

ARTIFICIAL NEURAL NETWORK-BASED ROBOTICS

A Thesis

presented to

the Faculty of California Polytechnic State University,

San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Electrical Engineering

by

Justin Ng

June 2018

© 2018  
Justin Ng  
ALL RIGHTS RESERVED

## COMMITTEE MEMBERSHIP

TITLE: Artificial Neural Network-Based Robotics

AUTHOR: Justin Ng

DATE SUBMITTED: June 2018

COMMITTEE CHAIR: Andrew Danowitz, Ph.D.  
Assistant Professor of Electrical Engineering

COMMITTEE MEMBER: Xiao-Hua Yu, Ph.D.  
Professor of Electrical Engineering

COMMITTEE MEMBER: Fred W. DePiero, Ph.D.  
Professor of Electrical Engineering

## ABSTRACT

Artificial Neural Network-Based Robotics

Justin Ng

Artificial neural networks (ANNs) are highly-capable alternatives to traditional problem solving schemes due to their ability to solve non-linear systems with a non-algorithmic approach. The applications of ANNs range from process control to pattern recognition and, with increasing importance, robotics. This paper demonstrates continuous control of a robot using an actor-critic algorithm based on deep deterministic policy gradients (DDPG) originally conceived by Google DeepMind. The robot performs tasks such as locomotion within an enclosed area and object transportation. The paper also details the robot design process and explores the challenges of implementation in a real-time system.

## ACKNOWLEDGMENTS

Thanks to:

- Everyone for everything.

## TABLE OF CONTENTS

	Page
LIST OF TABLES . . . . .	vii
LIST OF FIGURES . . . . .	viii
CHAPTER	
1 Mechanical Design . . . . .	1
1.1 Introduction . . . . .	1
1.2 Base Platform . . . . .	5
1.3 Shooting Mechanism . . . . .	6
1.4 Ball Hopper . . . . .	9
1.5 Control Unit . . . . .	13
BIBLIOGRAPHY . . . . .	15
APPENDICES	
A Interconnect PCB Schematic . . . . .	18
B Interconnect PCB Layout . . . . .	25
C Interconnect PCB Bill of Materials . . . . .	27
D STM32CubeMX Report . . . . .	31

## LIST OF TABLES

Table	Page
1.1 Roborodentia 2018 Mechanical Requirements . . . . .	1

## LIST OF FIGURES

Figure	Page
1.1 Photograph of Robot . . . . .	2
1.2 Full Robot Render – Isometric View . . . . .	3
1.3 Full Robot Render – Top View . . . . .	3
1.4 Full Robot Render – Front View . . . . .	4
1.5 Full Robot Render – Right View . . . . .	4
1.6 Base Platform . . . . .	5
1.7 Shooting Mechanism – Exploded View . . . . .	7
1.8 Shooting Mechanism – Top View . . . . .	7
1.9 Shooting Mechanism – Cross Section View . . . . .	8
1.10 Shooting Mechanism – Shooter Wheel . . . . .	9
1.11 Ball Hopper . . . . .	10
1.12 Ball Hopper – Exploded View . . . . .	10
1.13 Ball Hopper – Cross Section View . . . . .	11
1.14 Ball Hopper – Dispensing Gate . . . . .	12
1.15 Ball Hopper – Braces . . . . .	13
1.16 Control Unit . . . . .	14
1.17 Control Unit – Standoffs . . . . .	14
B.1 Interconnect PCB Layout – Top Layer . . . . .	25
B.2 Interconnect PCB Layout – Bottom Layer . . . . .	26

# Chapter 1

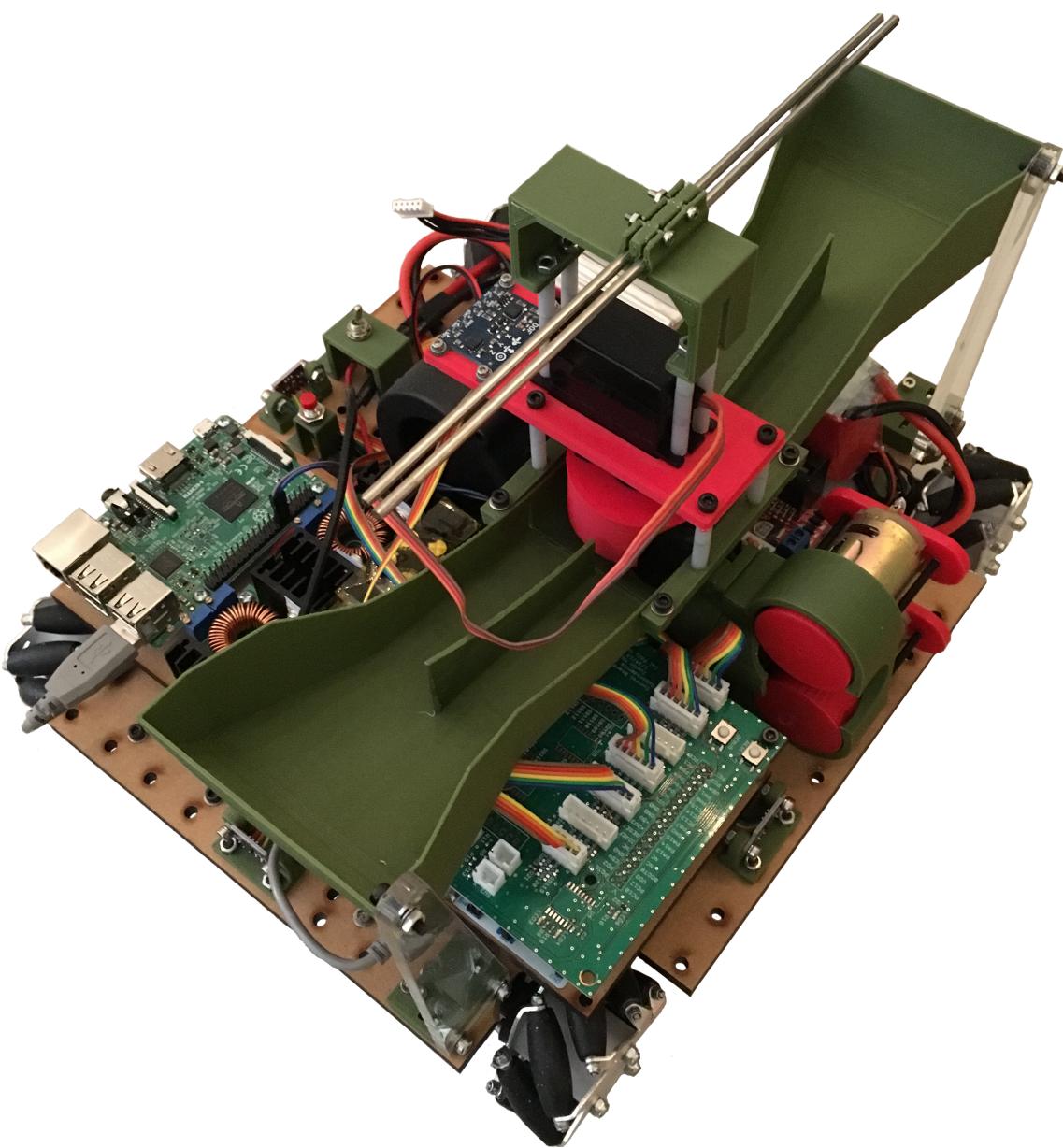
## MECHANICAL DESIGN

### 1.1 Introduction

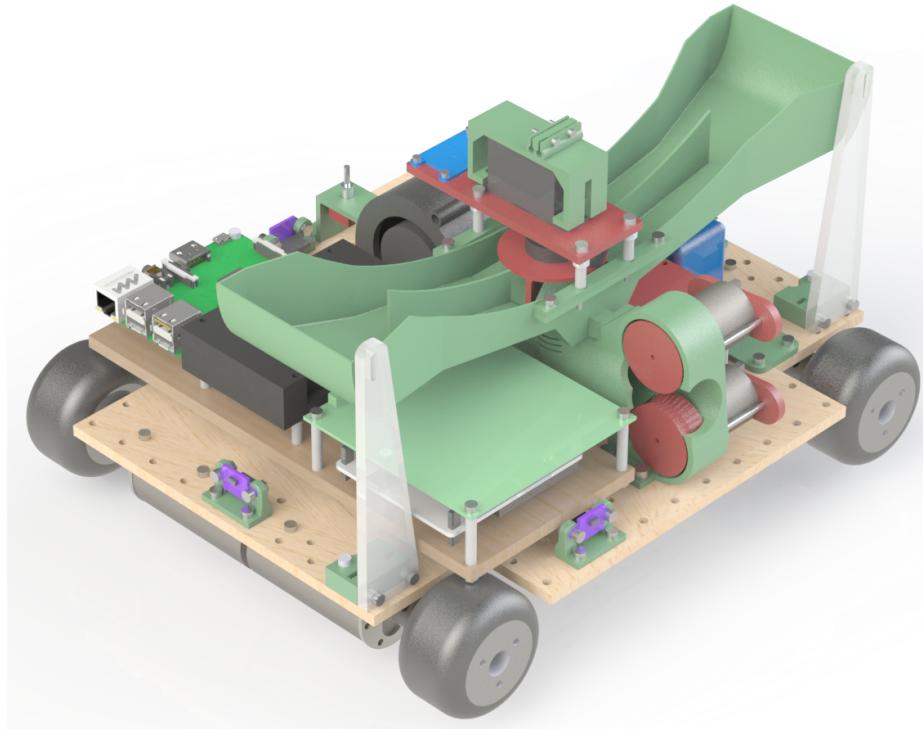
The robot meets the design specification shown in Table 1.1. It consists of four subassemblies: the base platform, shooting mechanism, ball hopper, and control unit. Each section was first modeled in SolidWorks, an industry-standard solid modeling CAD program. The designed parts were then fabricated using a laser cutter or 3D printer and assembled with metric hardware. Figure 1.1 displays a photograph of the robot while figures 1.2 through 1.5 show standard view renders of the SolidWorks model. Note that the robot uses mecanum wheels (a type of omni-directional wheel) which are modeled here as regular wheels for simplicity.

**Table 1.1: Roborodentia 2018 Mechanical Requirements**

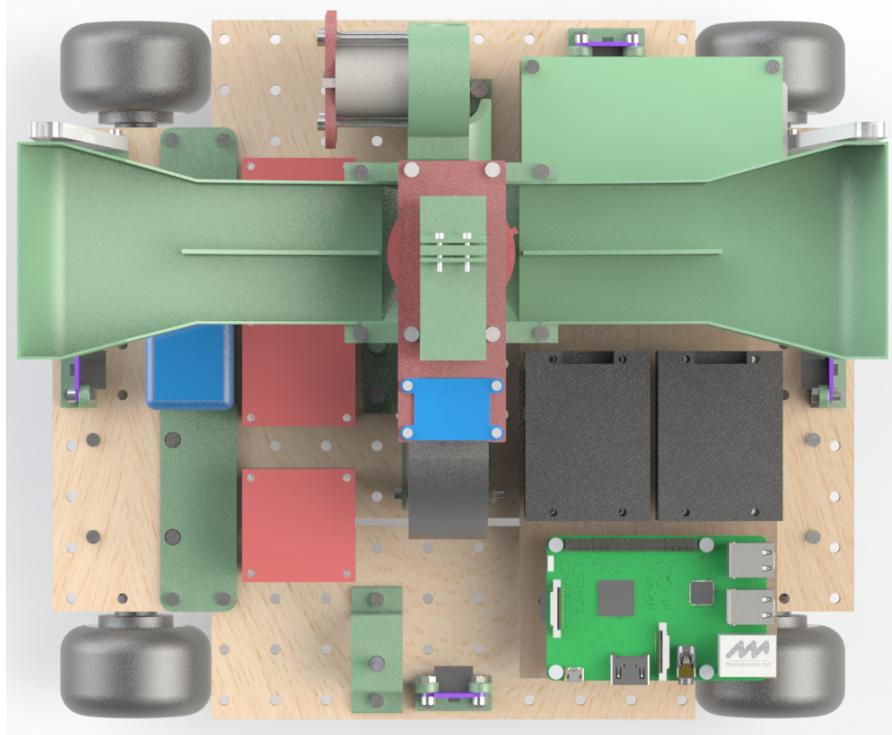
Requirement
1 Maximum footprint of 12" x 14" or smaller at start of match but may expand up to 14" x 17" during match.
2 Maximum height of 14" at start of match but no restriction during match.
3 Robot may not disassemble into multiple parts.
4 Robot may not be airborne.
5 Shooting mechanisms may not accelerate balls past 50 feet per second.



**Figure 1.1: Photograph of Robot**



**Figure 1.2: Full Robot Render – Isometric View**



**Figure 1.3: Full Robot Render – Top View**

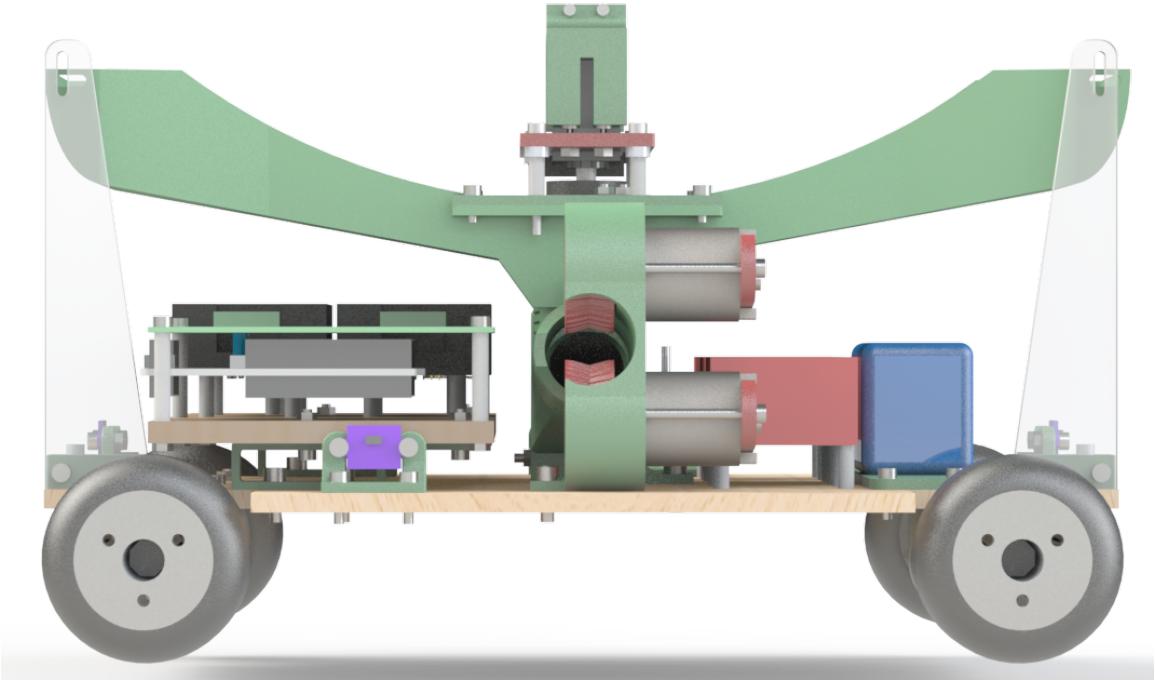


Figure 1.4: Full Robot Render – Front View

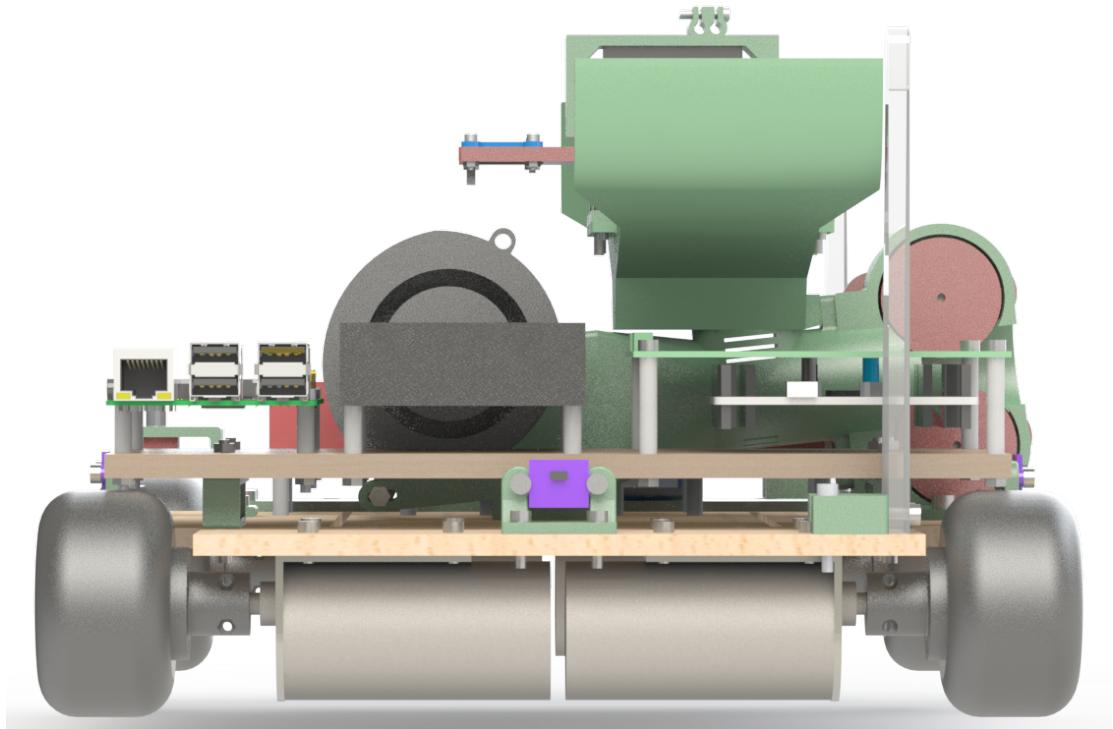
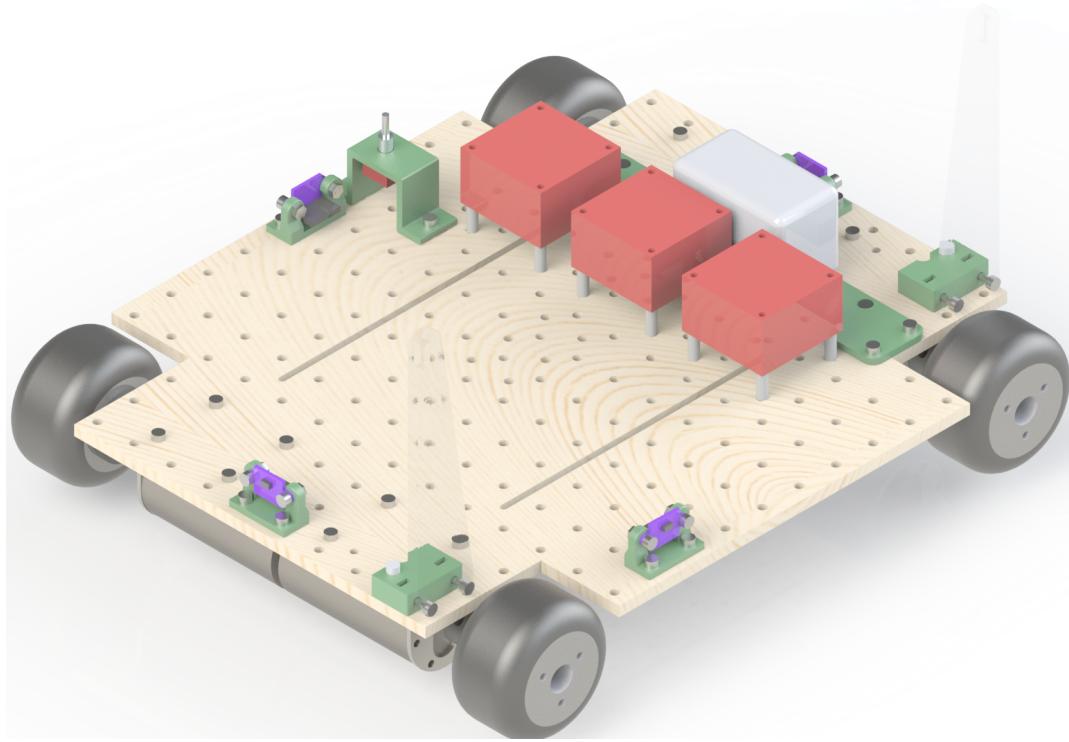


Figure 1.5: Full Robot Render – Right View

## 1.2 Base Platform

The base platform of the robot, made from 1/4" medium density fiberboard (MDF), serves as the primary structural component and a mounting point for the motors, electronics, shooting mechanism, and hopper. The wood is laser cut with a 20 mm grid of 4.5 mm holes to allow modular placement of components and the corners are removed to allow clearance for the wheels. Figures 1.6 shows the assembled view of the subassembly.



**Figure 1.6: Base Platform**

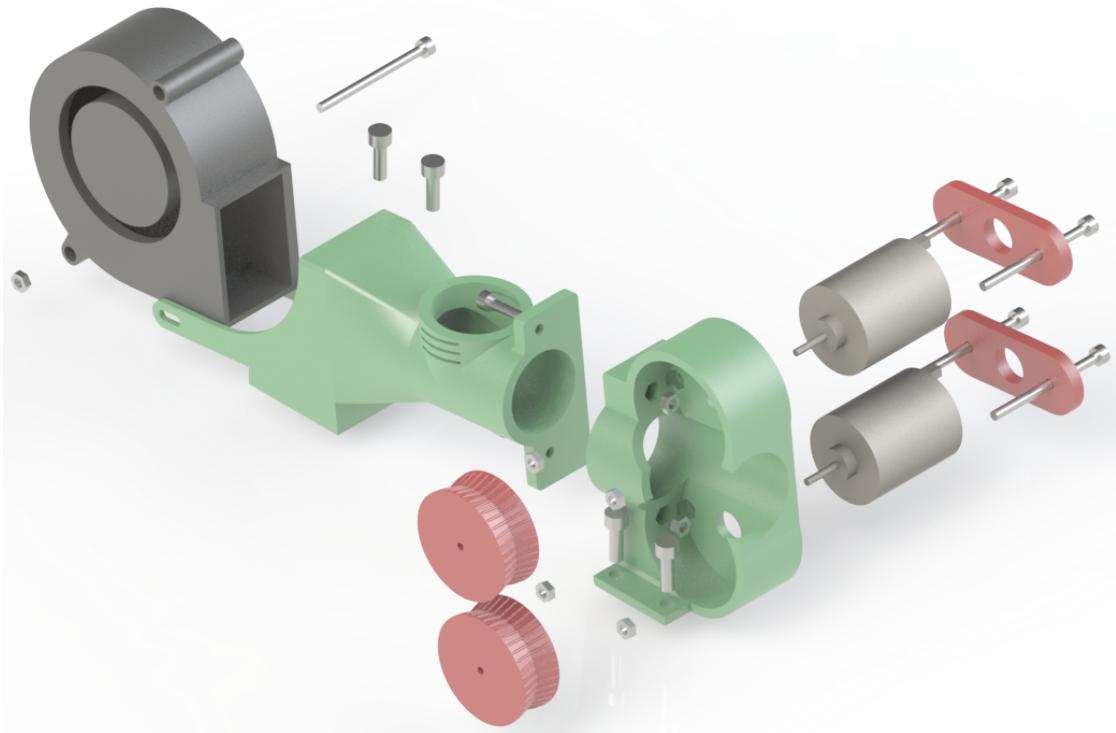
Four 12V Pololu 37D motors geared at a 70:1 ratio drive each of the 60 mm mecanum wheels. Each wheel contains eight angled rollers so unlike regular wheels which only produce a force vector perpendicular to the axis, mecanum wheels also produce a vector parallel to the axis. With the appropriate combination of speed and direction of each wheel, the robot can achieve simultaneous translation and rotation

in any direction.

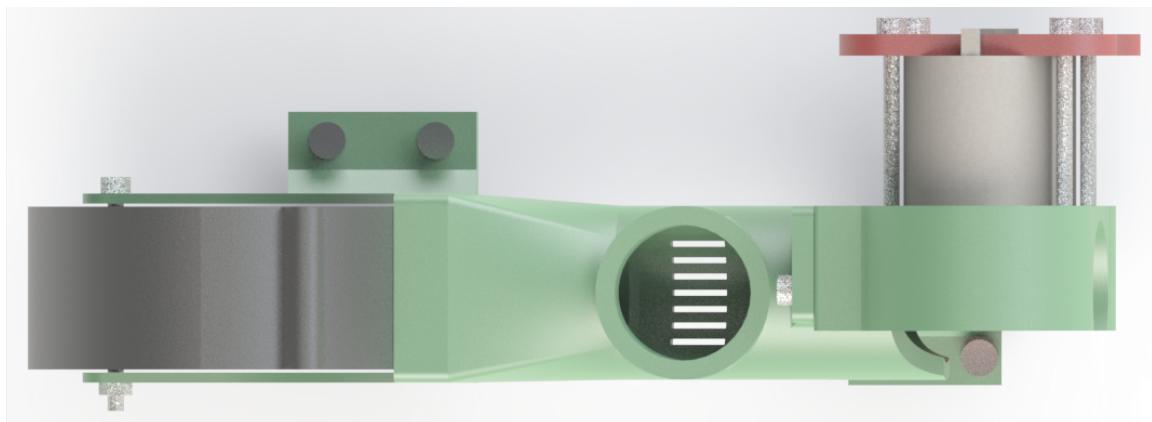
Several electronic components are mounted directly on the base platform. Along the four edges of the platform, four ST Microelectronics VL53L0X laser rangefinders mounted on 3D printed brackets sense distance. These sensors cost between \$6 to \$20 mounted on a small PCB with supporting circuitry and can sense distances between 30 mm and 2000 mm at a rate of 30 Hz and less than 10% error in most test conditions [15]. A 4S, 1200 mAH LiPo battery powers the system through a on/off toggle switch.

### 1.3 Shooting Mechanism

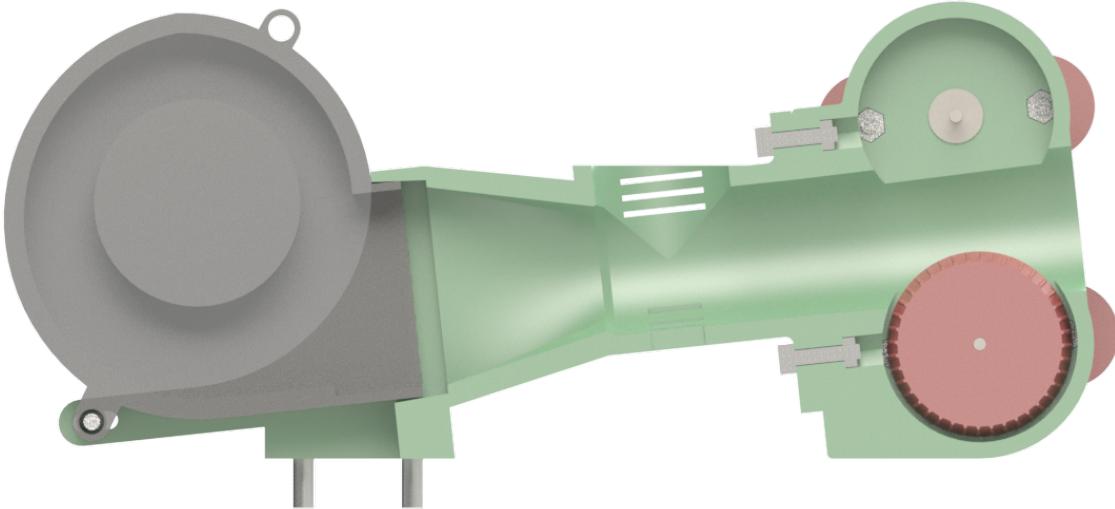
The shooting mechanism naturally takes inspiration from the official Nerf Rival Blaster toys since the manufacturer specifically optimized them to fire Nerf Rival balls in a way similar to baseball pitching machines. Figure 1.7 shows an exploded view of the subassembly while Figure 1.8 displays the top view. The mechanism consists of two sections: the **barrel** (left green part in Figure 1.7) and the **wheel housing** (right green part in Figure 1.7). Both parts were fabricated using a fused deposition modeling (FDM) 3D printer as the geometries are highly complex. Therefore, the shooting mechanism consists of two separate components versus a unibody design to allow each half to be fabricated with optimal print direction, strength, and finish quality. The barrel is angled 6° above horizontal, targeting the vertical center of the nets.



**Figure 1.7:** Shooting Mechanism – Exploded View



**Figure 1.8:** Shooting Mechanism – Top View

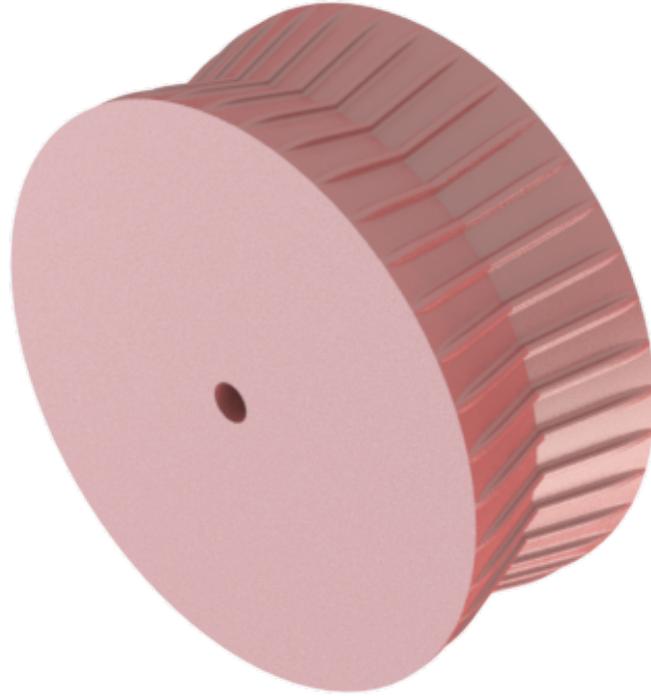


**Figure 1.9: Shooting Mechanism – Cross Section View**

The **barrel** directs balls from the **ball hopper** to the **wheel housing**. First, the ball enters the barrel through a vertical chute by force of gravity. As the ball falls into the barrel, a high-pressure centrifugal (or blower fan) attached at the back of the barrel pushes it into the wheel housing inlet. As seen in Figure 1.9, the barrel slightly narrows in the area behind the top chute to prevent the ball from rolling backwards towards the blower fan. A loft feature creates a smooth transition between the rectangular fan connection and the circular barrel. The foam balls, nominally 23 mm in diameter, would occasionally jam in a 24 mm barrel so all pathways are 25 mm. In the initial design, the pressure created by the blower fan was so high that it prevented the ball from falling down the vertical chute so strategically placed vents reduce the barrel pressure as the ball falls through the chute. As the ball travels down the chute into the barrel, it blocks the vents, increasing the pressure and forcing the ball into the wheel housing.

Inside the **wheel housing**, two counter-rotating 34mm wheels press fitted to two high-speed 12 V motors rapidly accelerate the foam ball up to 50 feet per second. The 14 mm gap between wheels compresses the ball to increase grip, thereby improving

energy transfer. The motors lightly press fit into the wheel housing and are secured with 3D printed braces. The perimeter of each 3D printed wheel, detailed in Figure 1.10, consists of a ribbed V-groove to increase the contact patch and grip with the compressed foam ball. Two "feet" with bolt holes at the bottom of the barrel and wheel housing secure the shooting mechanism to the base platform.



**Figure 1.10: Shooting Mechanism – Shooter Wheel**

#### 1.4 Ball Hopper

The robot must obtain the foam balls from supply tubes mounted on two sides of the side. The bottoms of the supply tubes are positioned seven inches above the floor and a swinging flap holds the balls in. The ball hopper, shown in Figure 1.11 is a large 3D printed component designed to push the swinging flap away, collect the balls, store them, and dispense them into the shooting mechanism. Figure 1.12 shows an exploded view of the subassembly.

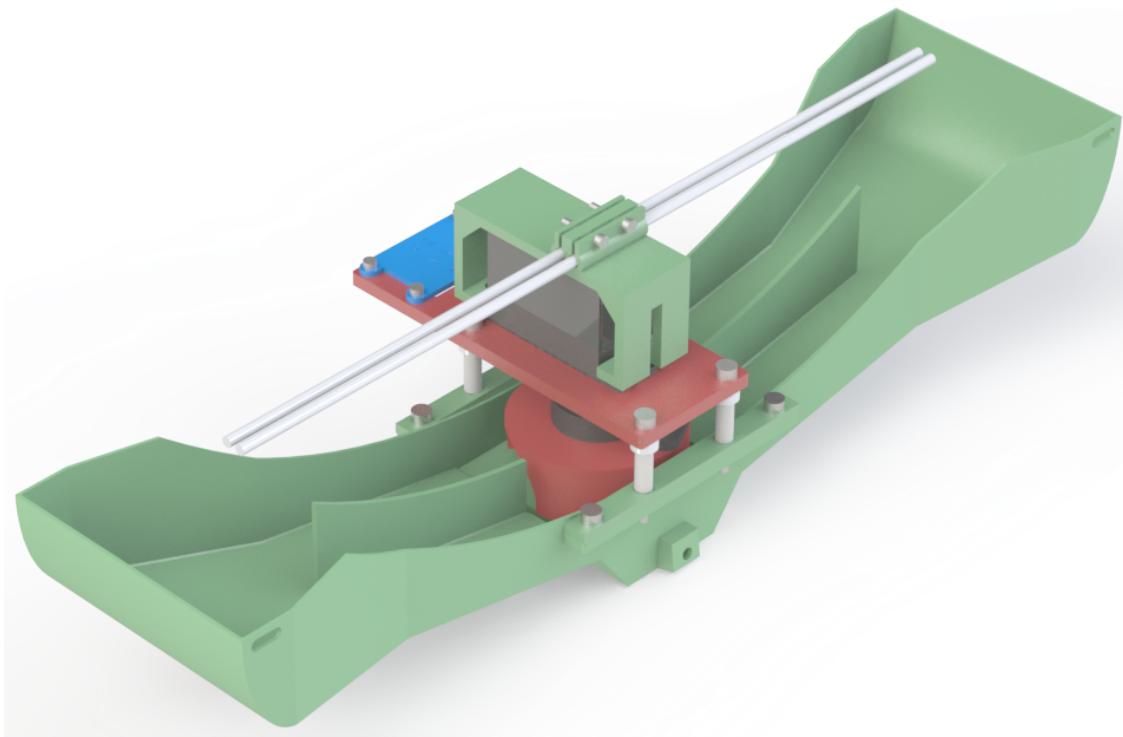


Figure 1.11: Ball Hopper

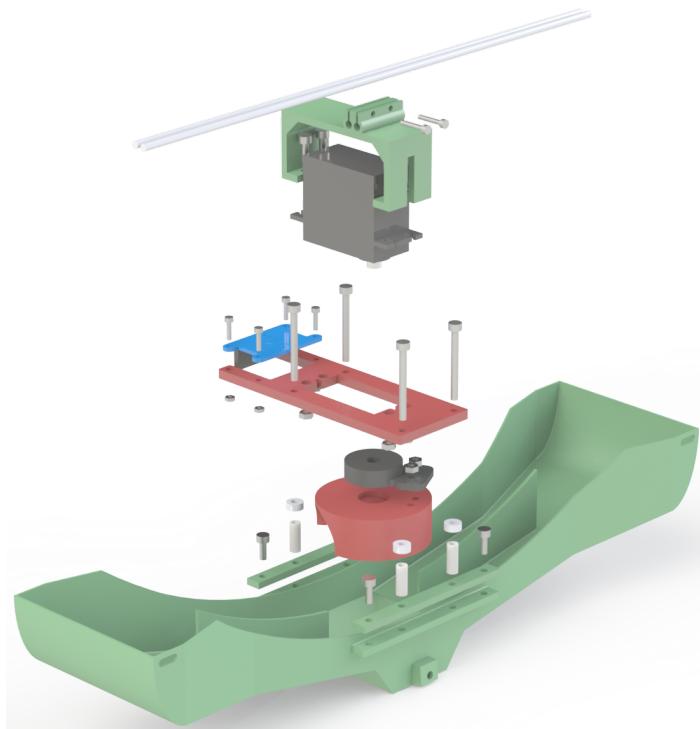
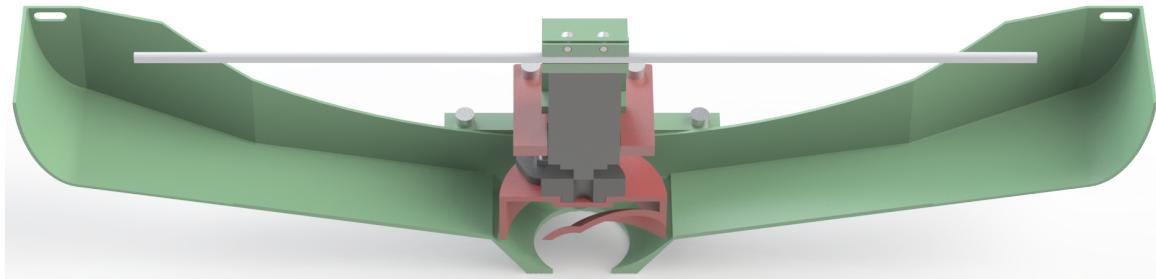


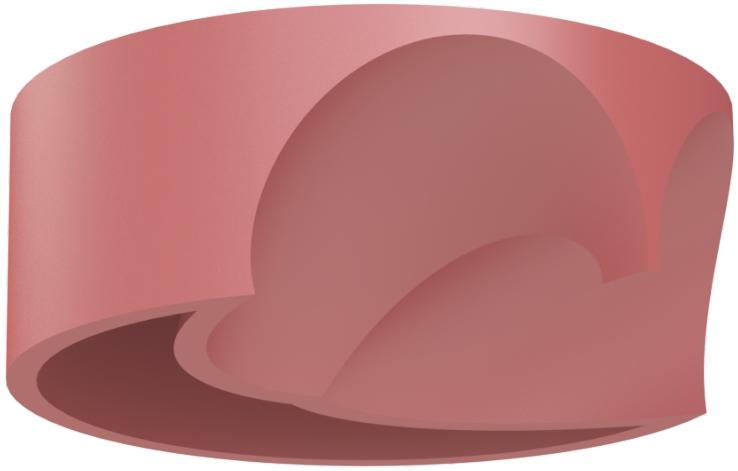
Figure 1.12: Ball Hopper – Exploded View

First, the robot moves the hopper underneath the supply tube. As the flap swings open, the balls rolls down the steep sloped portion of the hopper. Visible in the cross section view of Figure 1.13, The slope rapidly becomes less steep in order to transition the balls downward momentum into sideways momentum, keeping balls from jamming against each other. The balls then roll into one of two channels before stopping at the dispensing gate.



**Figure 1.13: Ball Hopper – Cross Section View**

The dispensing gate, shown in Figure 1.14, controls the movement of balls between hopper channel and shooting mechanism entrance. Its complex shape directs balls into the center of the ball hopper from one channel at a time to prevent jamming. A common 180° movement servo, mounted in a 3D printed bracket above the center of the hopper, controls the dispensing gate. Fastened to the same bracket, an inertial measurement unit (IMU) measures magnetic compass heading and acceleration in three dimensions.



**Figure 1.14: Ball Hopper – Dispensing Gate**

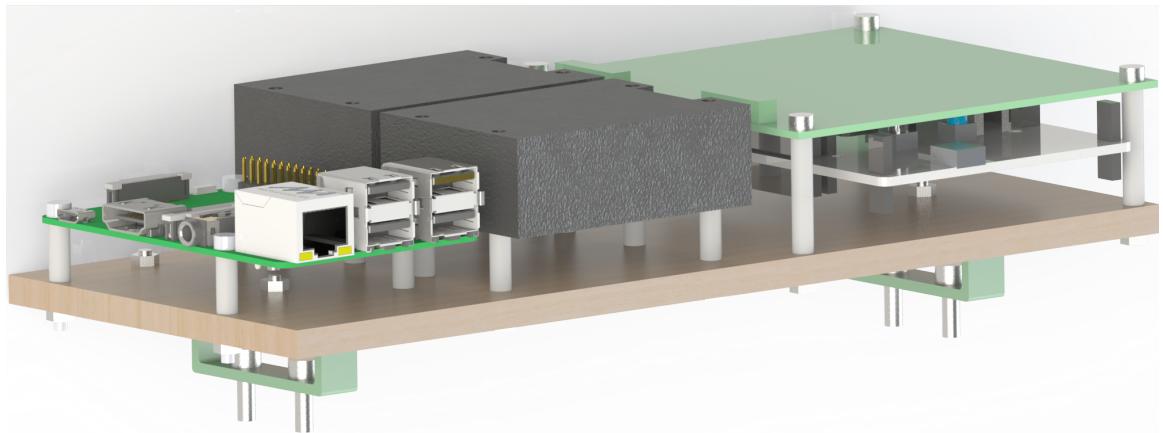
The ball hopper is mounted at three points: the top of the shooting mechanism and the left and right edges of the robot using 3D printed and acrylic braces shown in Figure 1.15.



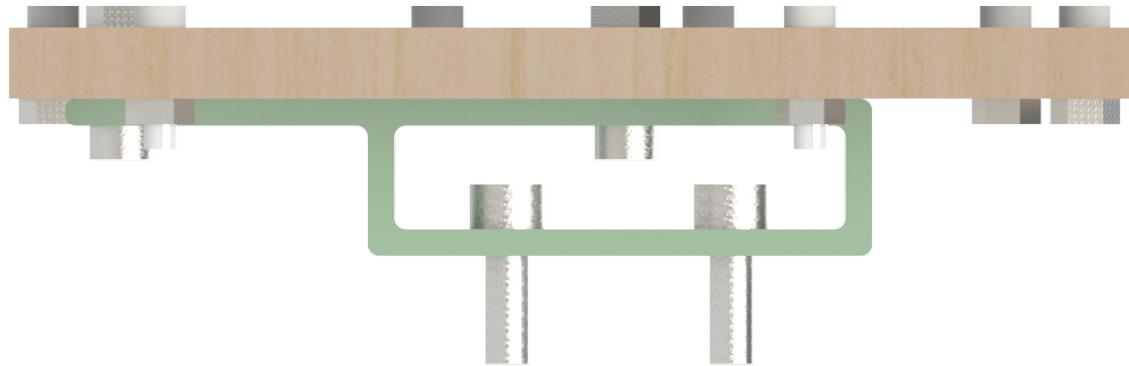
**Figure 1.15: Ball Hopper – Braces**

## 1.5 Control Unit

The control unit, shown in Figure 1.16, consists of a 1/4" MDF board with various electronic components mounted: two off-the-shelf DC-DC switching converters, a custom interconnect printed circuit board (PCB), an off-the-shelf STM32 Nucleo-64 development board, and the Raspberry Pi computer. Two 3D printed standoffs, the green parts shown in Figure 1.17, connect the control unit to the platform and raise it slightly to avoid colliding with the robot's wheels.



**Figure 1.16:** Control Unit



**Figure 1.17:** Control Unit – Standoffs

## BIBLIOGRAPHY

- [1] . . . , 2018. [Online; accessed May 11, 2018].
- [2] Adafruit. Adafruit 9-DOF IMU Breakout.  
<https://www.adafruit.com/product/1714>, 2014. [Online; accessed May 15, 2018].
- [3] AliExpress. DC-DC CC CV Buck Converter.  
[https://www.aliexpress.com/item/DC-DC-CC-CV-Buck-Converter-Volt-Step-Down-12V-19V-24V-Car-Laptop-Power-Supply/32822603345.html?spm=2114.search0104.3.135.191f73dfqonWDU&ws\\_ab\\_test=searchweb0\\_0,searchweb201602\\_2\\_10152\\_10151\\_10065\\_10344\\_10130\\_10068\\_10324\\_10547\\_10342\\_10325\\_10546\\_10343\\_10340\\_10548\\_10341\\_10545\\_10696\\_10084\\_10083\\_10618\\_10307\\_10059\\_308\\_100031\\_10103\\_10624\\_10623\\_10622\\_10621\\_10620,searchweb201603\\_32,ppcSwitch\\_5&algo\\_expid=30a33cc9-3acf-4021-b514-6ba550085dd9-19&algo\\_pvid=30a33cc9-3acf-4021-b514-6ba550085dd9&priceBeautifyAB=0](https://www.aliexpress.com/item/DC-DC-CC-CV-Buck-Converter-Volt-Step-Down-12V-19V-24V-Car-Laptop-Power-Supply/32822603345.html?spm=2114.search0104.3.135.191f73dfqonWDU&ws_ab_test=searchweb0_0,searchweb201602_2_10152_10151_10065_10344_10130_10068_10324_10547_10342_10325_10546_10343_10340_10548_10341_10545_10696_10084_10083_10618_10307_10059_308_100031_10103_10624_10623_10622_10621_10620,searchweb201603_32,ppcSwitch_5&algo_expid=30a33cc9-3acf-4021-b514-6ba550085dd9-19&algo_pvid=30a33cc9-3acf-4021-b514-6ba550085dd9&priceBeautifyAB=0), 2018. [Online; accessed May 11, 2018].
- [4] Cal Poly. Roborodentia - Cal Poly, San Luis Obispo. <http://www.myurl.com>, 2018. [Online; accessed May 11, 2018].
- [5] Fabio Varesano. FreeIMU Magnetometer and Accelerometer Calibration GUI.  
<http://www.varesano.net/blog/fabio/freeimu-magnetometer-and-accelerometer-calibration-gui-alpha-version-out>, 2012. [Online; accessed May 11, 2018].
- [6] R. R. Labbe. Kalman and Bayesian Filters in Python, Sep 2017.
- [7] Leopoldo Armesto. How to generate a PPM signal with Arduino to control a

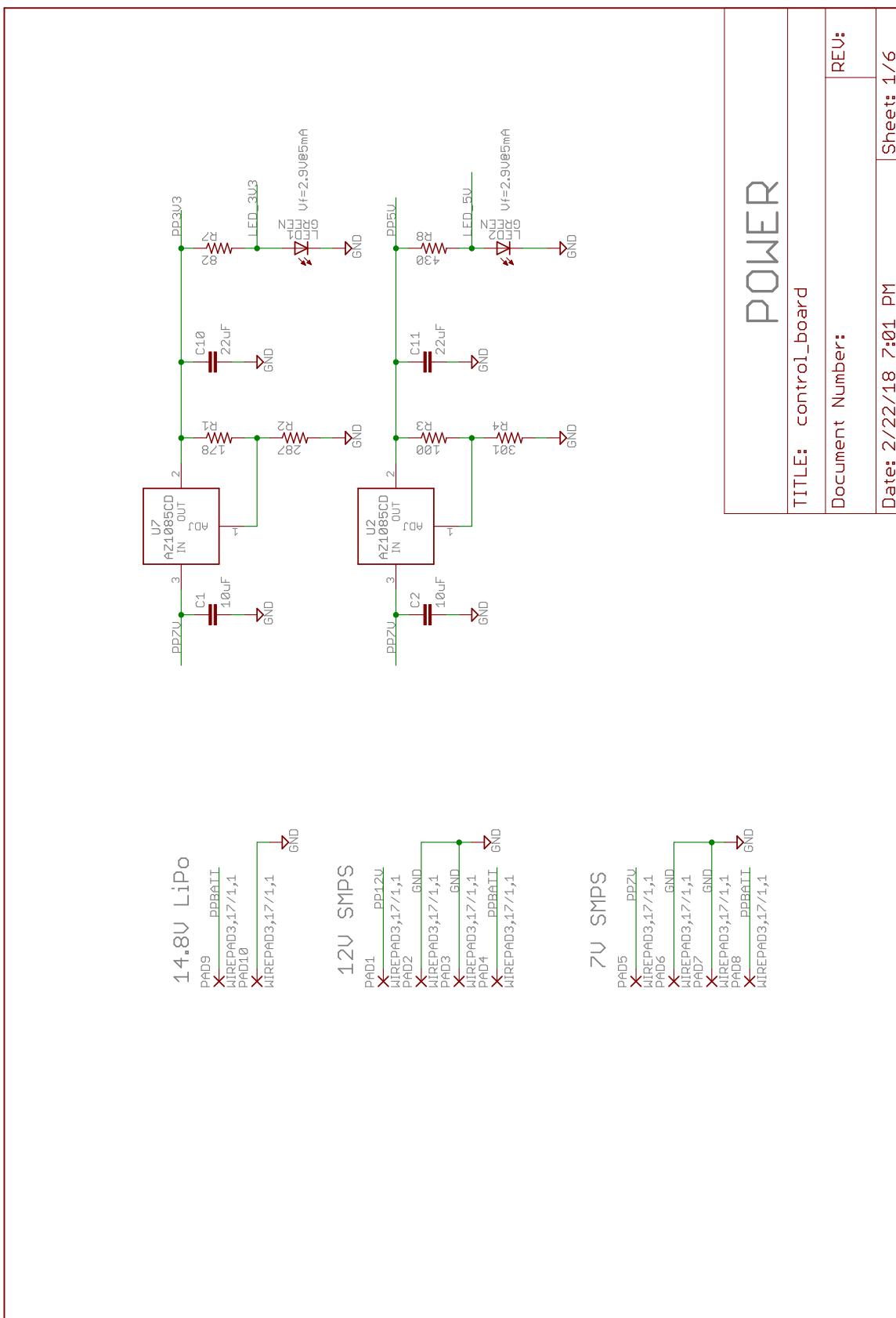
- servo? <http://robotica.webs.upv.es/en/how-to-generate-a-ppm-signal-with-arduino-to-control-a-servo/>, 2015. [Online; accessed May 11, 2018].
- [8] MechaMan. Working with L298N DC Motor Driver. <http://fritzing.org/projects/working-with-l298n-dc-motor-driver>, 2018. [Online; accessed May 13, 2018].
- [9] R. Negenborn. *Robot Localization and Kalman Filters*. PhD thesis, Sep 2003.
- [10] Nevada Mark. FAQ: Hard & Soft Iron Correction for Magnetometer Measurements. <https://ez.analog.com/docs/DOC-2544>, 2014. [Online; accessed May 11, 2018].
- [11] D. H. Nguyen and B. Widrow. Neural Networks for Self-Learning Control Systems. *IEEE Control Systems Magazine*, Apr 1990.
- [12] STMicroelectronics. LSM303DLHC Datasheet. <http://www.st.com/resource/en/datasheet/DM00027543.pdf>, 2013. [Online; accessed May 15, 2018].
- [13] STMicroelectronics. STM32 Nucleo-64 User Manual. [http://www.st.com/content/ccc/resource/technical/document/user\\_manual/98/2e/fa/4b/e0/82/43/b7/DM00105823.pdf/files/DM00105823.pdf/jcr:content/translations/en.DM00105823.pdf](http://www.st.com/content/ccc/resource/technical/document/user_manual/98/2e/fa/4b/e0/82/43/b7/DM00105823.pdf/files/DM00105823.pdf/jcr:content/translations/en.DM00105823.pdf), 2017. [Online; accessed May 11, 2018].
- [14] STMicroelectronics. VL53L0X. <http://www.st.com/en/imaging-and-photonics-solutions/vl53l0x.html>, 2018. [Online; accessed May 15, 2018].

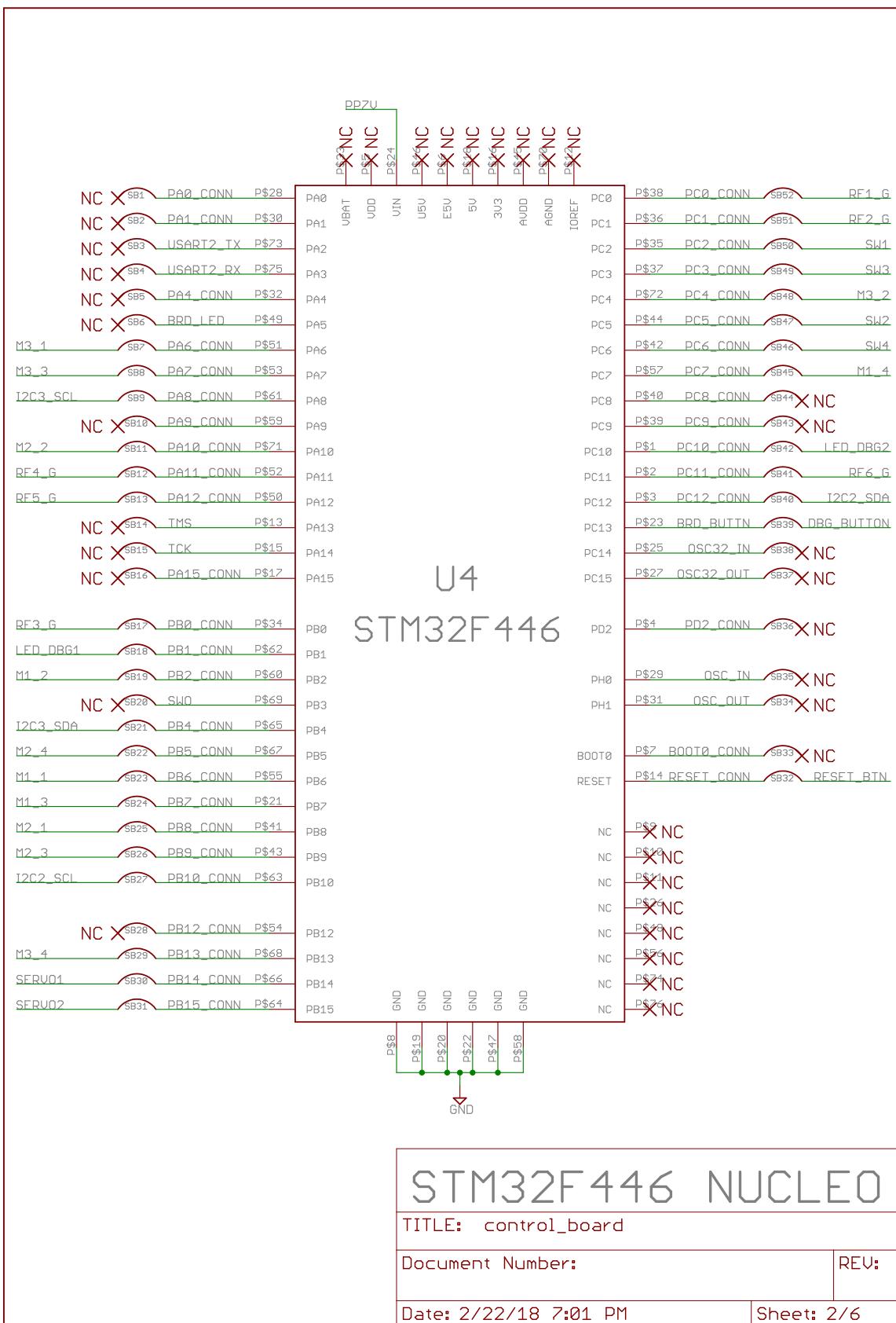
[15] STMicroelectronics. VL53L0X Datasheet.  
<http://www.st.com/content/ccc/resource/technical/document/datasheet/group3/b2/1e/33/77/c6/92/47/6b/DM00279086/files/DM00279086.pdf/jcr:content/translations/en.DM00279086.pdf>, 2018.  
[Online; accessed May 12, 2018].

## APPENDICES

### Appendix A

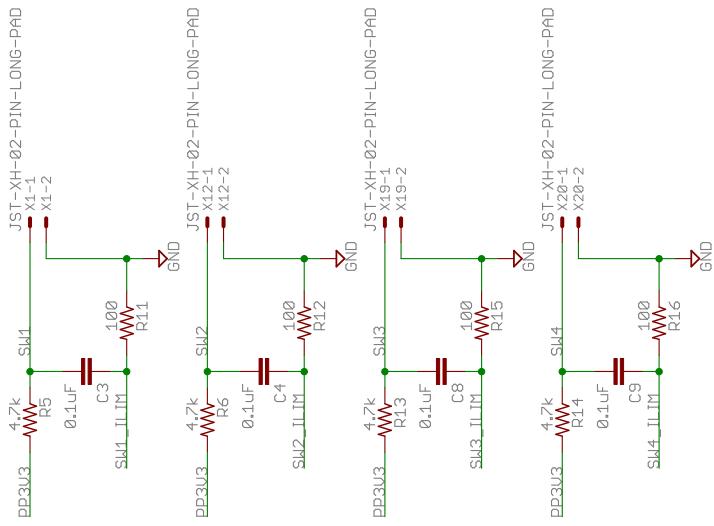
#### INTERCONNECT PCB SCHEMATIC



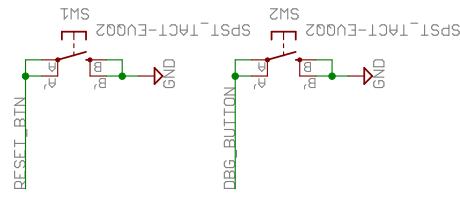


## **Microswitches**

## Debug Buttons



Debug LEDs

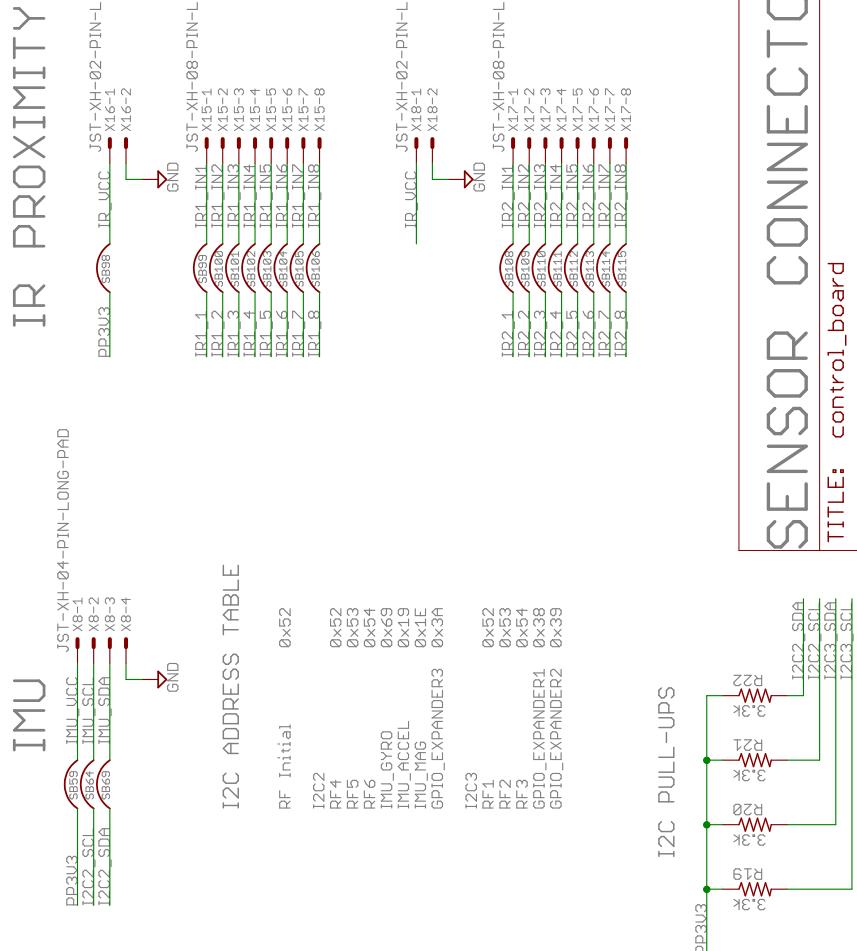
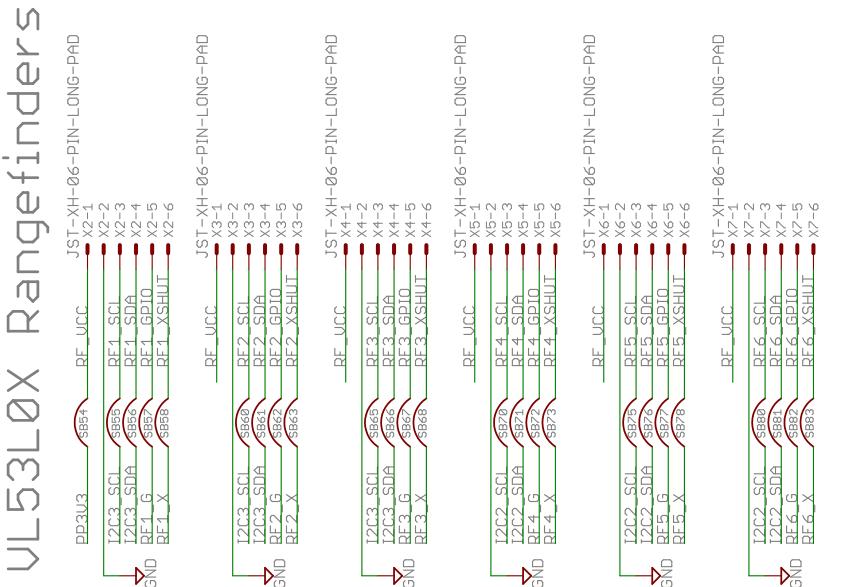


## Switches & LEDs

TITLE: control\_board

Document Number: REV:

Date: 3/22/18 7:01 PM Sheet: 3/6

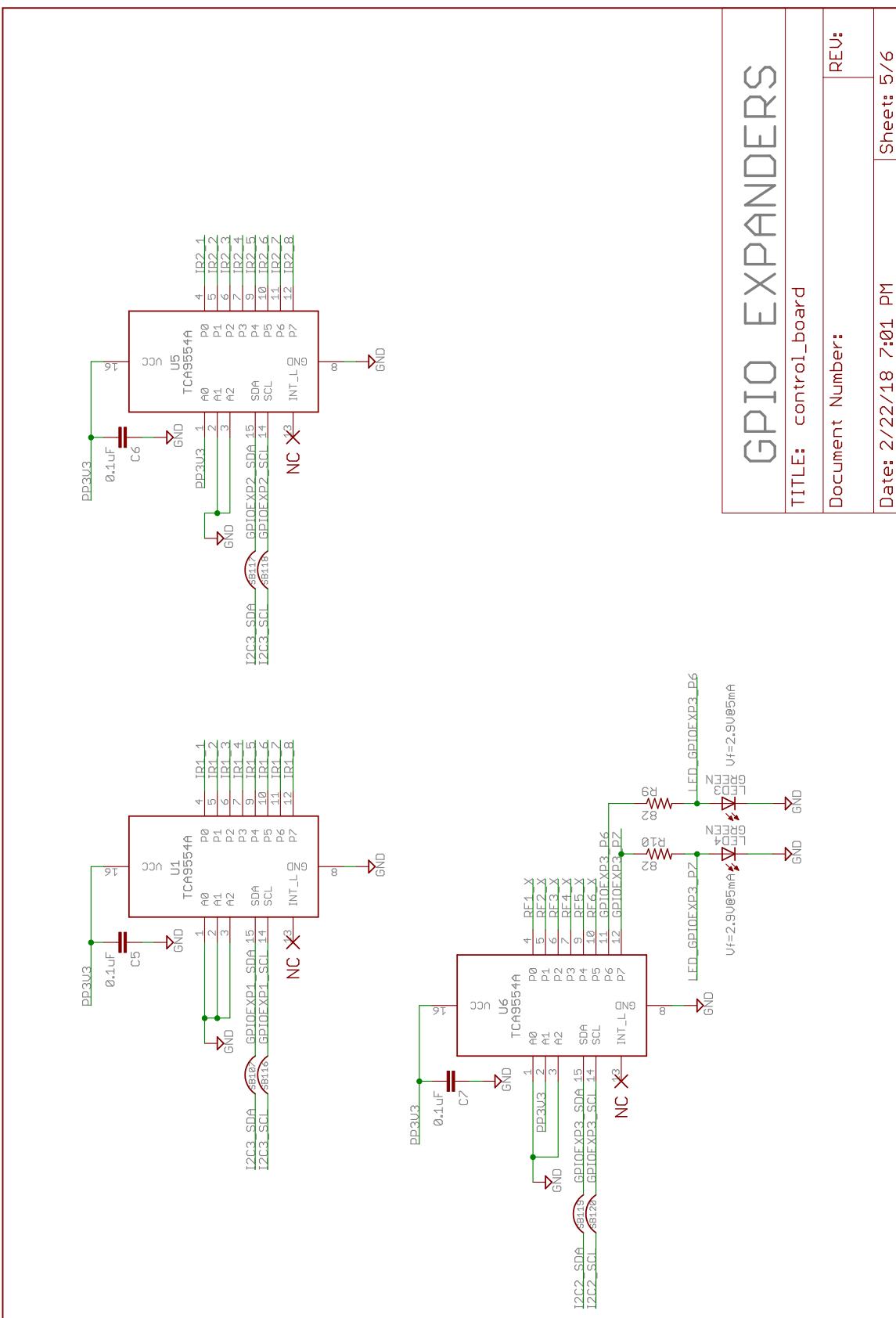


Տօջամտն Խաղաքար:

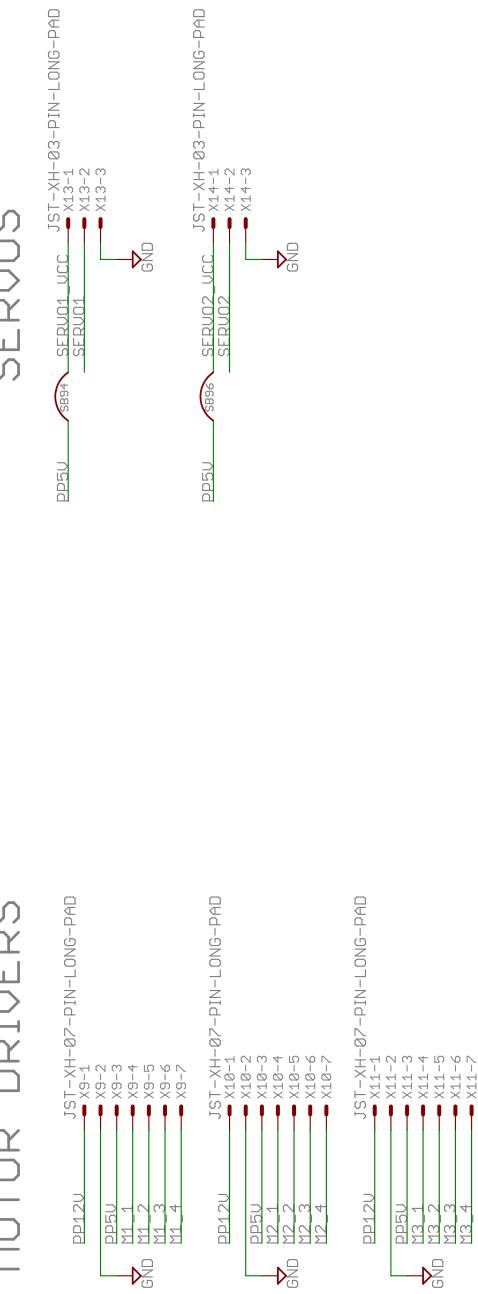
Document Number:

РЕУ

Date: 2/22/18 7:01 PM Sheet: 4/6



## MOTOR DRIVERS



## SERVOS

## MOTOR DRIVERS

TITLE: control_board	REV:
Document Number:	
Date: 2/22/18 7:01 PM	Sheet: 6/6

## Appendix B

### INTERCONNECT PCB LAYOUT

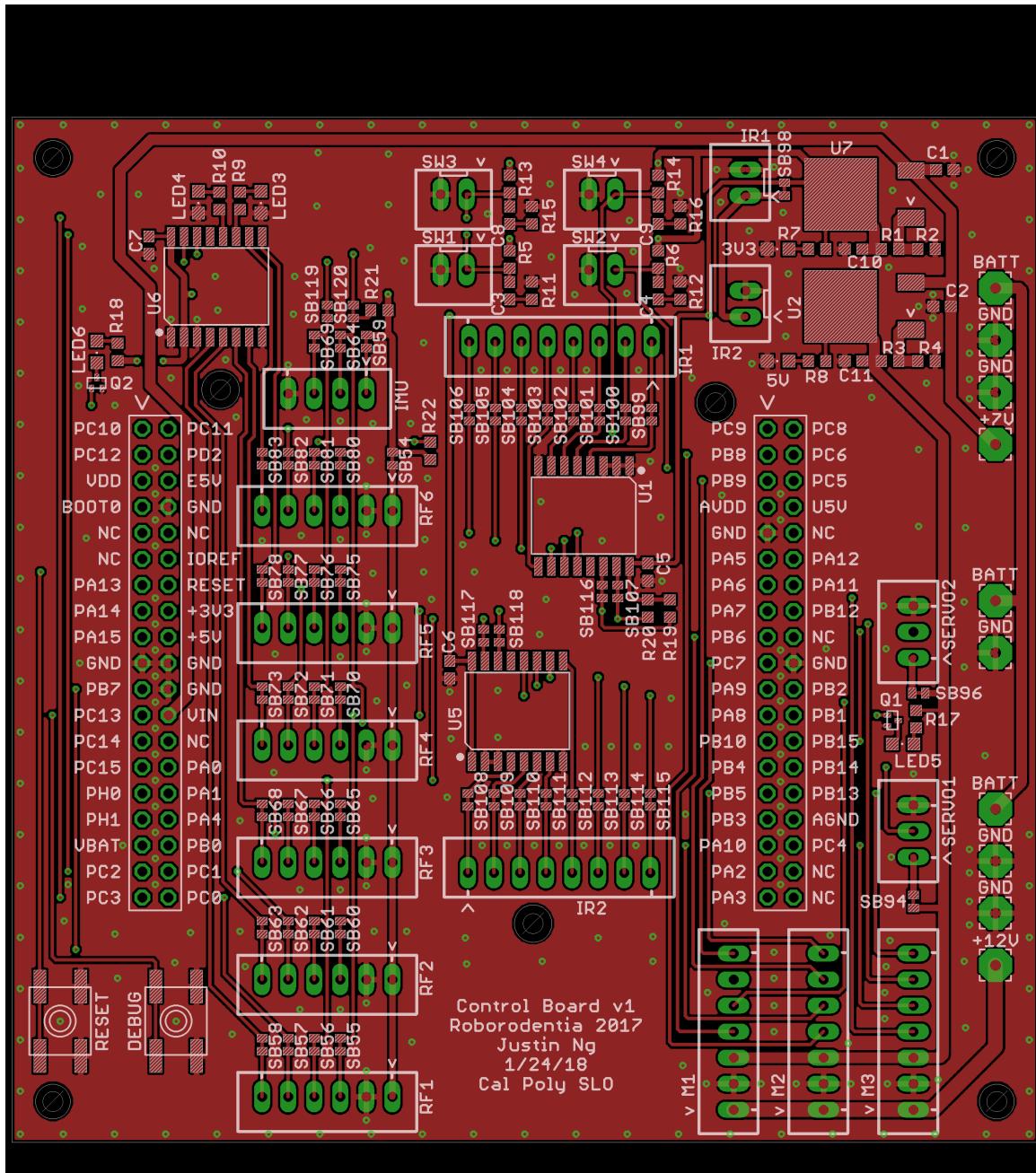


Figure B.1: Interconnect PCB Layout – Top Layer

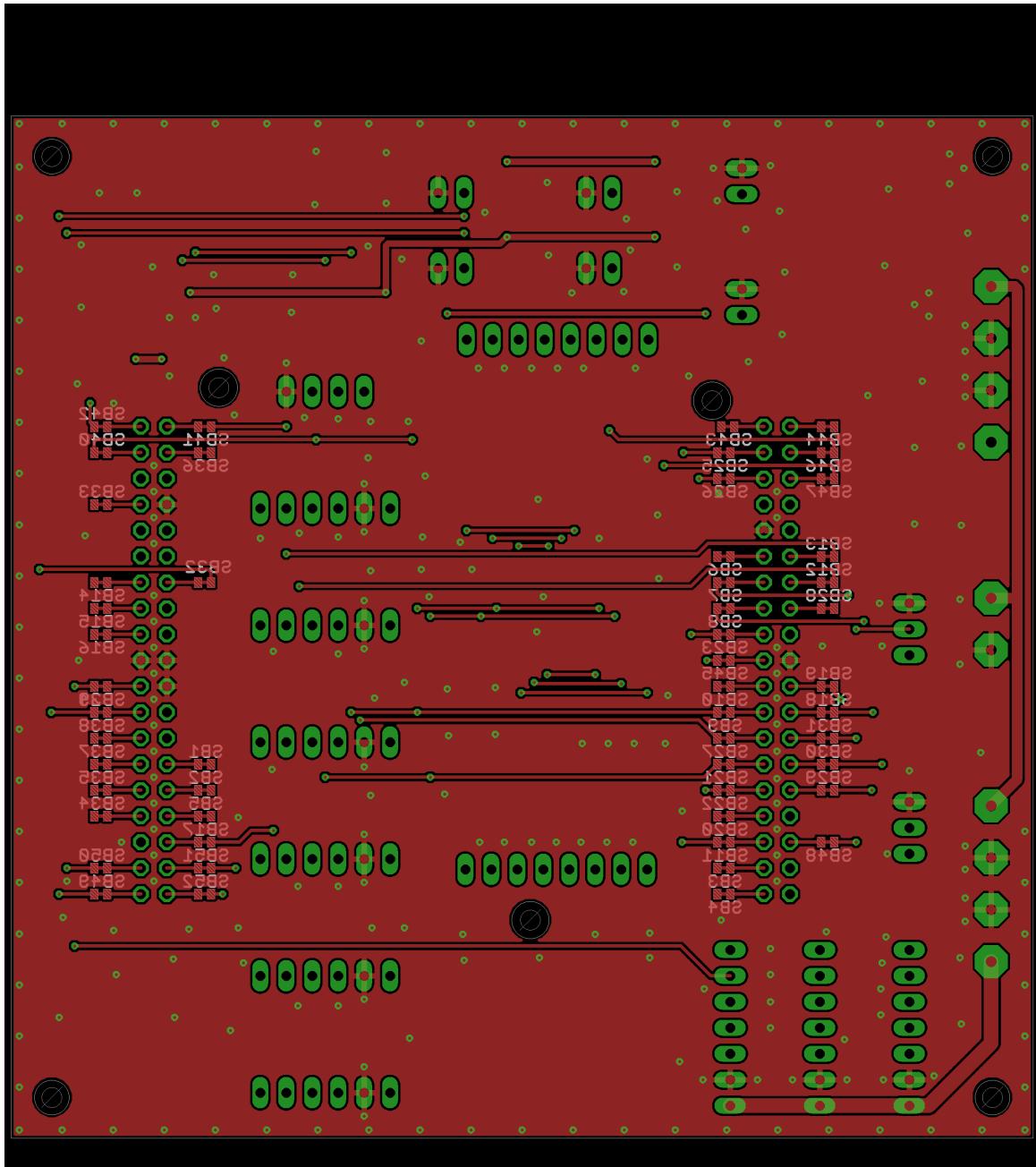


Figure B.2: Interconnect PCB Layout – Bottom Layer

Appendix C  
INTERCONNECT PCB BILL OF MATERIALS

Qty	Value	Package	Parts	Description	DIGIKEY PN
2	AZ1085CD	TO252	U2, U7	AZ1085C	AZ1085CD-ADJTRG1DICT-ND
7	0.1uF	C0603	C3, C4, C5, C6, C7, C8, C9	CAPACITOR	445-5667-1-ND
2	10uF	C0603	C1, C2	CAPACITOR	490-13248-1-ND
2	22uF	C0603	C10, C11	CAPACITOR	490-10476-1-ND
3	TCA9554A	SOIC16	U1, U5, U6	I2C 8-bit GPIO Expander	296-45456-1-ND
6		JST-XH-02	X1, X12, X16, X18, X19, X20	JST XH Connector 2 Pin	455-2247-ND
2		JST-XH-03	X13, X14	JST XH Connector 3 Pin	455-2248-ND
1		JST-XH-04	X8	JST XH Connector 4 Pin	455-2249-ND
6		JST-XH-06	X2, X3, X4, X5, X6, X7	JST XH Connector 6 Pin	455-2271-ND
3		JST-XH-07	X9, X10, X11	JST XH Connector 7 Pin	455-2252-ND
2		JST-XH-08	X15, X17	JST XH Connector 8 Pin	455-2251-ND
6	GREEN	CHIPLED_0805	LED1, LED2, LED3, LED4, LED5, LED LED6	LED	732-4971-1-ND
2	RE1C002UN	SOT416FL	Q1, Q2	Logic-level N-FET	RE1C002UNTCLCT-ND
4	82	R0603	R7, R9, R10, R18	RESISTOR	311-82.0HRCT-ND
5	100	R0603	R3, R11, R12, R15, R16	RESISTOR	311-100HRCT-ND

1	178	R0603	R1	RESISTOR	311-178HRCT-ND
1	287	R0603	R2	RESISTOR	311-287HRCT-ND
1	301	R0603	R4	RESISTOR	311-301HRCT-ND
2	430	R0603	R8, R17	RESISTOR	311-430HRCT-ND
4	3.3k	R0603	R19, R20, R21, R22	RESISTOR	311-3.30KHRCT-ND
4	4.7k	R0603	R5, R6, R13, R14	RESISTOR	311-4.70KHRCT-ND
2	SPST	EVQ-Q2	SW1, SW2	SMT 6mm switch	P12955SCT-ND
1	STM32F446	NUCLEO	U4	STM32 NUCLEO-64	497-15882-ND
10		3,17/1,1	PAD1, PAD2, PAD3, PAD4, PAD5, PAD6, PAD7, PAD8, PAD9, PAD10	Wire PAD connect wire on PCB	n/a

---

105	BRIDGE	SB1, SB2, SB3, SB4, SB5, SB6, SB7, SB8, SB9, SB10, SB11, SB12, SB13, SB14, SB15, SB16, SB17, SB18, SB19, SB20, SB21, SB22, SB23, SB24, SB25, SB26, SB27, SB28, SB29, SB30, SB31, SB32, SB33, SB34, SB35, SB36, SB37, SB38, SB39, SB40, SB41, SB42, SB43, SB44, SB45, SB46, SB47, SB48, SB49, SB50, SB51, SB52, SB54, SB55, SB56, SB57, SB58, SB59, SB60, SB61, SB62, SB63, SB64, SB65, SB66, SB67, SB68, SB69, SB70, SB71, SB72, SB73, SB75, SB76, SB77, SB78, SB80, SB81, SB82, SB83, SB94, SB96, SB98, SB99, SB100, SB101, SB102, SB103, SB104, SB105, SB106, SB107, SB108, SB109, SB110, SB111, SB112, SB113, SB114, SB115, SB116, SB117, SB118, SB119, SB120	Solder bridge with knife-cuttable prebridged connection.	n/a
-----	--------	--	--	-----

---

## Appendix D

### STM32CUBEMX REPORT

## ***1. Description***

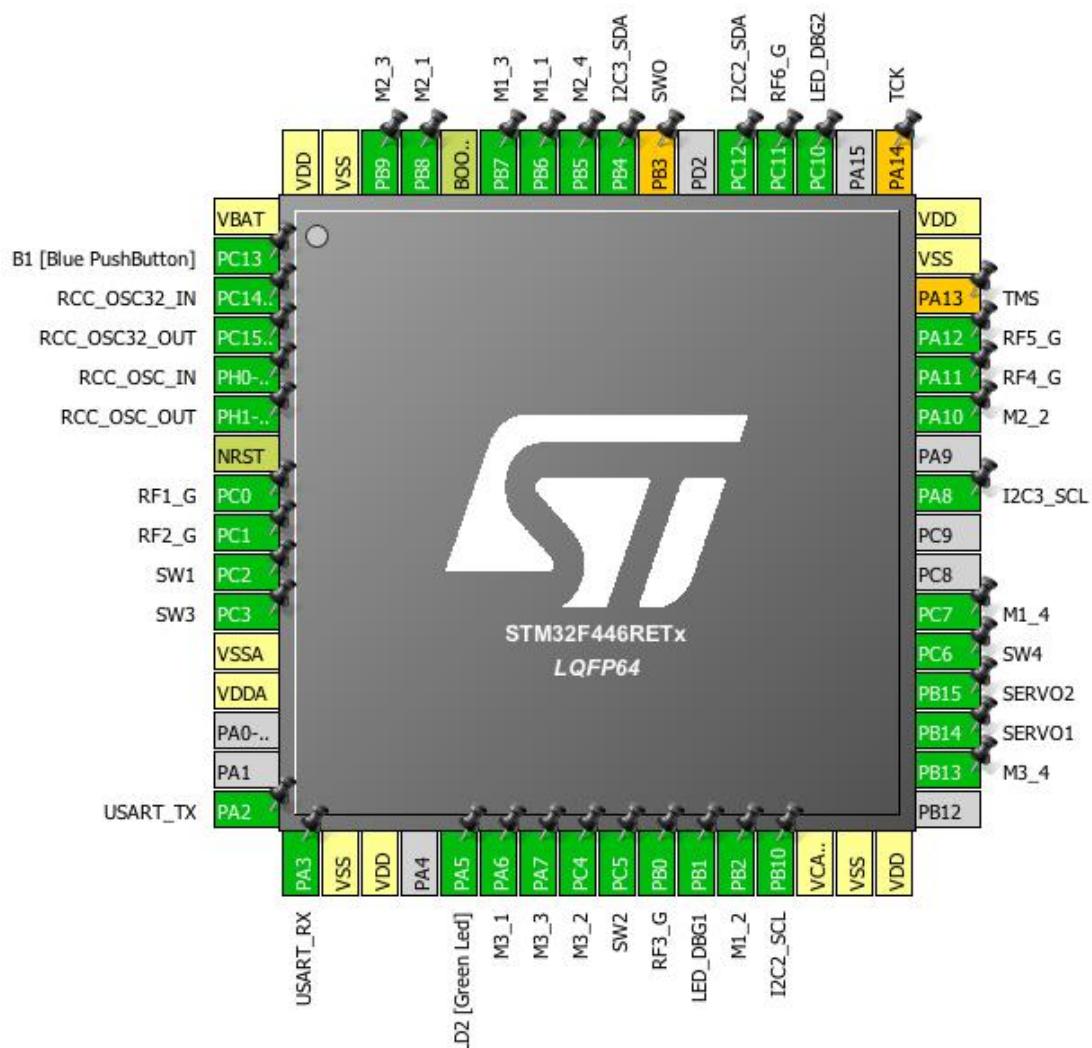
### **1.1. Project**

Project Name	firmware_new
Board Name	NUCLEO-F446RE
Generated with:	STM32CubeMX 4.24.0
Date	05/19/2018

### **1.2. MCU**

MCU Series	STM32F4
MCU Line	STM32F446
MCU name	STM32F446RETx
MCU Package	LQFP64
MCU Pin number	64

## **2. Pinout Configuration**



### 3. Pins Configuration

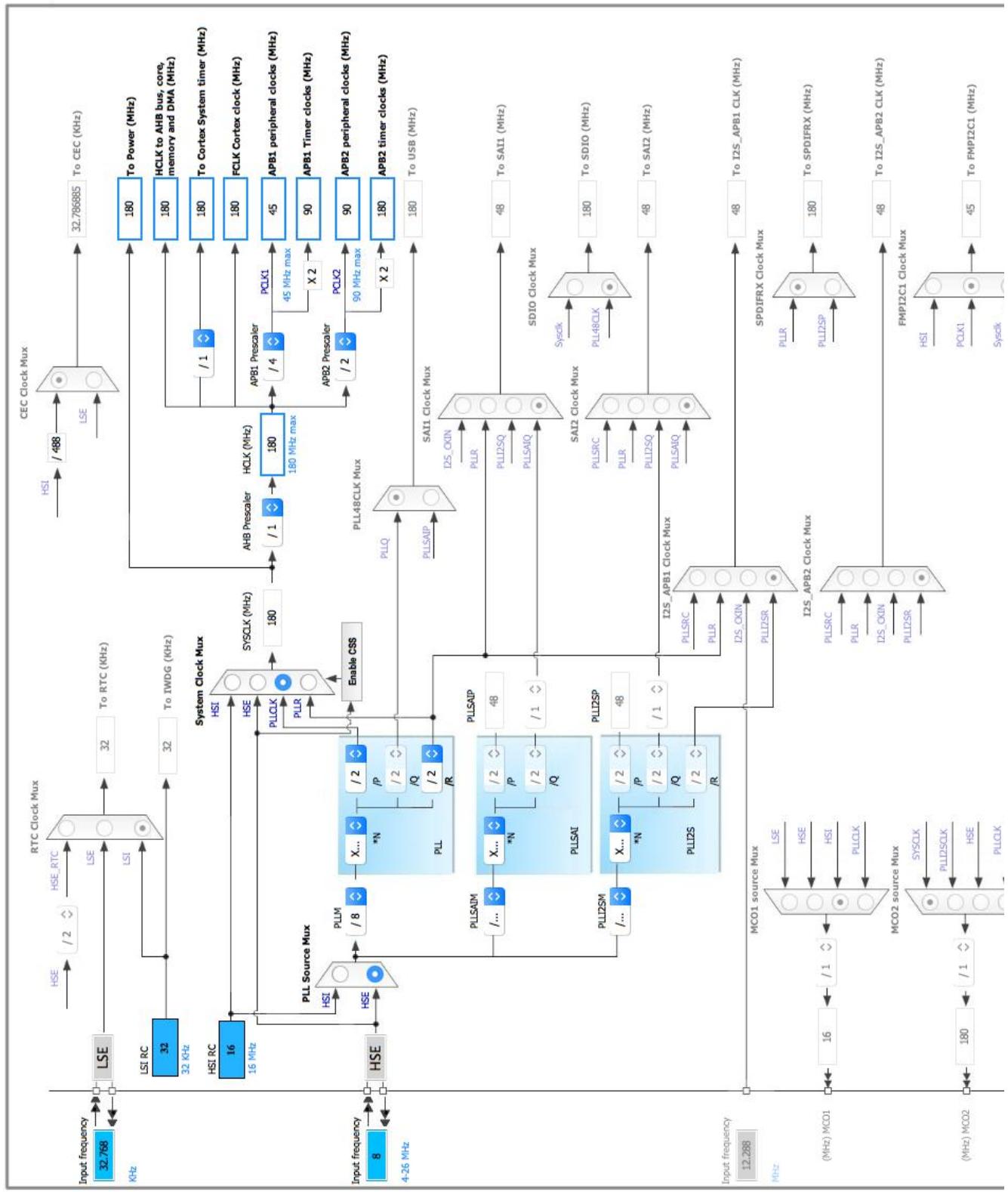
Pin Number LQFP64	Pin Name (function after reset)	Pin Type	Alternate Function(s)	Label
1	VBAT	Power		
2	PC13	I/O	GPIO_EXTI13	B1 [Blue PushButton]
3	PC14-OSC32_IN	I/O	RCC_OSC32_IN	
4	PC15-OSC32_OUT	I/O	RCC_OSC32_OUT	
5	PH0-OSC_IN	I/O	RCC_OSC_IN	
6	PH1-OSC_OUT	I/O	RCC_OSC_OUT	
7	NRST	Reset		
8	PC0	I/O	GPIO_EXTI0	RF1_G
9	PC1	I/O	GPIO_EXTI1	RF2_G
10	PC2 *	I/O	GPIO_Output	SW1
11	PC3 *	I/O	GPIO_Output	SW3
12	VSSA	Power		
13	VDDA	Power		
16	PA2	I/O	USART2_TX	USART_TX
17	PA3	I/O	USART2_RX	USART_RX
18	VSS	Power		
19	VDD	Power		
21	PA5 *	I/O	GPIO_Output	LD2 [Green Led]
22	PA6	I/O	TIM3_CH1	M3_1
23	PA7	I/O	TIM3_CH2	M3_3
24	PC4 *	I/O	GPIO_Output	M3_2
25	PC5 *	I/O	GPIO_Output	SW2
26	PB0 *	I/O	GPIO_Input	RF3_G
27	PB1 *	I/O	GPIO_Output	LED_DBG1
28	PB2 *	I/O	GPIO_Output	M1_2
29	PB10	I/O	I2C2_SCL	
30	VCAP_1	Power		
31	VSS	Power		
32	VDD	Power		
34	PB13 *	I/O	GPIO_Output	M3_4
35	PB14	I/O	TIM12_CH1	SERVO1
36	PB15	I/O	TIM12_CH2	SERVO2
37	PC6 *	I/O	GPIO_Output	SW4
38	PC7 *	I/O	GPIO_Output	M1_4
41	PA8	I/O	I2C3_SCL	
43	PA10 *	I/O	GPIO_Output	M2_2

Pin Number LQFP64	Pin Name (function after reset)	Pin Type	Alternate Function(s)	Label
44	PA11	I/O	GPIO_EXTI11	RF4_G
45	PA12	I/O	GPIO_EXTI12	RF5_G
46	PA13 **	I/O	SYS_JTMS-SWDIO	TMS
47	VSS	Power		
48	VDD	Power		
49	PA14 **	I/O	SYS_JTCK-SWCLK	TCK
51	PC10 *	I/O	GPIO_Output	LED_DBG2
52	PC11 *	I/O	GPIO_Input	RF6_G
53	PC12	I/O	I2C2_SDA	
55	PB3 **	I/O	SYS_JTDO-SWO	SWO
56	PB4	I/O	I2C3_SDA	
57	PB5 *	I/O	GPIO_Output	M2_4
58	PB6	I/O	TIM4_CH1	M1_1
59	PB7	I/O	TIM4_CH2	M1_3
60	BOOT0	Boot		
61	PB8	I/O	TIM4_CH3	M2_1
62	PB9	I/O	TIM4_CH4	M2_3
63	VSS	Power		
64	VDD	Power		

\* The pin is affected with an I/O function

\*\* The pin is affected with a peripheral function but no peripheral mode is activated

## **4. Clock Tree Configuration**



## 5. IPs and Middleware Configuration

### 5.1. I2C2

I2C: I2C

#### 5.1.1. Parameter Settings:

##### Master Features:

I2C Speed Mode	<b>Fast Mode *</b>
I2C Clock Speed (Hz)	400000
Fast Mode Duty Cycle	Duty cycle Tlow/Thigh = 2

##### Slave Features:

Clock No Stretch Mode	Disabled
Primary Address Length selection	7-bit
Dual Address Acknowledged	Disabled
Primary slave address	0
General Call address detection	Disabled

### 5.2. I2C3

I2C: I2C

#### 5.2.1. Parameter Settings:

##### Master Features:

I2C Speed Mode	<b>Fast Mode *</b>
I2C Clock Speed (Hz)	400000
Fast Mode Duty Cycle	Duty cycle Tlow/Thigh = 2

##### Slave Features:

Clock No Stretch Mode	Disabled
Primary Address Length selection	7-bit
Dual Address Acknowledged	Disabled
Primary slave address	0
General Call address detection	Disabled

### 5.3. RCC

**High Speed Clock (HSE): Crystal/Ceramic Resonator**

**Low Speed Clock (LSE) : Crystal/Ceramic Resonator**

#### 5.3.1. Parameter Settings:

##### System Parameters:

VDD voltage (V)	3.3
Instruction Cache	Enabled
Prefetch Buffer	Enabled
Data Cache	Enabled
Flash Latency(WS)	5 WS (6 CPU cycle)

##### RCC Parameters:

HSI Calibration Value	16
TIM Prescaler Selection	Disabled
HSE Startup Timeout Value (ms)	100
LSE Startup Timeout Value (ms)	5000

##### Power Parameters:

Power Regulator Voltage Scale	Power Regulator Voltage Scale 1
Power Over Drive	Enabled

### 5.4. SYS

**Timebase Source: SysTick**

### 5.5. TIM3

**Clock Source : Internal Clock**

**Channel1: PWM Generation CH1**

**Channel2: PWM Generation CH2**

#### 5.5.1. Parameter Settings:

##### Counter Settings:

Prescaler (PSC - 16 bits value)	1 *
Counter Mode	Up
Counter Period (AutoReload Register - 16 bits value )	2047 *
Internal Clock Division (CKD)	No Division

**Trigger Output (TRGO) Parameters:**

Master/Slave Mode	Disable (no sync between this TIM (Master) and its Slaves)
Trigger Event Selection	Reset (UG bit from TIMx_EGR)

**PWM Generation Channel 1:**

Mode	PWM mode 1
Pulse (16 bits value)	0
Fast Mode	Disable
CH Polarity	High

**PWM Generation Channel 2:**

Mode	PWM mode 1
Pulse (16 bits value)	0
Fast Mode	Disable
CH Polarity	High

## 5.6. TIM4

**mode: Clock Source**

**Channel1: PWM Generation CH1**

**Channel2: PWM Generation CH2**

**Channel3: PWM Generation CH3**

**Channel4: PWM Generation CH4**

**5.6.1. Parameter Settings:**

**Counter Settings:**

Prescaler (PSC - 16 bits value)	<b>1 *</b>
Counter Mode	Up
Counter Period (AutoReload Register - 16 bits value)	<b>2047 *</b>
Internal Clock Division (CKD)	No Division

**Trigger Output (TRGO) Parameters:**

Master/Slave Mode	Disable (no sync between this TIM (Master) and its Slaves)
Trigger Event Selection	Reset (UG bit from TIMx_EGR)

**PWM Generation Channel 1:**

Mode	PWM mode 1
Pulse (16 bits value)	0
Fast Mode	Disable
CH Polarity	High

**PWM Generation Channel 2:**

Mode	PWM mode 1
------	------------

Pulse (16 bits value)	0
Fast Mode	Disable
CH Polarity	High

**PWM Generation Channel 3:**

Mode	PWM mode 1
Pulse (16 bits value)	0
Fast Mode	Disable
CH Polarity	High

**PWM Generation Channel 4:**

Mode	PWM mode 1
Pulse (16 bits value)	0
Fast Mode	Disable
CH Polarity	High

## 5.7. TIM5

**mode: Clock Source**

**5.7.1. Parameter Settings:**

**Counter Settings:**

Prescaler (PSC - 16 bits value)	<b>9000 *</b>
Counter Mode	Up
Counter Period (AutoReload Register - 32 bits value)	<b>0xFFFFFFFF *</b>
Internal Clock Division (CKD)	No Division

**Trigger Output (TRGO) Parameters:**

Master/Slave Mode	Disable (no sync between this TIM (Master) and its Slaves)
Trigger Event Selection	Reset (UG bit from TIMx_EGR)

## 5.8. TIM12

**mode: Clock Source**

**Channel1: PWM Generation CH1**

**Channel2: PWM Generation CH2**

**5.8.1. Parameter Settings:**

**Counter Settings:**

Prescaler (PSC - 16 bits value)	<b>354 *</b>
Counter Mode	Up
Counter Period (AutoReload Register - 16 bits value )	<b>3178 *</b>
Internal Clock Division (CKD)	No Division

**PWM Generation Channel 1:**

Mode	PWM mode 1
Pulse (16 bits value)	<b>63 *</b>
Fast Mode	Disable
CH Polarity	High

**PWM Generation Channel 2:**

Mode	PWM mode 1
Pulse (16 bits value)	<b>63 *</b>
Fast Mode	Disable
CH Polarity	High

## 5.9. USART2

**Mode: Asynchronous**

**5.9.1. Parameter Settings:**

**Basic Parameters:**

Baud Rate	<b>921600 *</b>
Word Length	8 Bits (including Parity)
Parity	None
Stop Bits	1

**Advanced Parameters:**

Data Direction	Receive and Transmit
Over Sampling	16 Samples

\* User modified value

## 6. System Configuration

### 6.1. GPIO configuration

IP	Pin	Signal	GPIO mode	GPIO pull/up pull down	Max Speed	User Label
I2C2	PB10	I2C2_SCL	Alternate Function Open Drain	Pull-up	Very High *	
	PC12	I2C2_SDA	Alternate Function Open Drain	Pull-up	Very High *	
I2C3	PA8	I2C3_SCL	Alternate Function Open Drain	Pull-up	Very High *	
	PB4	I2C3_SDA	Alternate Function Open Drain	Pull-up	Very High *	
RCC	PC14-OSC32_IN	RCC_OSC32_IN	n/a	n/a	n/a	
	PC15-OSC32_OUT	RCC_OSC32_OUT	n/a	n/a	n/a	
	PH0-OSC_IN	RCC_OSC_IN	n/a	n/a	n/a	
	PH1-OSC_OUT	RCC_OSC_OUT	n/a	n/a	n/a	
TIM3	PA6	TIM3_CH1	Alternate Function Push Pull	No pull-up and no pull-down	Low	M3_1
	PA7	TIM3_CH2	Alternate Function Push Pull	No pull-up and no pull-down	Low	M3_3
TIM4	PB6	TIM4_CH1	Alternate Function Push Pull	No pull-up and no pull-down	Low	M1_1
	PB7	TIM4_CH2	Alternate Function Push Pull	No pull-up and no pull-down	Low	M1_3
	PB8	TIM4_CH3	Alternate Function Push Pull	No pull-up and no pull-down	Low	M2_1
	PB9	TIM4_CH4	Alternate Function Push Pull	No pull-up and no pull-down	Low	M2_3
TIM12	PB14	TIM12_CH1	Alternate Function Push Pull	No pull-up and no pull-down	Low	SERVO1
	PB15	TIM12_CH2	Alternate Function Push Pull	No pull-up and no pull-down	Low	SERVO2
USART2	PA2	USART2_TX	Alternate Function Push Pull	Pull-up	Very High *	USART_TX
	PA3	USART2_RX	Alternate Function Push Pull	Pull-up	Very High *	USART_RX
Single Mapped Signals	PA13	SYS_JTMS-SWDIO	n/a	n/a	n/a	TMS
	PA14	SYS_JTCK-SWCLK	n/a	n/a	n/a	TCK
	PB3	SYS_JTDO-	n/a	n/a	n/a	SWO

firmware\_new Project  
Configuration Report

IP	Pin	Signal	GPIO mode	GPIO pull/up pull down	Max Speed	User Label
		SWO				
GPIO	PC13	GPIO_EXTI13	<b>External Interrupt Mode with Falling edge trigger detection</b>	No pull-up and no pull-down	n/a	B1 [Blue PushButton]
	PC0	GPIO_EXTI0	<b>External Interrupt Mode with Falling edge trigger detection</b>	<b>Pull-up *</b>	n/a	RF1_G
	PC1	GPIO_EXTI1	<b>External Interrupt Mode with Falling edge trigger detection</b>	<b>Pull-up *</b>	n/a	RF2_G
	PC2	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	SW1
	PC3	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	SW3
	PA5	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	LD2 [Green Led]
	PC4	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	M3_2
	PC5	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	SW2
	PB0	GPIO_Input	Input mode	<b>Pull-up *</b>	n/a	RF3_G
	PB1	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	LED_DBG1
	PB2	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	M1_2
	PB13	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	M3_4
	PC6	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	SW4
	PC7	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	M1_4
	PA10	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	M2_2
	PA11	GPIO_EXTI11	<b>External Interrupt Mode with Falling edge trigger detection</b>	<b>Pull-up *</b>	n/a	RF4_G
	PA12	GPIO_EXTI12	<b>External Interrupt Mode with Falling edge trigger detection</b>	<b>Pull-up *</b>	n/a	RF5_G
	PC10	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	LED_DBG2
	PC11	GPIO_Input	Input mode	No pull-up and no pull-down	n/a	RF6_G
	PB5	GPIO_Output	Output Push Pull	No pull-up and no pull-down	Low	M2_4

## 6.2. DMA configuration

DMA request	Stream	Direction	Priority
I2C2_RX	DMA1_Stream2	Peripheral To Memory	Low
I2C2_TX	DMA1_Stream7	Memory To Peripheral	<b>High *</b>
I2C3_RX	DMA1_Stream1	Peripheral To Memory	Low
I2C3_TX	DMA1_Stream4	Memory To Peripheral	<b>High *</b>
USART2_RX	DMA1_Stream5	Peripheral To Memory	<b>Very High *</b>
USART2_TX	DMA1_Stream6	Memory To Peripheral	<b>Very High *</b>

### I2C2\_RX: DMA1\_Stream2 DMA request Settings:

Mode: Normal  
Use fifo: Disable  
Peripheral Increment: Disable  
Memory Increment: **Enable \***  
Peripheral Data Width: Byte  
Memory Data Width: Byte

### I2C2\_TX: DMA1\_Stream7 DMA request Settings:

Mode: Normal  
Use fifo: Disable  
Peripheral Increment: Disable  
Memory Increment: **Enable \***  
Peripheral Data Width: Byte  
Memory Data Width: Byte

### I2C3\_RX: DMA1\_Stream1 DMA request Settings:

Mode: Normal  
Use fifo: Disable  
Peripheral Increment: Disable  
Memory Increment: **Enable \***  
Peripheral Data Width: Byte  
Memory Data Width: Byte

I2C3\_TX: DMA1\_Stream4 DMA request Settings:

Mode: Normal  
Use fifo: Disable  
Peripheral Increment: Disable  
Memory Increment: **Enable \***  
Peripheral Data Width: Byte  
Memory Data Width: Byte

USART2\_RX: DMA1\_Stream5 DMA request Settings:

Mode: **Circular \***  
Use fifo: Disable  
Peripheral Increment: Disable  
Memory Increment: **Enable \***  
Peripheral Data Width: Byte  
Memory Data Width: Byte

USART2\_TX: DMA1\_Stream6 DMA request Settings:

Mode: Normal  
Use fifo: Disable  
Peripheral Increment: Disable  
Memory Increment: **Enable \***  
Peripheral Data Width: Byte  
Memory Data Width: Byte

### 6.3. NVIC configuration

Interrupt Table	Enable	Preenmption Priority	SubPriority
Non maskable interrupt	true	0	0
Hard fault interrupt	true	0	0
Memory management fault	true	0	0
Pre-fetch fault, memory access fault	true	0	0
Undefined instruction or illegal state	true	0	0
System service call via SWI instruction	true	0	0
Debug monitor	true	0	0
Pendable request for system service	true	0	0
System tick timer	true	0	0
DMA1 stream1 global interrupt	true	0	0
DMA1 stream2 global interrupt	true	0	0
DMA1 stream4 global interrupt	true	0	0
DMA1 stream5 global interrupt	true	0	0
DMA1 stream6 global interrupt	true	0	0
I2C2 event interrupt	true	0	0
I2C2 error interrupt	true	0	0
USART2 global interrupt	true	0	0
DMA1 stream7 global interrupt	true	0	0
I2C3 event interrupt	true	0	0
I2C3 error interrupt	true	0	0
PVD interrupt through EXTI line 16		unused	
Flash global interrupt		unused	
RCC global interrupt		unused	
EXTI line 0 interrupt		unused	
EXTI line 1 interrupt		unused	
TIM3 global interrupt		unused	
TIM4 global interrupt		unused	
EXTI line[15:10] interrupts		unused	
TIM8 break interrupt and TIM12 global interrupt		unused	
TIM5 global interrupt		unused	
FPU global interrupt		unused	

\* User modified value

## 7. Power Consumption Calculator report

### 7.1. Microcontroller Selection

Series	STM32F4
Line	STM32F446
MCU	STM32F446RETx
Datasheet	027107_Rev6

### 7.2. Parameter Selection

Temperature	25
Vdd	3.3

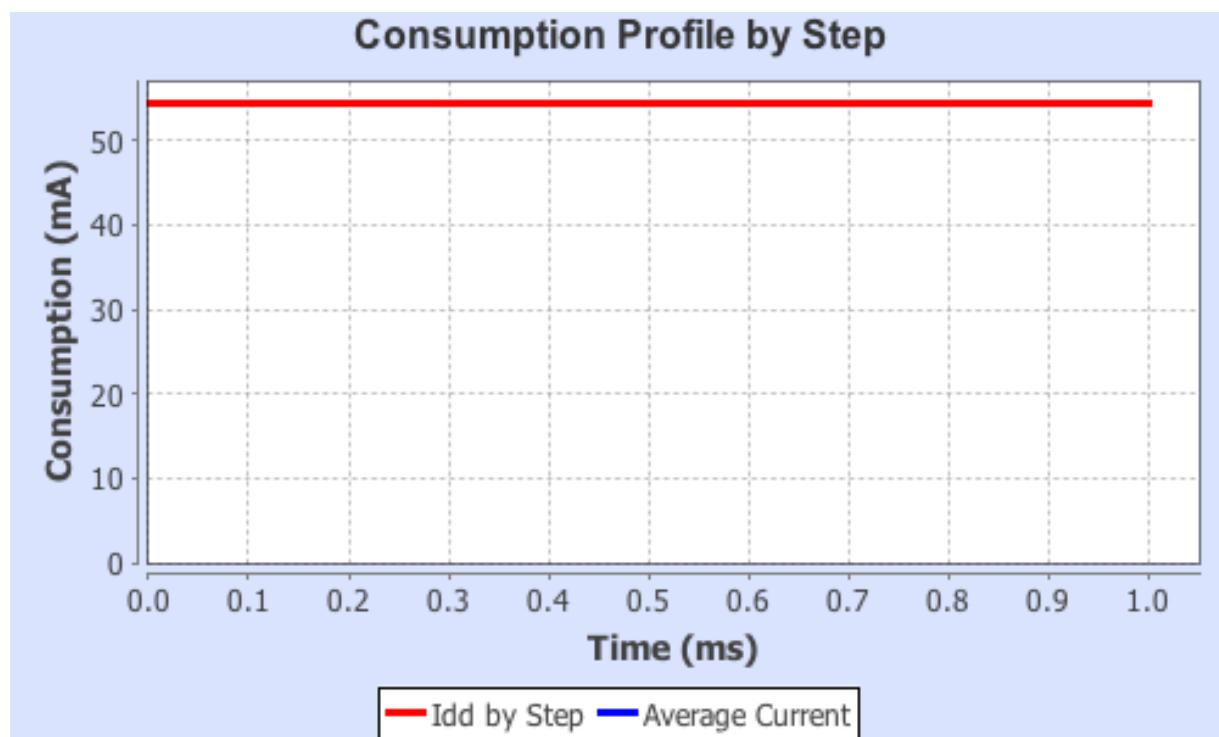
### 7.3. Sequence

<b>Step</b>	Step1
<b>Mode</b>	RUN
<b>Vdd</b>	3.3
<b>Voltage Source</b>	Vbus
<b>Range</b>	Scale1-High
<b>Fetch Type</b>	RAM/FLASH/REGON/ART/PREFETCH
<b>Clock Configuration</b>	HSE PLL
<b>Clock Source Frequency</b>	4 MHz
<b>CPU Frequency</b>	180 MHz
<b>Peripherals</b>	DMA1 DMA2 GPIOA GPIOB GPIOC I2C2 I2C3 SYS TIM1 TIM2 TIM3 TIM4 TIM12 USART2
<b>Additional Cons.</b>	0 mA
<b>Average Current</b>	54.31 mA
<b>Duration</b>	1 ms
<b>DMIPS</b>	225.0
<b>T<sub>a</sub> Max</b>	96.76
<b>Category</b>	In DS Table

#### 7.4. RESULTS

Sequence Time	1 ms	Average Current	54.31 mA
Battery Life	0	Average DMIPS	225.0 DMIPS

#### 7.5. Chart



## 8. Software Project

### 8.1. Project Settings

Name	Value
Project Name	firmware_new
Project Folder	/Users/justinng/Documents/Github/robordentia2017/firmware_new
Toolchain / IDE	Makefile
Firmware Package Name and Version	STM32Cube FW_F4 V1.18.0

### 8.2. Code Generation Settings

Name	Value
STM32Cube Firmware Library Package	Copy all used libraries into the project folder
Generate peripheral initialization as a pair of '.c/.h' files	Yes
Backup previously generated files when re-generating	No
Delete previously generated files when not re-generated	Yes
Set all free pins as analog (to optimize the power consumption)	No

## ***9. Software Pack Report***