design of the Power LED Board

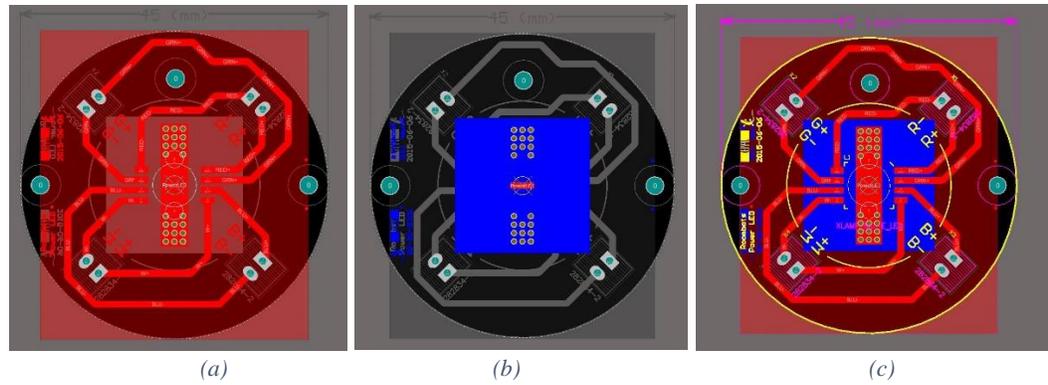


Figure 18 PCB Design of the Power LED Board in 2D view, (a) single layer top side, (b) single layer bottom side, (c) multilayer

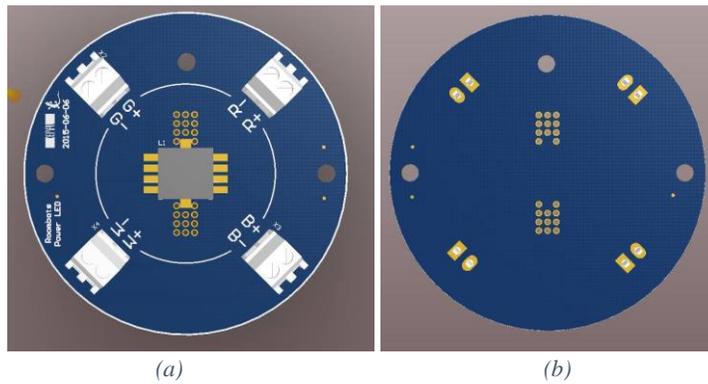


Figure 19 PCB Design of the Power LED Board in 3D view, (a) top side, (b) bottom side

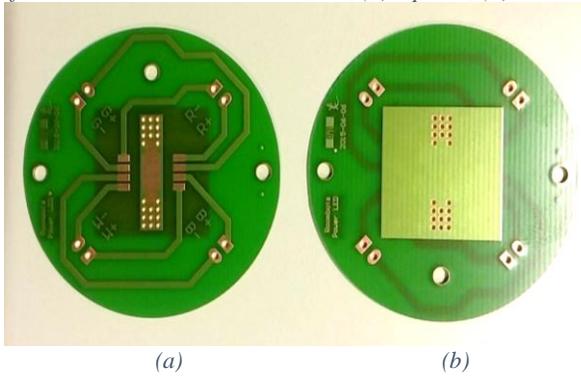


Figure 20 PCB of the Power LED Board after production, (a) top side, (b) bottom side

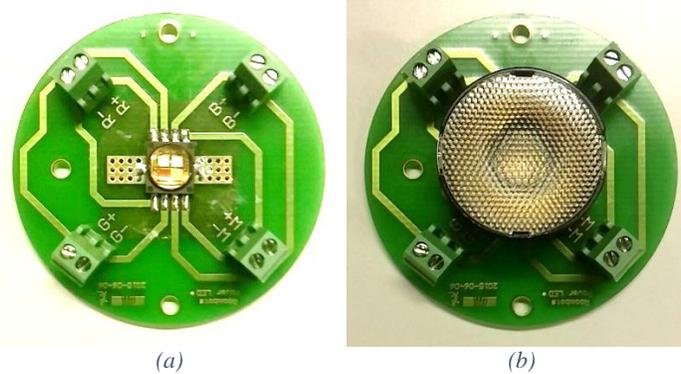


Figure 21 PCB of the Power LED after soldering, (a) without lens and color mixer, (b) with lens and color mixer

## 2.2. Firmware Development

For the firmware of the Spotlight Board, like many other aspects firmware of the Roombots boards taken as reference and then required changes made in order get appropriate pin configurations. First change made on GPIO pins, because during hardware design many connections moved. After applying these changes on the firmware PWM modules configured accordingly and status pins from the LED drivers were assigned. When the configuration was completed correctly, we added PWM functions and communication commands added for test and usage. For the Spotlight Board, the board name was configured as “*S0-99*”.

### 2.2.1. Hardware Test Functions

For testing the hardware from serial commands, we used two commands to interact with the Spotlight Board. The first one is the on-board debug LED control command which is included in almost all the Roombots’ boards.

*Table 1 Command to change state of the onboard LED*

Command	Related Function	Parameter Controlled
“ <i>l</i> ” or “ <i>led</i> ”	command_led()	Changes the status of the onboard LED

From the *Table 1*, for example when the user wants to turn on the LED, “*sS0-99ll*” should be sent from the Bluetooth serial. The first “*s*” indicates a parameter wanted to be changed and then board name also added in front of the command. Just like this when user wants to toggle the LED, “*sS0-99lt*” should be sent from Bluetooth serial.

Second one is the main command of the Spotlight Board which controls the Power LED.

*Table 2 Command to control the Power LED*

Command	Related Function	Parameter Controlled
“ <i>c</i> ” or “ <i>color</i> ”	command_rgbw()	Changes the color of the Power LED

This command can be used in various ways but just for quick hardware test, short versions created to set the brightness of the color channels to 0%, 25%, 50%, 75% and 100%. Although it is not intended to use in the final product, these versions are still in the final firmware.

*Table 3 Characters added to the end of the color command to set LEDs to certain brightness levels*

<b>Brightness Level</b>	<b>Appended Character for RED Channel</b>	<b>Appended Character for GREEN Channel</b>	<b>Appended Character for BLUE Channel</b>	<b>Appended Character for WHITE Channel</b>
0%	'0'	'5'	't'	'f'
25%	'1'	'6'	'x'	'y'
50%	'2'	'7'	'c'	'h'
75%	'3'	'8'	'd'	'i'
100%	'4'	'9'	'e'	'j'

For example, when the user wants to test the brightness of the RED LED at 25%, “sS0-99c1” should be sent from the Bluetooth serial or for testing the BLUE channel at 50% “sS0-99cd” should be sent from the Bluetooth serial. These quick testing commands are just able to affect one LED, so when a second command sent to the board including a different color channel setting from first command, the color channel set with the first command will not be affected. For example, when we take the previous example, the brightness of the RED LED will be still 25%, when the brightness of the BLUE LED is set.

### 2.2.2. User Interface

User interface of the Spotlight Board is also provided by the same function explained in the previous part but in order to give as many as options to the user, we extended the usage of the function. In addition to the commands listed in *Table 2* and *Table 3*, user can also set the brightness levels of the color channels to desired values and can also control multiple channels with a single command. In order to do this a command including first letter of the color name, in this case ‘r’, ‘g’, ‘b’ and ‘w’, should be sent with the desired brightness level appended, user can add up to all color channels in

one command regardless of their order. For example if the RED channel is desired to be set at 25% brightness while the GREEN channel is desired to be set at 75% brightness, “sS0-99cr025g075” or “sS0-99cg075r025” may be sent from the Bluetooth serial.

### 2.3. Results

After implementing software, current levels consumed by the Power LED at different brightness levels are measured with the power source’s current consumption indicator and compared with the expected values. The color quality and mixture is also controlled but visual output is a highly dependent to the observer so, there is no chance to conclude that the Power LED is giving correct color mixture and also camera is not able to capture the exact color since there are numerous processes going with image formation. Color quality can be explained with the help of comparison between the other colors generated by the Power LED. Comparison between measured and expected current can be found in *Table 4*. Some examples from the color mixtures can be found in *Figure 21*.

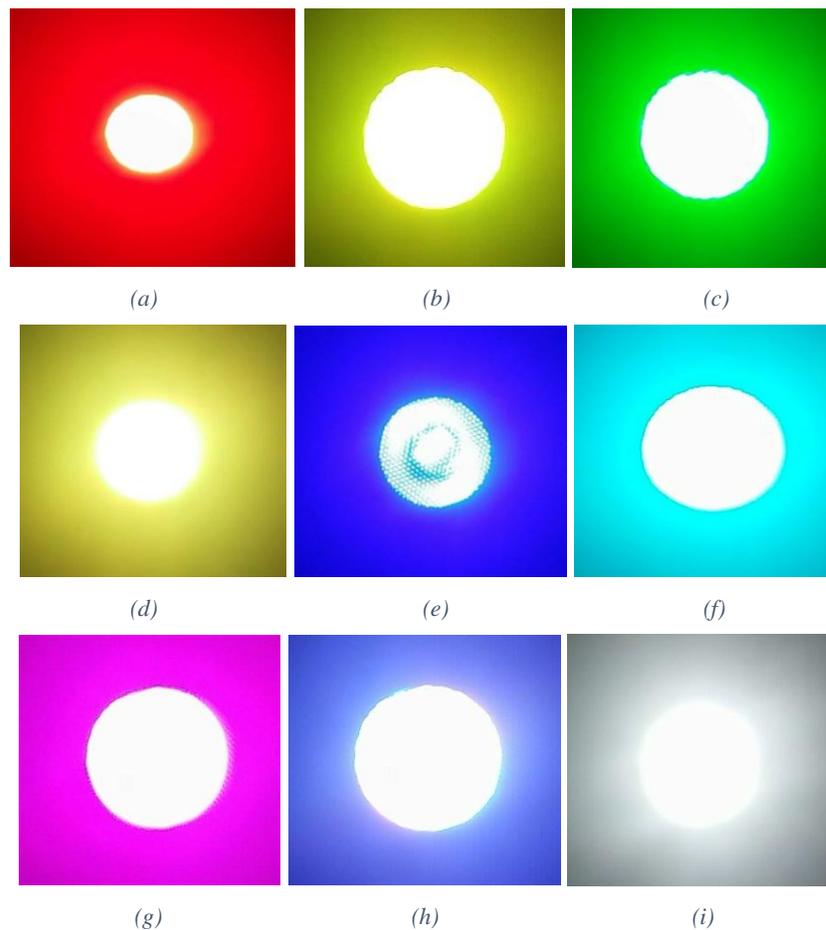


Figure 22 Color samples from the Spotlight; (a) RED 25%, (b) YELLOW: RED 25%, GREEN 25%, (c) GREEN 25%, (d) ORANGE: RED 75%-GREEN 25%, (e) BLUE 25%, (f) CYAN: BLUE 25%-GREEN 75%, (g) MAGENTA: BLUE 25%-RED 75, (h) WHITE: BLUE 50%-RED 50%-GREEN 50%, (i) WHITE 25%

Table 4 Comparison between Measured and Expected Current Consumptions

#	Brightness Level				Expected Current Consumption (mA)	Measured Current Consumption (mA)
	RED	GREEN	BLUE	WHITE		
1	25%	0%	0%	0%	87 mA	70 mA
2	50%	0%	0%	0%	175 mA	160 mA
3	75%	0%	0%	0%	262 mA	250 mA
4	99%	0%	0%	0%	350 mA	310 mA
5	0%	25%	0%	0%	87 mA	70 mA
6	0%	50%	0%	0%	175 mA	160 mA
7	0%	75%	0%	0%	262 mA	260 mA
8	0%	99%	0%	0%	350 mA	320 mA
9	0%	0%	25%	0%	87 mA	70 mA
10	0%	0%	50%	0%	175 mA	170 mA
11	0%	0%	75%	0%	262 mA	270 mA
12	0%	0%	99%	0%	350 mA	330 mA
13	0%	0%	0%	25%	87 mA	70 mA
14	0%	0%	0%	50%	175 mA	170 mA
15	0%	0%	0%	75%	262 mA	250 mA
16	0%	0%	0%	99%	350 mA	320 mA
17	25%	25%	0%	0%	175 mA	150 mA
18	25%	25%	25%	0%	262 mA	220 mA
19	25%	25%	25%	25%	350 mA	300 mA
20	50%	50%	0%	0%	350 mA	320 mA
21	50%	50%	50%	0%	525 mA	490 mA
22	50%	50%	50%	50%	700 mA	660 mA
23	75%	75%	0%	0%	525 mA	520 mA
24	75%	75%	75%	0%	787 mA	800 mA
25	75%	75%	75%	75%	1050 mA	1060 mA
26	99%	99%	0%	0%	700 mA	640 mA
27	99%	99%	99%	0%	1050 mA	1000 mA
28	99%	99%	99%	99%	1400 mA	1290 mA

As it can be observed from the table there is a nonlinearity in the consumed current levels as a result of hardware properties. For example LEDs will not be giving any light when their brightness level set to the 5% and also reaches the maximum value at 90% or more.

### 3. Gripper Board

#### 3.1. Hardware Design

##### 3.1.1. Board Specific Components

For the Gripper Board there are 3 board specific components: the **L293D Motor Driver**, the **p-channel MOSFETs** and the **Pressure Sensor**. As MOSFETs were already in the Roombots library **L293D Motor Driver** and **Pressure Sensor** were added to the Altium designer as new integrated libraries.

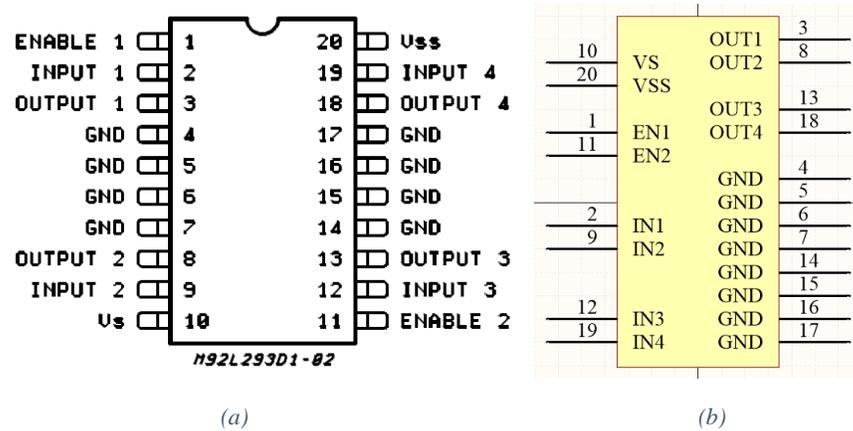


Figure 23 L293D Motor Driver Schematic, (a) pin configuration from datasheet, [5], (b) Schematic Implementation in Altium Designer.

For L293D Driver an Altium footprint library is already supplied by ST-Microelectronics, so this footprint was directly added to the integrated library. [12]

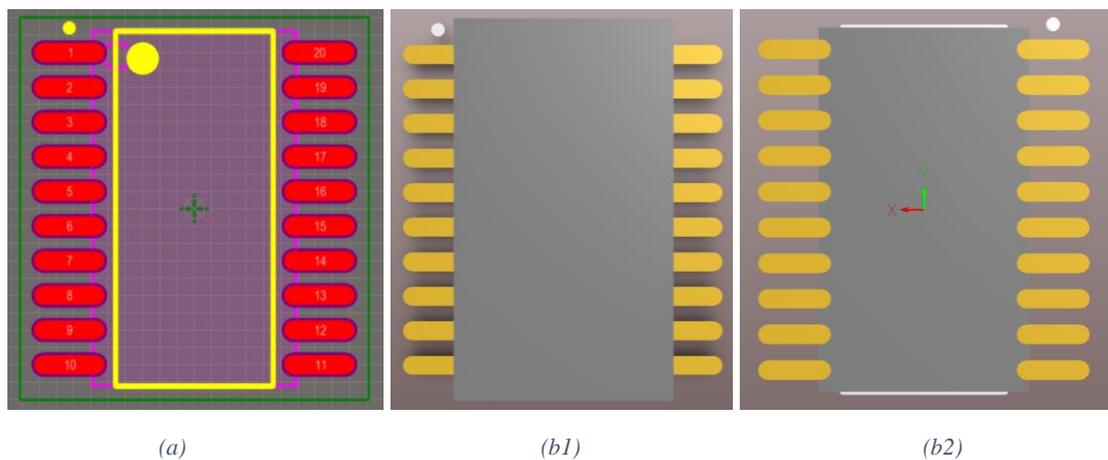


Figure 24 TL4242 L293D Driver PCB Layout, (a) PCB Layout, (b) 3D view (b1) from top, (b2) from bottom

For the Pressure Sensor, different types were provided from Honeywell, so both surface mount and single-in-line models were implemented in Altium designer but just the single-in-line version was used.

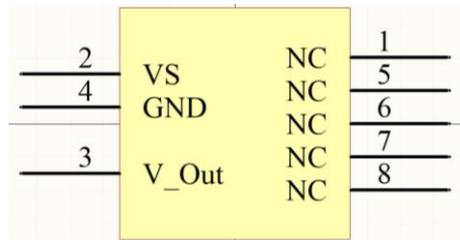


Figure 25 Schematic Design of the Pressure Sensor

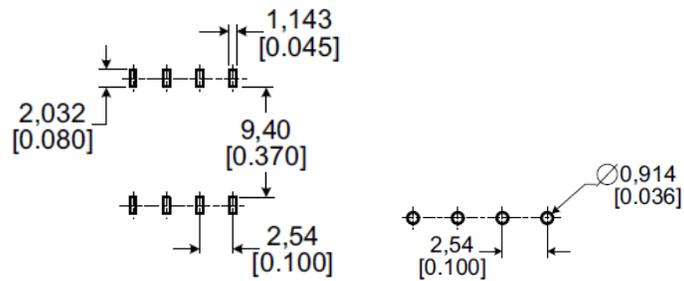


Figure 26 Recommended PCB Layouts for Pressure Sensor SMT and SIP packages from datasheet [6]

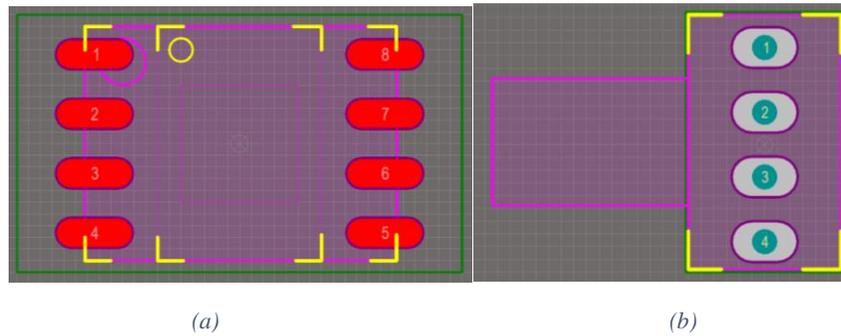


Figure 27 PCB Layout Designs Implemented in Altium Designer, (a) SMT Package, (b) SIP Package

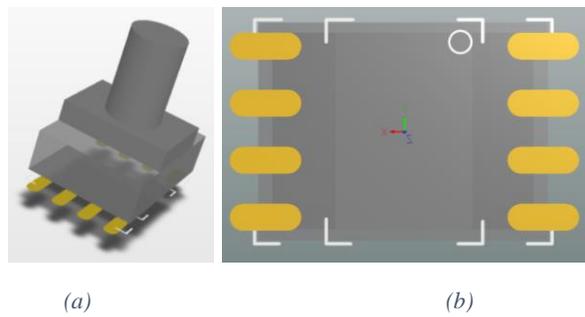


Figure 28 3D View of SMT Package, (a) Side View, (b) Bottom View

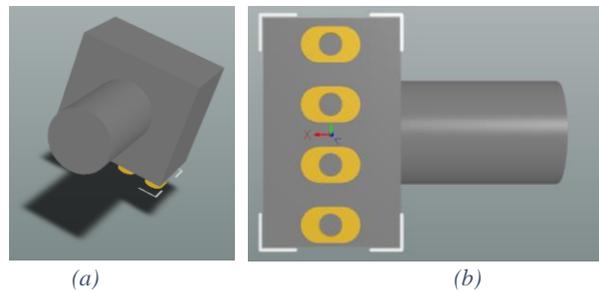


Figure 29 3D View of SIP Package, (a) Side View, (b) Bottom View

### 3.1.2. Schematic

The schematic of the Gripper Board was designed by following the same steps as for the Spotlight Board. The required changes are made on the design and board specific components are added. With L293D motor driver we are able to control 2 DC motors with different speeds and directions, but air pump is not efficient when it is used reverse, so instead of changing air pump’s rotation direction we are using different valve configurations; so there is just one PWM channel is needed but to make the system redundant and compatible with some different air pump models all outputs of L293D is used. As we are using the same number of required PWM outputs from the microcontroller same pins with the Spotlight Board used for PWM.

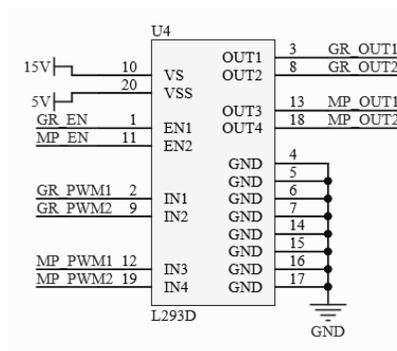


Figure 30 L293D Implementation in the Gripper Board Schematic

It has been stated that for the valve controllers p-channel MOSFETS are used, in the system there are 3 valves but one extra MOSFET added for redundancy and future usage.

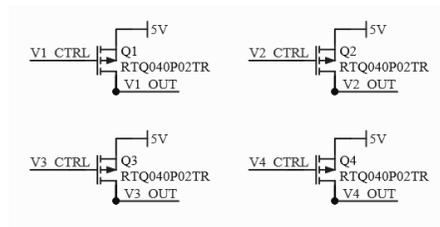


Figure 31 Valve controlling unit in the Gripper Board Schematic

For the pressure sensor, we used analog input of the microcontroller but it is only capable of inputs up to 3.3V; since the output of the pressure sensor is up to 5V, we added a simple voltage divider to the output of the pressure sensor.

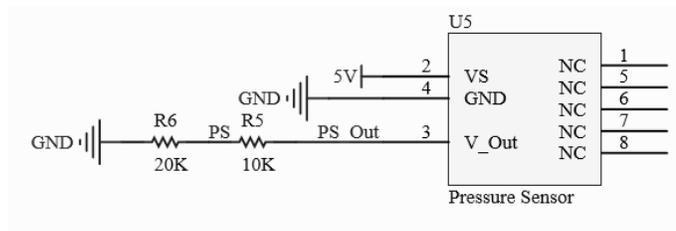


Figure 32 Pressure Sensor Implementation in the Gripper Board Schematic

In order to control the L293D motor driver 4 PWM channels and 2 digital input pins are needed. Since the number of independent PWM channels are same with the Spotlight board same configuration is used. Enable pins and gate pins of the MOSFETs are connected to the digital input pins and the reduced output of the pressure sensor is connected to the analog input pin of the microcontroller. In order to have better sensing results, 2 ferrites are used with the microcontroller. Ferrites are able to filter unexpected high frequencies in the signal.

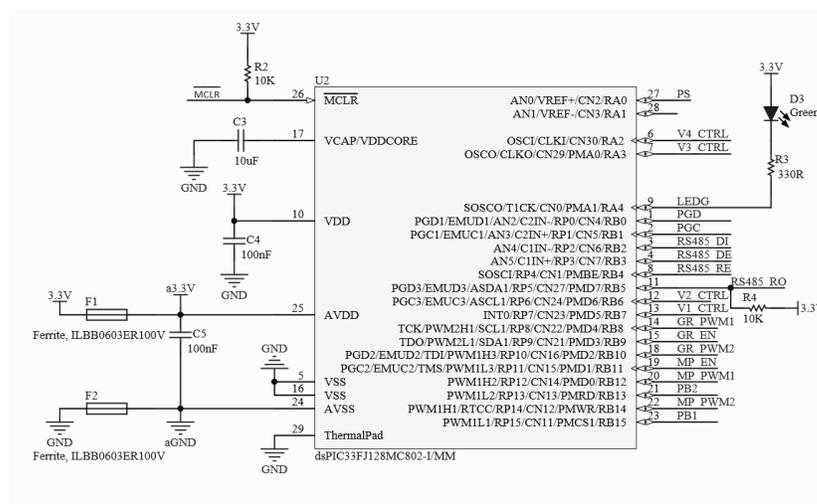


Figure 33 Microcontroller Circuit in the Gripper Board Schematic

Complete design of the Gripper Board Schematic can be found in the **Appendix**.

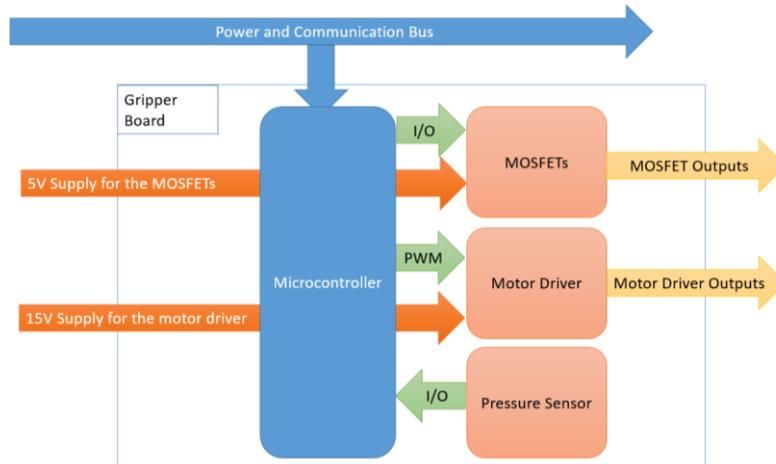
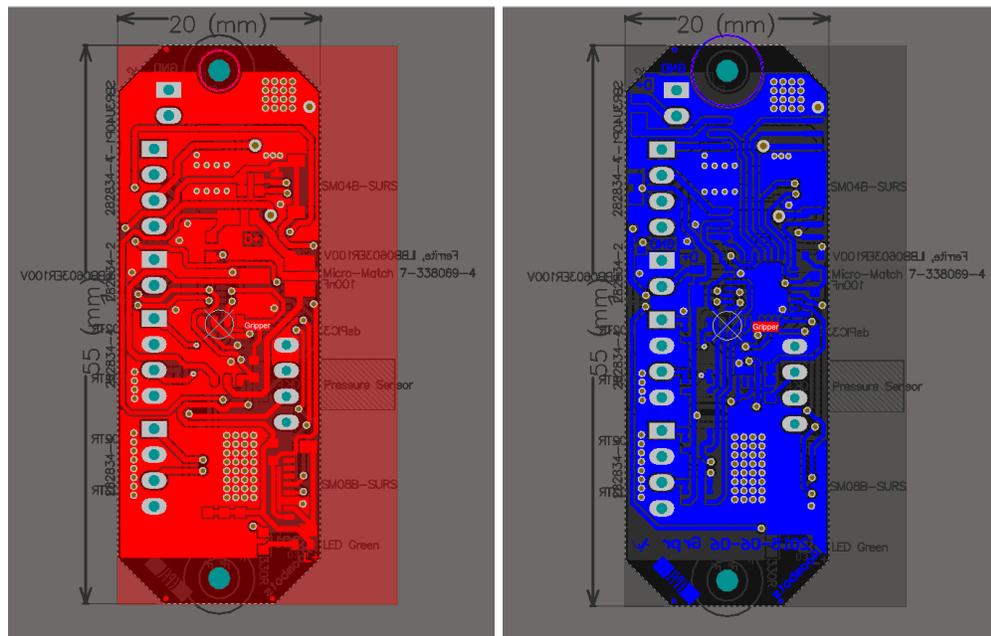


Figure 34 Block Diagrams of Main Electrical Connections of the Gripper Board

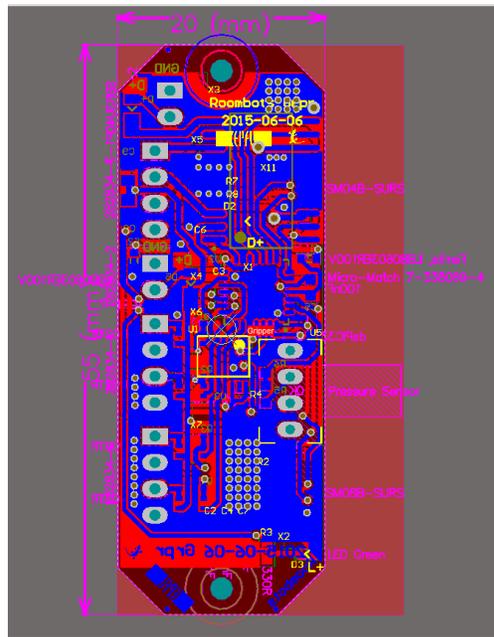
### 3.1.3. PCB Layout

The PCB Layout of the Gripper Board is implemented in Altium Designer by using the schematic design. A two sided PCB is designed for Spotlight Board.



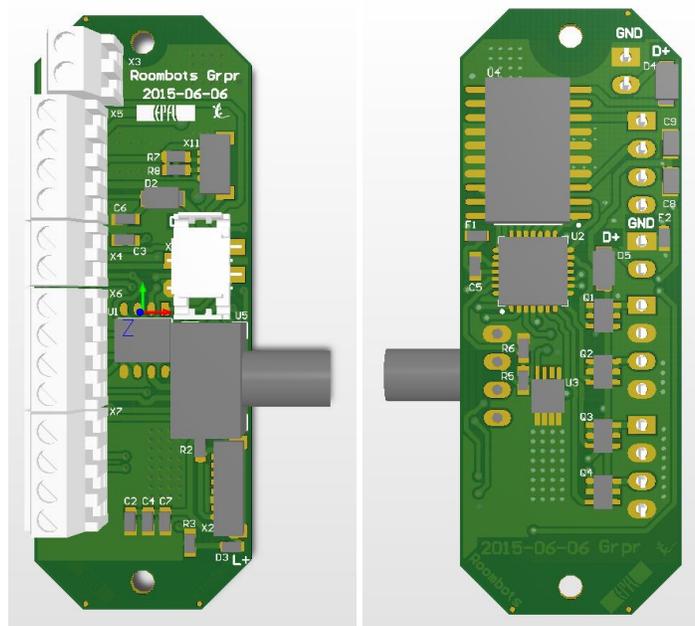
(a)

(b)



(c)

Figure 35 PCB Design of the Gripper Board in 2D view, (a) single layer top side, (b) single layer bottom side, (c) multilayer

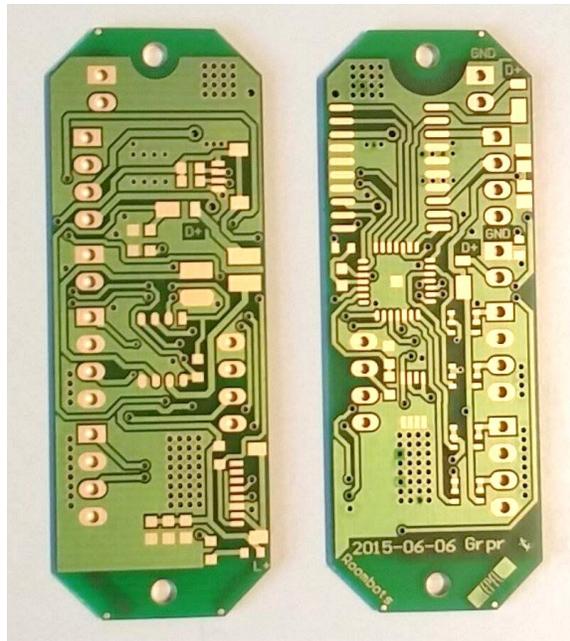


(a)

(b)

Figure 36 PCB Design of the Gripper Board in 3D view, (a) top side, (b) bottom side

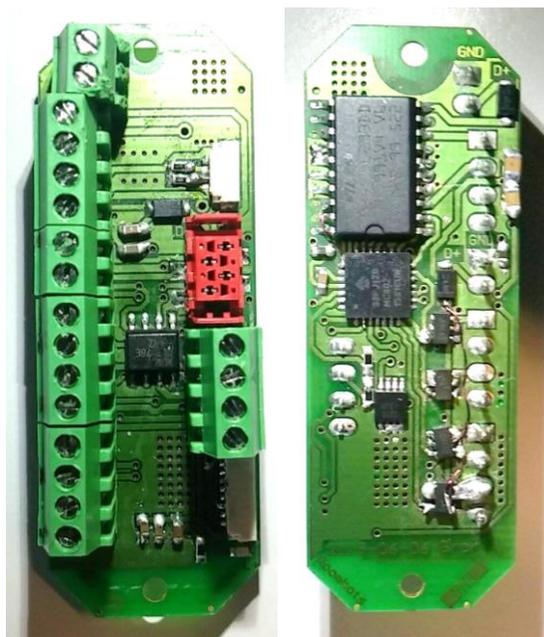
After PCB design is ready and checked, we sent it to the EPFL workshop for production and after production it is soldered by using prepared instructions.



(a)

(b)

*Figure 37 PCB of the Gripper Board after production, (a) top side, (b) bottom side*



(a)

(b)

*Figure 38 PCB of the Gripper Board after soldering, (a) top side, (b) bottom side*

### 3.2. Firmware Development

Before writing the firmware of the Gripper Board we need to look at how valves work and what will be the system’s operation with different valve settings.

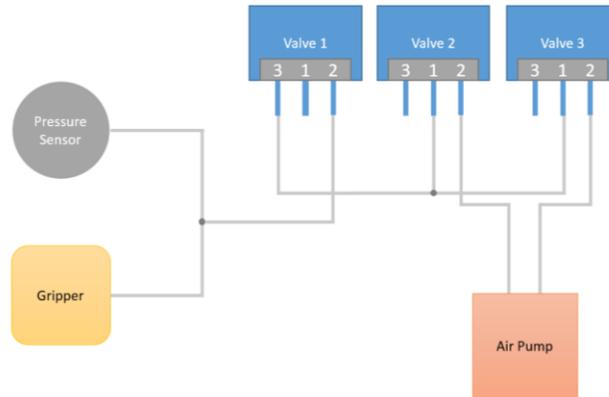


Figure 39 Block Diagram of the Gripper System with Air Flow Connections

Each valve has two states: default (off) and on. When the valve is off, air connections 2 and 3 are connected; when the valve is switched on, air connections 1 and 3 are connected. We are also provided with the table with different valve states and system’s operation at these states.

Table 5 Universal Gripper System States with Different Valve Settings

#	Valve States			Operation
	Valve 1	Valve 2	Valve 3	
1	0	0	0	<b>Hold;</b> Gripper keeps it’s pressure
2	1	0	0	<b>Atmospheric;</b> System keeps the pressure of the Gripper at 1 atm.
3	0	1	0	<b>Vacuum;</b> Air Pump is able to vacuum the air inside of the Gripper
4	0	0	1	<b>+Pressure;</b> Air Pump is able pump air into the Gripper

Firmware of the Gripper Board is based on this table. Main template of the firmware is the same with the Spotlight Board, PWM configuration is also same. Required changes made

on the digital GPIO pins and ADC for reading the Pressure Sensor outputs configured. For the Spotlight Board, board name is configured as “**G0-99**”.

### 3.2.1. Hardware Test Functions

Before developing user functions to control the Universal Gripper, each component is tested with quick hardware test commands. On-board debug LED is also used for hardware testing with the same command with the Spotlight Board.

First, the Pressure Sensor is tested and its output compared with the expected output. A test command for reading the sensor output is developed.

*Table 6* Command to read sensor output

<b>Command</b>	<b>Related Function</b>	<b>Operation</b>
“gp” or “getpres”	command_get_pressure()	Returns the sensor output in 12-bits

For using this function we need to first add “?” character before the board name, since we are asking a question to the board instead of setting a parameter. “**?G0-99gp**”, is sent from the Bluetooth serial to read the output of the Pressure sensor.

After pressure sensor, **L293D** and voltage outputs tested with two different test commands.

*Table 7* Command to set outputs of the motor driver

<b>Command</b>	<b>Related Function</b>	<b>Operation</b>
“pwma”	command_test_pwm1()	Sets the first outputs of the L293D to desired values.
“pwmb”	command_test_pwm2()	Sets the second outputs of the L293D to desired values.

By using the **Table 7**, for example when the first outputs of the L293D driver wanted to be set at 50%, “**sG0-99pwma50**”, should be sent from the Bluetooth serial or when the second outputs of the L293D driver wanted to be set at 30%, “**sG0-99pwmb30**”,

should be sent from the Bluetooth serial. These two commands cannot be used at the same time, since the commands set the other PWM outputs to the 0.

Last components tested in the Gripper Board are the valves controlled with MOSFETs. Another test command is also developed for testing valves with the configurations listed in the *Table 5*.

*Table 8 Command to test valves*

Command	Related Function	Operation
“v”	command_test_valve()	Sets valves to the desired positions.

For using this function first letter of the intended state should be added to the end of the command. For example if the valves are wanted be set to *hold* position, “sG0-99vh” should be sent from the Bluetooth serial.

### 3.2.2. User Interface

User interface of the Gripper Board includes different functions than hardware test functions but hardware test functions is still in the final firmware. The main control commands of the user interface, configure the valves according to the *Table 5* and start and stop the air pump according to the sensor reading.

*Table 9 Commands to control the Universal Gripper*

Command	Related Function	Operation
“hold”	command_hold()	Sets system to “ <i>hold</i> ” position and stops the air pump.
“atm”	command_atm()	Sets system to “ <i>atmospheric</i> ” position and stops the air pump.
“grp”	command_grip()	Sets system to “ <i>vacuum</i> ” position and opens the air pump until minimum allowable pressure level reached.
“rls”	command_release()	Sets system to “ <i>+pressure</i> ” position and opens the air pump until maximum allowable pressure level reached.

When the user wants to the Universal Gripper, grips an object, “*sG0-99grp*” should be sent from the Bluetooth serial. When the user wants to the Universal Gripper, release a gripped object, either “*sG0-99rls*” or “*sG0-99atm*”; obviously “*rls*” command will release the object faster since air pump is sending air into the Universal Gripper.

As it can be seen from the **Table 9**, user control commands for the Universal Gripper sets the pressure inside the gripper according to the atmospheric, maximum and minimum allowable pressure levels. These pressure levels are configured when the firmware is programmed to the microcontroller but can be configured by the user for better results and also user can read the current pressure level inside the gripper.

*Table 10 Command to configure the internal gripper pressure*

<b>Command</b>	<b>Related Function</b>	<b>Operation</b>
“ <i>prconfig</i> ”	command_configure_pressure()	Sets and gets the different pressure types.

There are different types of pressure levels can be configured and read by this command.

*Table 11 Characters added to the end of the pressure configuration command to set or read pressure levels*

<b>Pressure Type</b>	<b>Appended Letter</b>	<b>Can be read or set?</b>
Maximum allowable pressure or releasing pressure	“ <i>r</i> ”	both
Minimum allowable pressure or gripping pressure	“ <i>g</i> ”	both
Atmospheric pressure	“ <i>a</i> ”	both
Desired pressure	“ <i>d</i> ”	both
Measured pressure	“ <i>m</i> ”	just read
Error margin	“ <i>e</i> ”	both

When the user wants to see the current pressure level inside the gripper, “*?G0-99prconfig*” should be sent from the Bluetooth serial. When the user wants to set the desired pressure level inside the gripper, desired level should be added to the end of the command and “*sG0-99prconfigd25*” should be sent from the Bluetooth serial. These pressure levels are between 0 and 50.

In addition to the pressure configuration, user also can set the speed of the air pump. By default speed of the air pump is set to the 75% but user can read and set a new value for this parameter.

*Table 12 Command to configure the air pump speed*

<b>Command</b>	<b>Related Function</b>	<b>Operation</b>
“ <i>pwmconfig</i> ”	command_configure_pwm()	Sets and gets the speed of the air pump.

When user wants to check the current speed level, “*?G0-99pwmconfig*” should be sent from the Bluetooth serial and when the user wants to set the speed of the air pump to 40%, “*sG0-99pwmconfig40*” should be sent from the Bluetooth serial.

**Note:** In order to control the Gripper Board, after turning the system on, user must wait for on-board LED to turn off. Gripper Board configures itself to the atmospheric conditions when it is switched on. User can also control the Universal Gripper with buttons.

### 3.3. Results

After hardware test functions and user interface implemented, readings from the pressure sensor compared with the expected values and multimeter measurements. Measured pressure calculated by the formula given in the datasheet of the sensor.

$$V_{out} = \frac{0.8 \times V_{Supply}}{P_{max} - P_{min}} \times (P_{applied} - P_{min}) + 0.1 \times V_{Supply}$$

*Equation 1 Output voltage of the sensor respect to the applied pressure [6]*

**Equation 1** can be simplified by using the features of the pressure sensor. From the datasheet we can get these parameters;  $V_{Supply} = 5\text{ V}$ ,  $P_{min} = 0\text{ atm}$  and  $P_{max} = 1\text{ atm}$ . [6] So, the output of the pressure sensor will be:

$$V_{out} = 4 \times \frac{P_{applied}}{1\text{ atm}} + 0.5$$

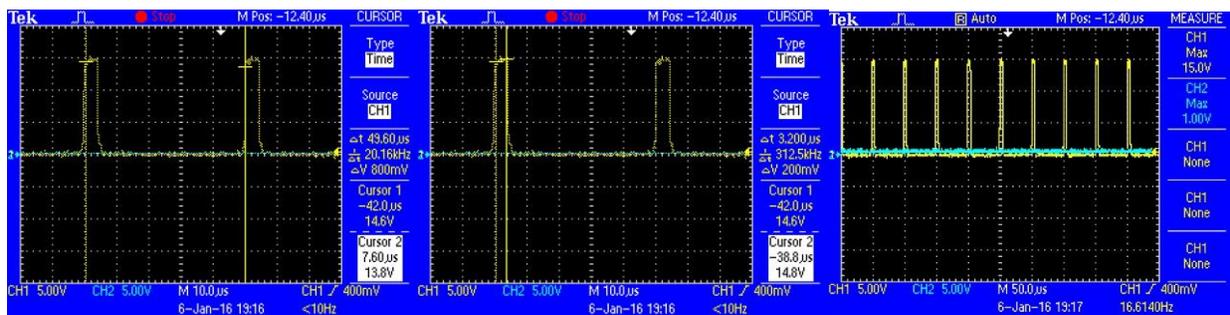
*Equation 2 Output voltage of the pressure sensor, simplified*

*Table 13 Pressure readings from the pressure sensor and comparison between expected values*

Output Voltage	12-bit Reading	Expected Pressure	Measured Pressure
3.3 V	1958	< 1atm	0.7 atm
4.3 V	3405	1 atm	0.95 atm
4.5 V	3868	> 1 atm	1 atm

As it can be seen from the **Table 13** pressure readings are slightly less than expected values but still there is a consistency in the results, so gripper control can be configured according to these results.

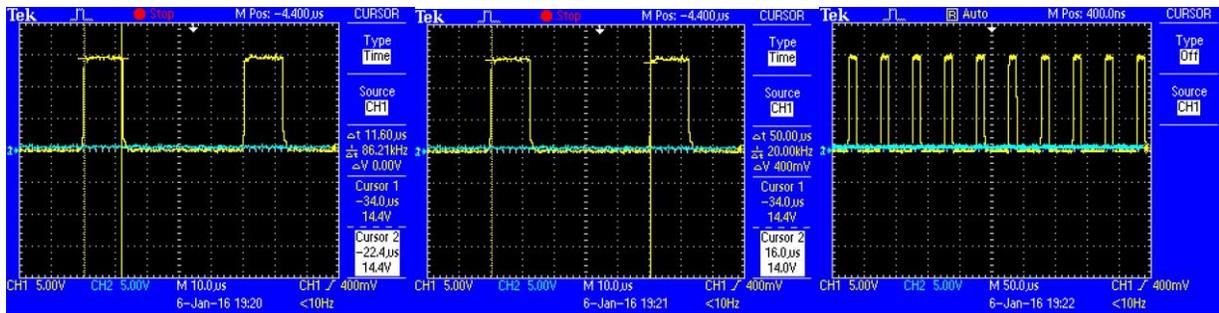
In addition to the pressure sensor measurements, PWM outputs of the L293D also measured with the oscilloscope. Oscilloscope results can be found in **Figure 38**. CH1 of the oscilloscope is connected to the first output of L293D and CH2 of the oscilloscope is connected to the second output of L293D.



(a1)

(a2)

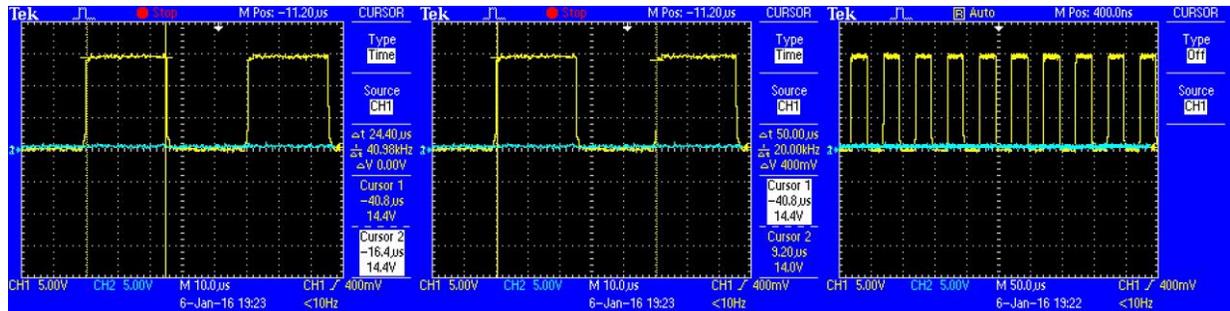
(a3)



(b1)

(b2)

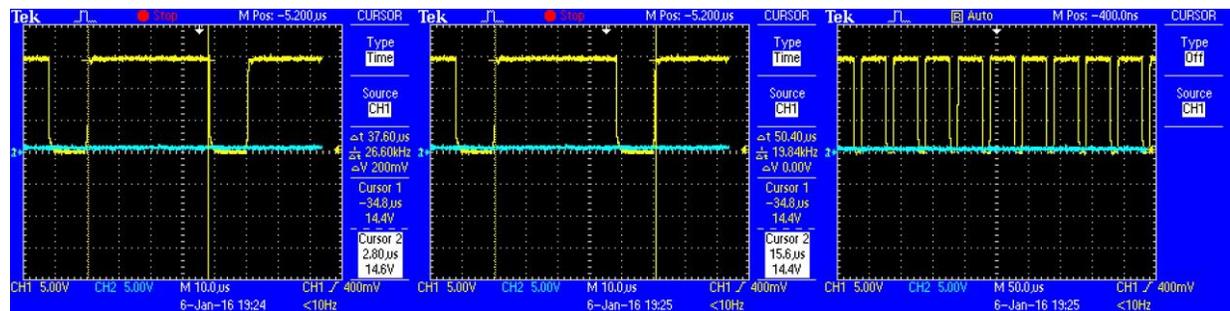
(b3)



(c1)

(c2)

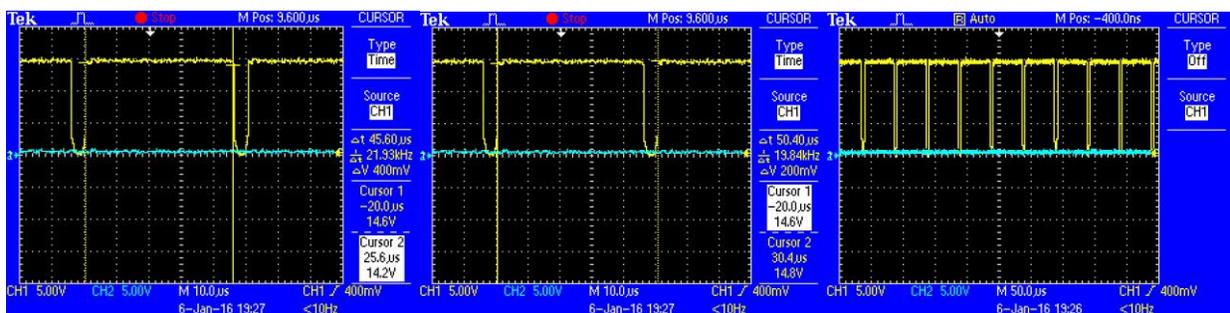
(c3)



(d1)

(d2)

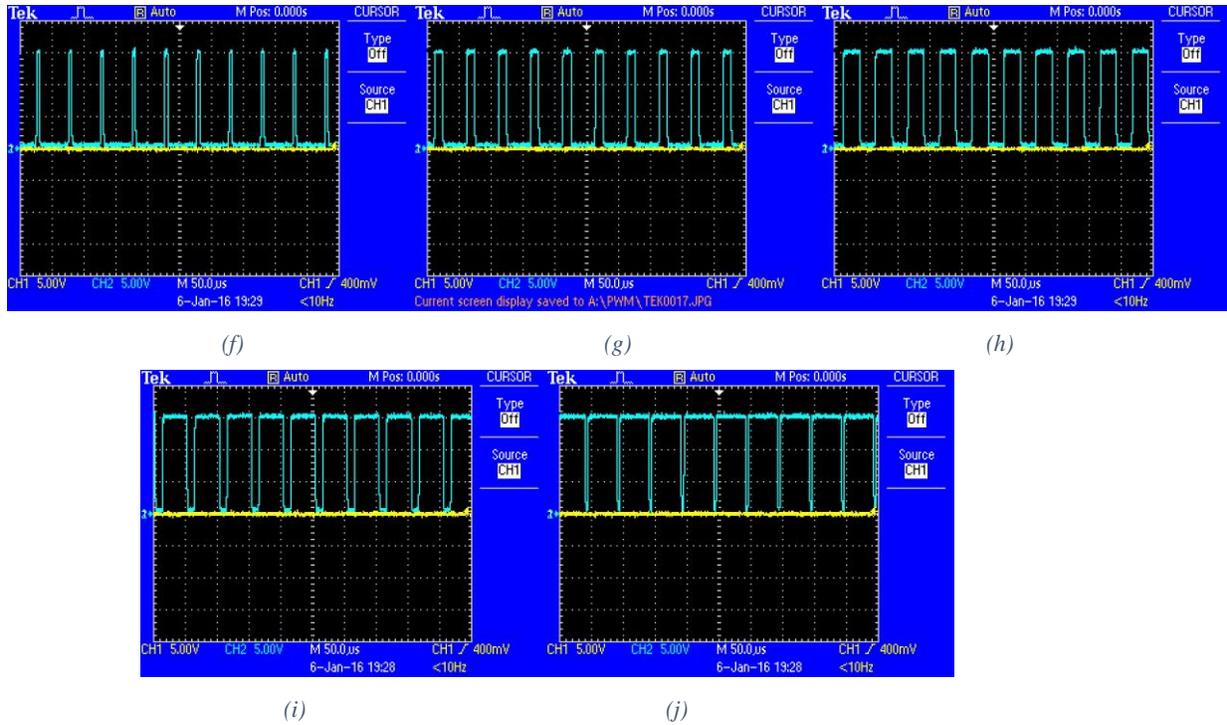
(d3)



(e1)

(e2)

(e3)



**Figure 40** Oscilloscope measurements of the L293D outputs with different PWM Levels, First Outputs; (a) 10%, (b) 25%, (c) 50%, (d) 75 %, (e) 90%, Second Outputs; (f) 10%, (g) 25%, (h) 50%, (i) 75% and (j) 90%

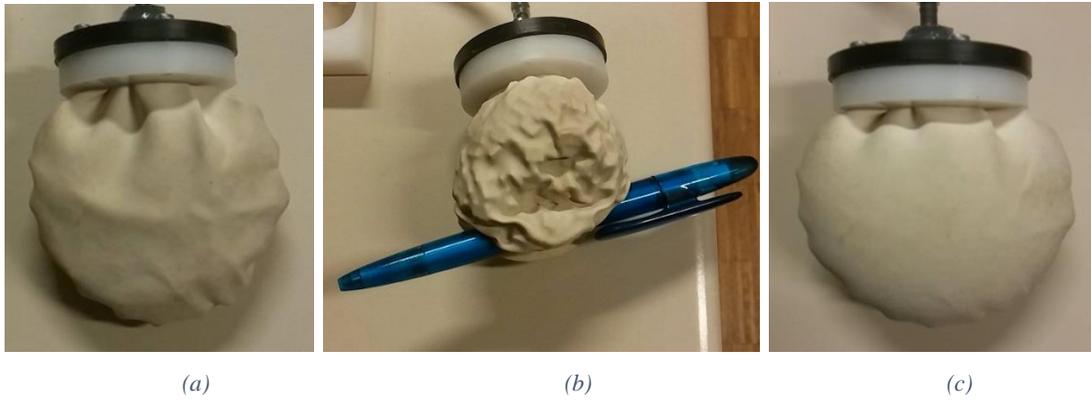
After oscilloscope results, measurements compared with the expected values for the first output. This comparison can be found in **Table 14**.

**Table 14** Oscilloscope results compared with expected values

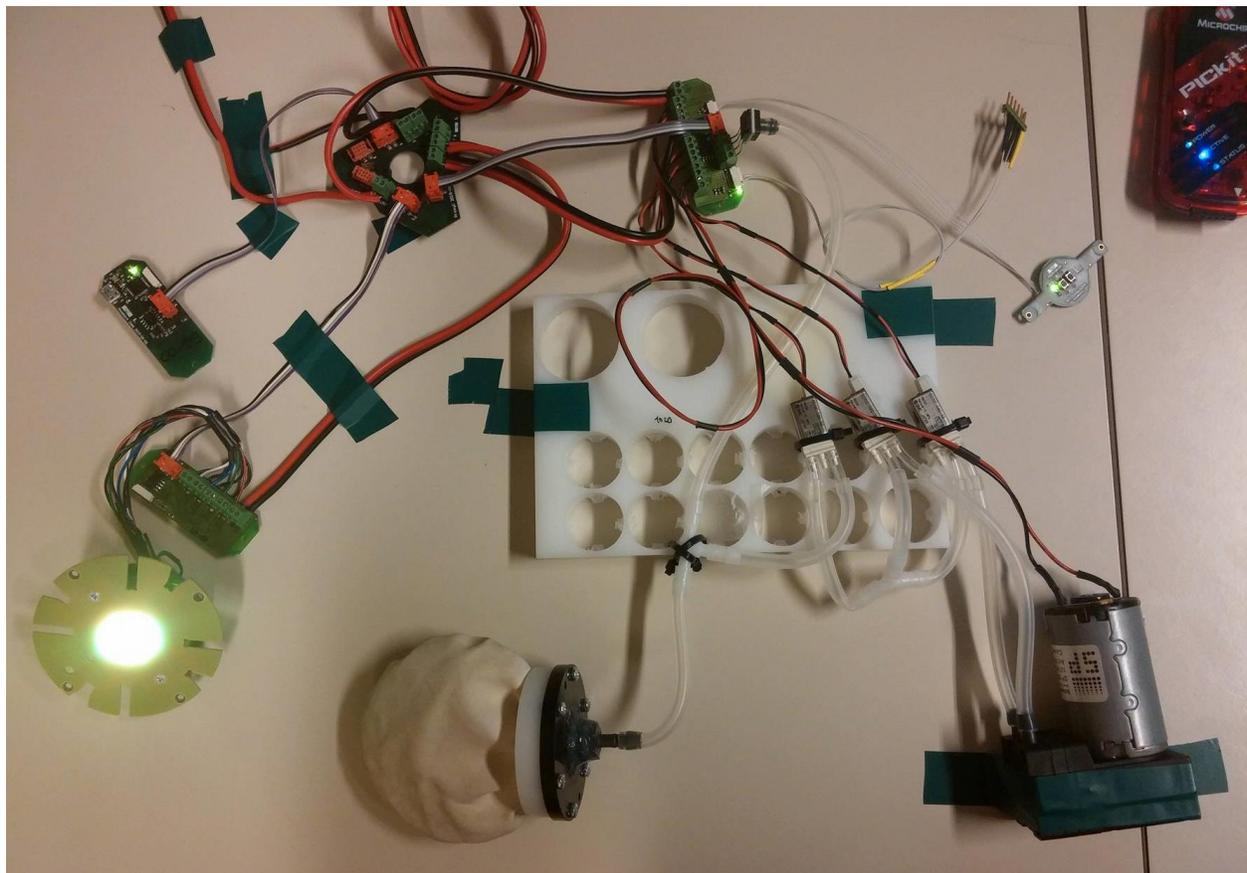
Expected Value	Measured Value	Error
10%	6.45%	35.5%
25%	23.2%	7.2%
50%	48.8%	2.4%
75%	74.6%	0.53%
90%	90.4%	0.44%

As it can be seen from the **Table 14** air pump control is accurate enough. Error rate is getting bigger when the PWM rate set to less but since we are mostly using high PWM rates this error is not affecting the control.

User command results of the Universal Gripper can be seen in the **Figure 39**.



*Figure 41 Universal Gripper in the different states, (a) Atmospheric, (b) Gripping an Object and (c) Maximum Pressure*



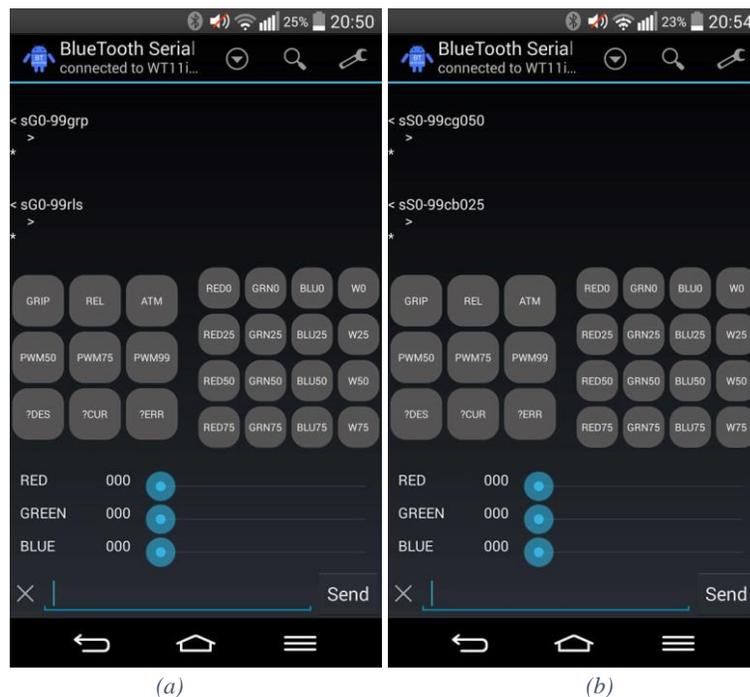
*Figure 42 Test setup with the all project coverage*

### 4. Android User Interface

In addition to the Bluetooth serial, user can also control the Universal Gripper and the Spotlight from an Android smartphone. In order to develop this interface a free application called “*Bluetooth Serial Controller*” downloaded and a new controller configuration is generated based on the boards’ firmware. Some common functions are added to the buttons and serial commands can also be sent from the application. In **Table 15** and **Figure 40** configured buttons and defined commands can be seen.

*Table 15 Buttons configured for the control of the Gripper and Spotlight*

Button Name	Command	Button Name	Command
GRIP	<i>sG0-99grp</i>	RED75	<i>sS0-99cr075</i>
REL	<i>sG0-99rel</i>	GRN0	<i>sS0-99cg0</i>
ATM	<i>sG0-99atm</i>	GRN25	<i>sS0-99cg025</i>
PWM50	<i>sG0-99pwmconfig50</i>	GRN50	<i>sS0-99cg050</i>
PWM75	<i>sG0-99pwmconfig75</i>	GRN75	<i>sS0-99cg075</i>
PWM99	<i>sG0-99pwmconfig99</i>	BLU0	<i>sS0-99cb0</i>
?DES	<i>?G0-99prconfigd</i>	BLU25	<i>sS0-99cb025</i>
?CUR	<i>?G0-99prconfigm</i>	BLU50	<i>sS0-99cb050</i>
?ERR	<i>?G0-99prconfige</i>	BLU75	<i>sS0-99cb075</i>
RED0	<i>sS0-99cr0</i>	W0	<i>sS0-99cw0</i>
RED25	<i>sS0-99cr025</i>	W25	<i>sS0-99cw025</i>
RED50	<i>sS0-99cr050</i>	W50	<i>sS0-99cw050</i>



*Figure 43 Android User Interface (a) during Gripper control and (b) during Spotlight control*

## 5. Conclusion

### 5.1. Summary

In this project we aimed to design a Roombots compatible controller for the Universal Gripper with mechanic design is completed and a Roombots compatible controller for a Spotlight. For the hardware design and firmware development. Previous Roombots designs and firmware were used as heritage. After completing the designs and developing the firmware, tests with the Gripper and Spotlight were also planned.

### 5.2. Achievements

Designs of the Gripper Board and the Spotlight Board were completed in Altium Designer by using the design of the Communication Board as a template. In addition to the Spotlight Board a sub-board called Power LED board was also designed. During hardware design, required components were also designed as new Integrated Libraries and added to the Altium Libraries.

Firmware development of the boards were implemented with MPLAB X IDE with the heritage of previous boards. Required modules such as PWM and ADC were configured and used with proper hardware. Quick hardware test functions and user interface functions were added. In addition to the Bluetooth serial commands, an Android user interface was also generated from the app called “Bluetooth Serial Controller”. In order to have manual controllability, two buttons are added to the Gripper Board.

Designed boards and developed firmware tested with the lab equipment and measured results are compared with the expected values.

### 5.3. Anticipated Future Improvements

Having observed the Spotlight Board results, it is easy to identify that BLUE LED is slightly more powerful than other three LEDs. This was an unexpected results and it makes harder for user to reach intended color mixture. In a future design, current going to BLUE channel can be reduced with an additional hardware or a new LED can be used with the board.

When we look at the pressure sensor results, it can be seen that measured pressure is slightly less than expected pressure and also used pressure sensor is not capable of sensing high pressures correctly, in order prevent these a new pressure sensor can be used.

Although we have an efficient control with the Android interface, a new app, just for controlling Roombots including Spotlight and Gripper Board can be developed. By doing so, more specialized controls can be added to the Android user interface.

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**Figure 42** Test setup with the all project coverage -----37

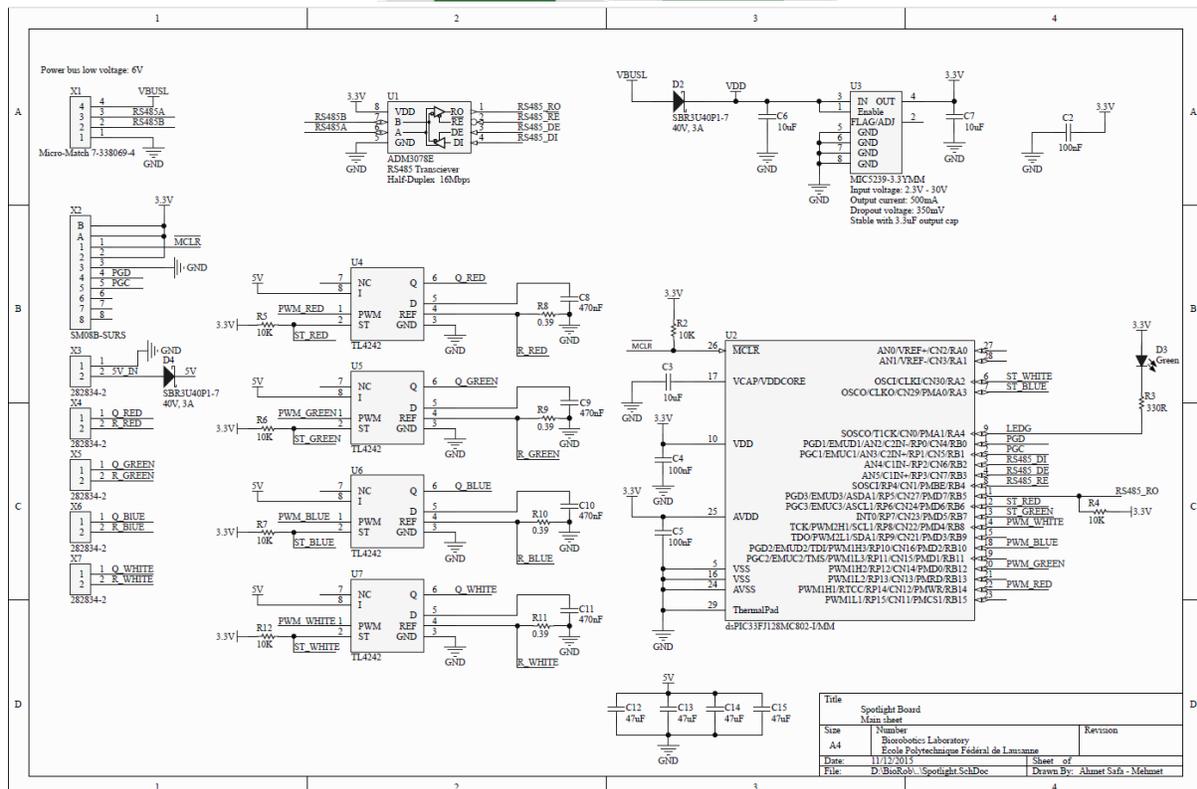
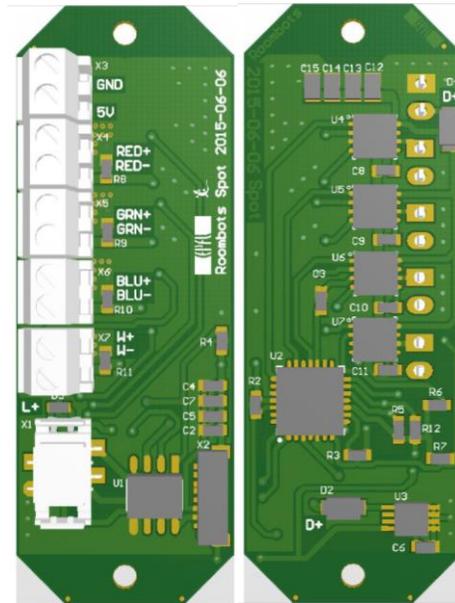
**Figure 43** Android User Interface (a) during Gripper control and (b) during Spotlight control -----38

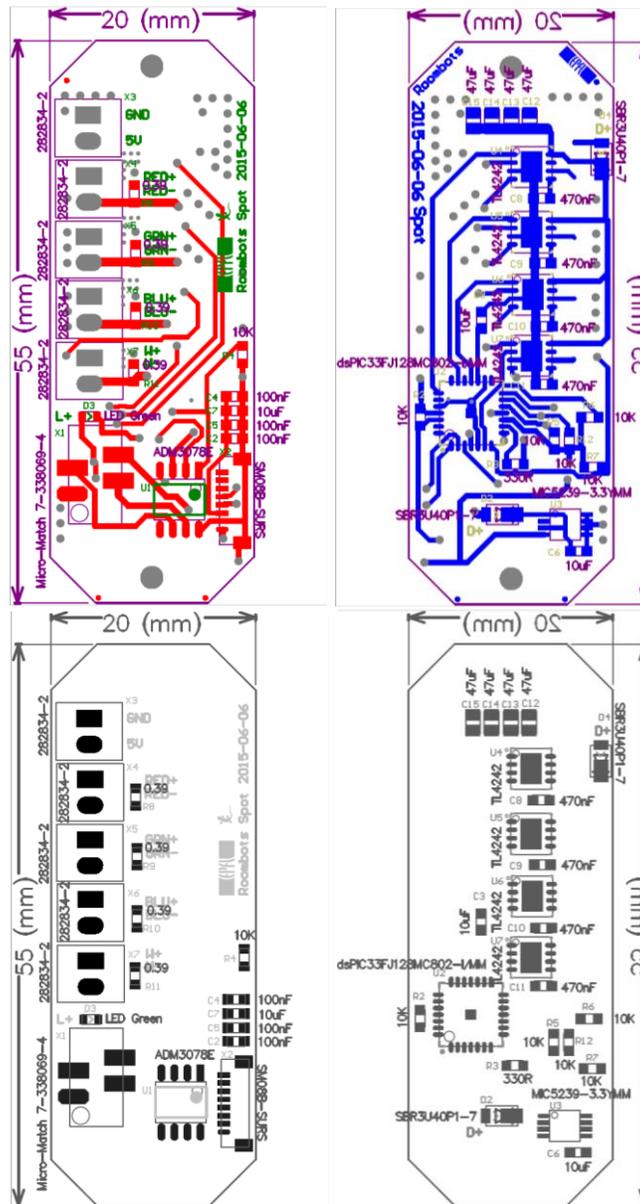
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# Appendix

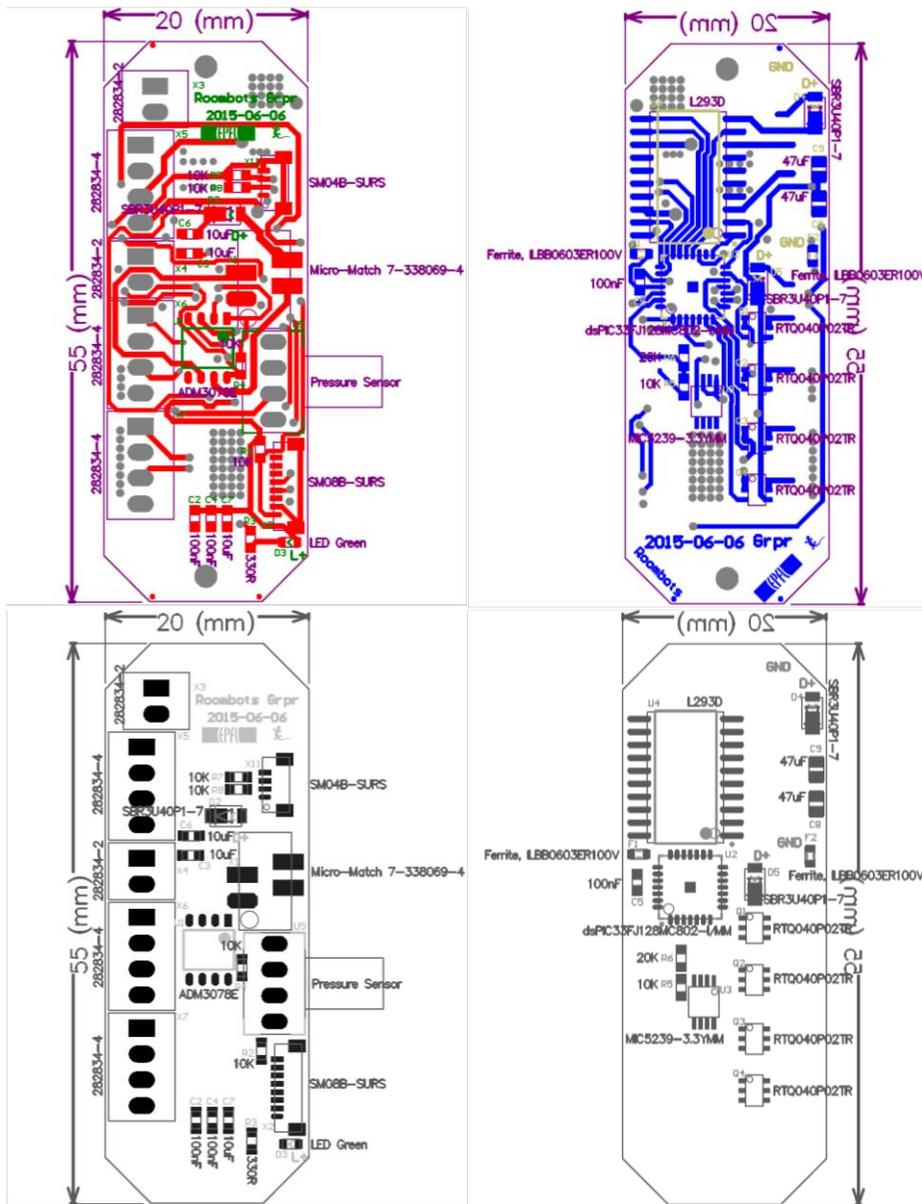
## A. Complete Design of Spotlight Board





Designator	Comment	Description	Footprint	LibRef	Quantity
C2, C4, C5	100nF	Capacitor, 50V, X7R	CAPC1608N	Cap	3
C3, C6, C7	10uF	Capacitor, 25V, X5R	CAPC1608N	Cap	3
C8, C9, C10, C11	470nF	Capacitor, 25V, X5R	CAPC1608N	Cap	4
C12, C13, C14, C15	47uF	Capacitor, 10V, X5R	CAPC2012L	Cap	4
D2, D4	SBR3U40P1-7	Schottky Diode	PowerDI123	D Schottky	2
D3	LED Green	LED	DIODE1608L	LED	1
R2, R4, R5, R6, R7, R12	10K	Resistor, 1% precision	RESC1608N_R	Res1	6
R3	330R	Resistor, 1% precision	RESC1608N_R	Res1	1
R8, R9, R10, R11	0.39	Resistor, 1% precision, set value for current	RESC1608N_R	Res1	4
U1	ADM3078E	Half-Duplex RS485 Transceiver, 3.3V, 16Mbps	SOIC-8_M	ADM3078E	1
U2	dsPIC33FJ128MC802-1MM	High-Performance 16-bit Digital Signal Controller, 128 KB Flash, 16 KB RAM, 28-Pin QFN, Industrial Temperature	QFN5-MM28_M_SmallExp	dsPIC33FJ128MC802-1MM	1
U3	MICS239-3.3Y1MM	LDO, 500mA, Vin2.3V-30V	MSOP-8	MICS239	1
U4, U5, U6, U7	TL4242	TL4242-ConstantCurrentLEDDriver	TL4242_DRJ_5-PWSO-N8	TL4242-ConstantCurrentLEDDriver	4
X1	Micro-Match 7-338069-4	4-pin mikro-match connector	Micro-Match 7-338069-4	Connector-4x1	1
X2	SM08B-SURS	8-pin programming connector	SM08B-SURS	SM08B-SURS	1
X3, X4, X5, X6, X7	282834-2	2-pin connector	282834-2	2x1	5





Designator	Comment	Description	Footprint	LibRef	Quantity
C2, C4, C5	100nF	Capacitor, 50V, X7R	CAPC1608N	Cap	3
C3, C6, C7	10uF	Capacitor, 25V, XSR	CAPC1608N	Cap	3
C8, C9	47uF	Capacitor, 10V, XSR	CAPC2012L	Cap	2
D2, D4, D5	SBR3U40P1-7	Schottky Diode	PowerD1123	D Schottky	3
D3	LED Green	LED	DIODE1608L	LED	1
F1, F2	Ferrite, LBB0603ER100V	Ferrite Bead, 0.05R 500mA	RESC1608L	Fuse 1	2
Q1, Q2, Q3, Q4	RTQ040P02TR	P-Channel MOSFET	TSOT23-6	pFET RTQ040P02TR	4
R2, R4, R5, R7, R8	10K	Resistor, 1% precision	RESC1608N_R	Res1	5
R3	330R	Resistor, 1% precision	RESC1608N_R	Res1	1
R6	20K	Resistor, 1% precision	RESC1608N_R	Res1	1
U1	ADM3078E	Half-Duplex RS485 Transceiver, 3.3V, 16Mbps	SOIC-8_N	ADM3078E	1
U2	dsPIC33F128MC802-1MM	High-Performance 16-bit Digital Signal Controller, 128 KB Flash, 16 KB RAM, 28-Pin QFN, Industrial Temperature	QFNS-MM28_M_SmallExp	dsPIC33F128MC802-1MM	1
U3	MIC5239-3.3VMM	LDO, 500mA, Vin:2.3V-30V	MSOP-8	MIC5239	1
U4	L293D		SO20_N	L293D_Driver	1
U5	Pressure Sensor	SSCMANN015PAAAS	DIP4_SIP_AN	SSCMANN015PAAAS	1
X1	Micro-Match 7-338069-4	4-pin mikro-match connector	Micro-Match 7-338069-4	Connector-4x1	1
X2	SM08B-SURS	8-pin programming connector	SM08B-SURS	SM08B-SURS	1
X3, X4	282834-2	2-pin connector	282834-2	2x1	2
X5, X6, X7	282834-4	4-pin connector	282834-4	4x1	3
X11	SM04B-SURS	4-pin button-sensor conn	SM04B-SURS	SM04B-SURS	1