ECHORD++ Flooring Fellow

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D1.1
System Design

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Deliverable authors: Giancarlo Teti, Nicola Canelli, Luca Volpi, Antonio Bertini, Leandro Bandini

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Service)	
RE	Restricted to a group specified by the consortium (including the Commission Service)	
CO	Confidential, only for members of the consortium (including the Commission Service)	**CO**

Document History

Version	Date	Author	Summary of Main Changes
1.0	21-01-2016	Giancarlo Teti (RT)	First version of the Deliverable and table of contents
1.1	06-02-2016	Nicola Canelli (RT)	Added contents to section 1
1.2	07-02.2016	Luca Volpi (RT)	Added contents to section 3
1.3	09-02-2016	Giancarlo Teti (RT)	Added contents to section 5
1.4	15/02/2016	Leandro Bandini, Antonio Bertini	Added contents to section 2
1.5	15/02/2016	Giancarlo Teti (RT)	Added contents to section 4

Table of Contents

Executive summary

Deliverable D1.1 “System Design” is the final outcome of task T1 “Design” and in particular of the activities carried out in tasks T1.3 “System design and architecture”, T1.4 “Mechanical design and specifications”, T1.5 “Electronics design and specification” and T1.6 “Software and Firmware design and specifications” and consists of the mechanical, electronics and software design of the system.

Mechanical design concerns the design of sponge tool and water bucket, the design of the mechanical structure supporting battery, laser scanner and camera, the modification of the mobile base to integrate the system components, and the selection and identification of motors, pumps and other sensors. Electronics design concerns mainly the definition of the control system architecture, the identifications of the main components, and the design of PCB implementing the low level control of brushless motor. Software design concerns the design of the ROS based software architecture of the 2F robot.

The document contains the mechanical, electronics and software design of the system and is organised as follow: Section 1 describes the general architecture of the system highlighting the main components subject of the design. Section 2 describes the mechanical design of the system realised using Solid Edge 3D CAD: a 3D pdf document containing the complete mechanical design is attached as annex to this document. Section 3 describes the electronics design and contains PCB schematic, layout and BOM of the driver for brushless motor realised using Altium Design 16. Section 4 includes the wiring diagram and section 5 describe the ROS based software architecture.

1 System Architecture

The 2F robot is based on the skeleton of the NEMH2O robot mobile base which integrates sponge tool and devices for sponge cleaning, battery pack, navigation sensor, quality control sensor and control electronics.

On the basis of the initial analysis of the state of the art and the study and characterisation of available commercial electrical sponge machines, the solution adopted in 2F is based on a cross belt sponge since it is the most technically advantageous in terms of compactness, ease of integration, and modularity.

In more details, the 2F robot consists of the following components:

- NEMH2O mobile base with tracks (left and right) actuated by 2 brushless motors with integrated hall effect encoders;
- cross belt sponge tool actuated by brushless motor with integrated hall effect encoders, mechanical squeeze system and pump flooding water for cleaning the sponge;
- water bucket with water level sensor;
- battery pack;
- laser scanner (navigation sensor);
- control system: compact PC, motor drivers (3) and related control electronics;
- USB cam (quality control sensor);
- switches and devices for HRI.

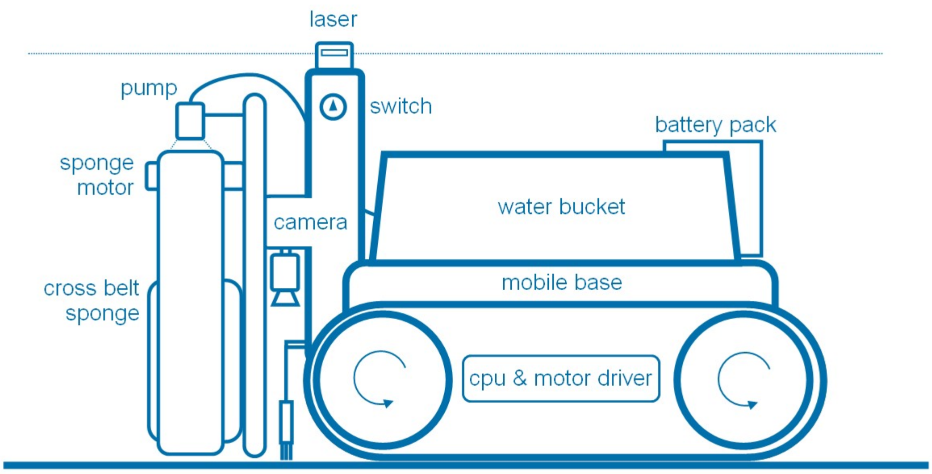


Figure 1: System architecture

The control system consist of a compact PC (INTEL NUC 5i5RYK) running the high level control software and the navigation software and of the low level control electronics. The low level control electronics consists of a microcontroller based board (STM32F0DISCOVERY) implementing PID control for 3 motors and of 3 drivers for brushless motor. Laser (RP Lidar) and USB camera are connected to the PC. The following schema show the architecture of the control system.

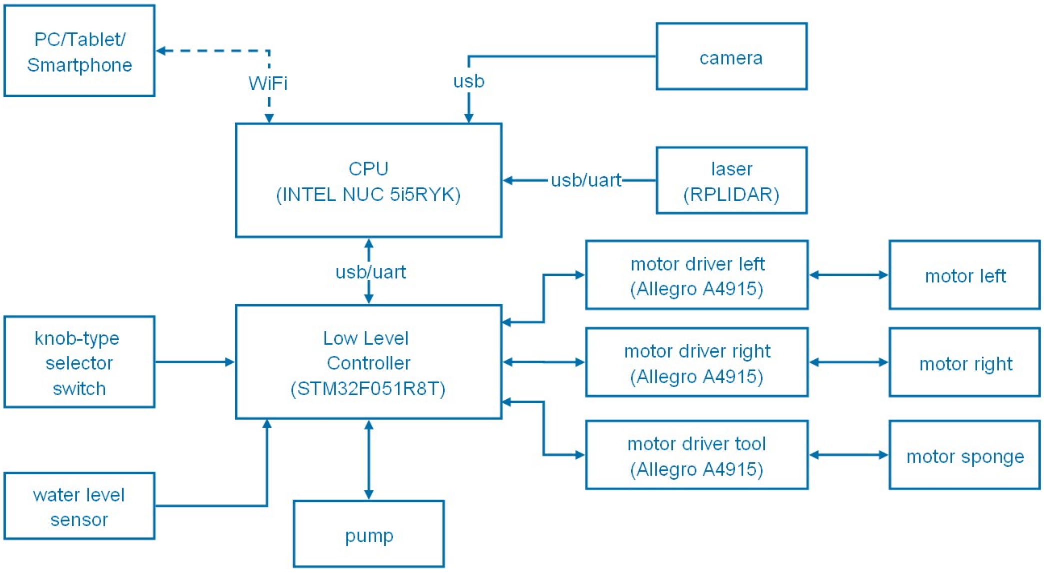


Figure 2: Control system architecture

Power is provided by a Lithium battery pack (Li-ion battery 25.9 VDC, 312 Wh). A main switch and a fuse are between the battery pack and the system devices. A VDC regulator provides power to the PC. Emergency button is between battery and motor drivers and shut off power when closed. The following schema show the connection of the power system.

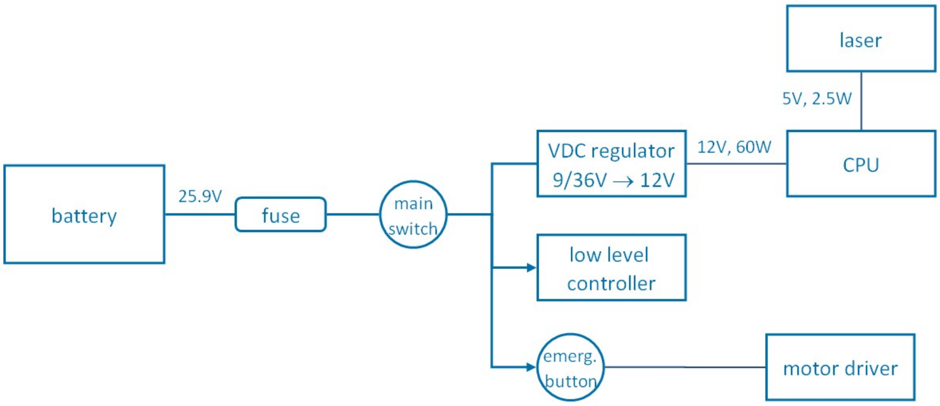


Figure 3: Power connection scheme

The user interface has been extremely simplified in order to reduce the number of devices on the robot and includes:

– knob type selector switch (3 positions) with led used to switch on/off the robot (ON and OFF position) and to start the automatic grout removing procedure (START position). The led indicate when the robot is ON.
– emergency stop button: to and shut off power to motor driver in case of emergency.
– internal buzzer to provide acoustic signal

System diagnosis and configuration and remote control is implemented by means of App on tablet/smartphone.

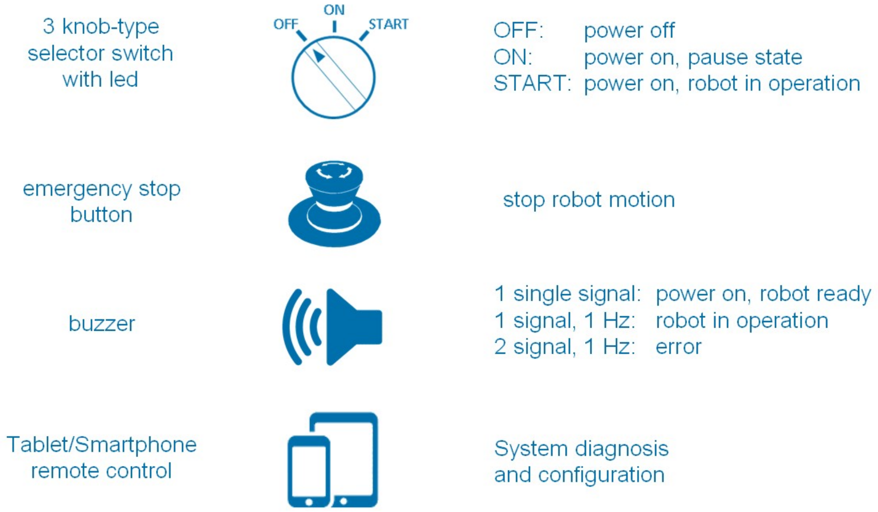


Figure 4: Switches and HRI devices

The quality control system measures the goodness of the grout removal of the sponge by comparing the floor before and after the passage of a comb, positioned after the sponge, on the floor: if the sponge is working properly, the passage of the comb does not effect on floor status. Vice versa, if the sponge is not working properly and grout is not well removed from the floor, the comb do effect on the floor by removing the residual grout and during is passage. Comparing the status of the floor before and after the passage of the comb provides an indication of the cleaning quality. While the robot moves the status of the floor is monitored with a camera positioned over the comb and pointing down. The camera compares the images before and after the passage of the comb on the floor: if images are ‘different’ means that the floor changed after the passage of the comb i.e. the sponge is not cleaning properly the floor. Vice versa, if the image are comparable, the sponge is cleaning properly the floor.

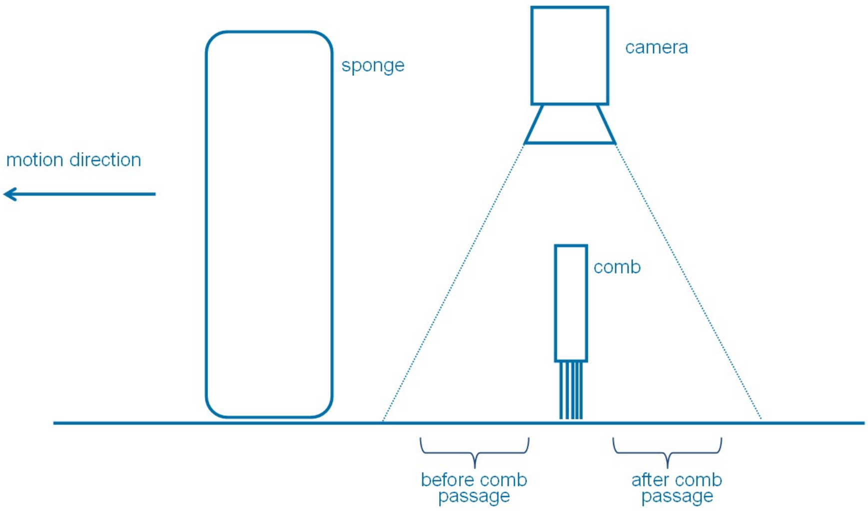


Figure 5: Scheme of the quality control system

1.1 List of Components

Component	Product Code	Description	Quantity
PC control unit	INTEL NUC 5i5RYK	Intel Core i5-5250U processor 1.6 GHz up to 2.7 GHz Turbo, dual core DDR3L SODIMMs 1.35V, 1333 Mhz 4 x USB 3.0 ports, Intel wireless AC 7265 M.2 12-19V DC power input, 15 W TDP	1
Laser	RP Lidar	360° Omnidirectional laser scanner Detection range: 6 m Sample rate: 2000 Sa/s Angular resolution: 1 deg Distance resolution: 0.2 cm Power: 5V, Interface: UART/USB	1
Camera	ELP-USB130W01MT	CCD: 1/3 inch, Lens: 3.6mm Max. Resolution 1280(H)X960(V) Min. illumination 0. 01lux Power 5V, 100mA~160mA Working temperature: -20~75 Board size /Weight: 38X38mm / about 30g	1
Low Level motor controller	STM32F0DISCOVERY	STM32F051R8T6 microcontroller board 64 KB Flash memory 8 KB RAM in an LQFP64 package	1
Motor Driver	2F brushless motor driver board	Microcontroller based board (Allegro A 4915) 5 to 50 V supply voltage Max current 2A	3
Motor	Fullin FL42RBL 64	Traction motor (2) and sponge motor (1) 24V, 5500 RPM	3
Reduction gear	IMS baseline PM42	Reduction ratio: 150:1	
Pump	Aerflow PQ 24DC	24V Brush DC motor, 2200 ml per min	1
Water level sensor	To be defined	-	1
Knob type selector switch	A165S/W	Rated voltage: 30 VDC Resistive load: 3 A Led: 24V	1
Emergency button	A165E-LS6D – 02 (DPST)	Rated voltage: 30 VDC Resistive load: 3 A Led: 24V	1
Battery	Li-ion battery	25.9 VDC, 312 Wh	1
VDC regulator	TEN 60-2422WIN	Input: 9/36V Output: 12V, 60W	1

2 Mechanical Design

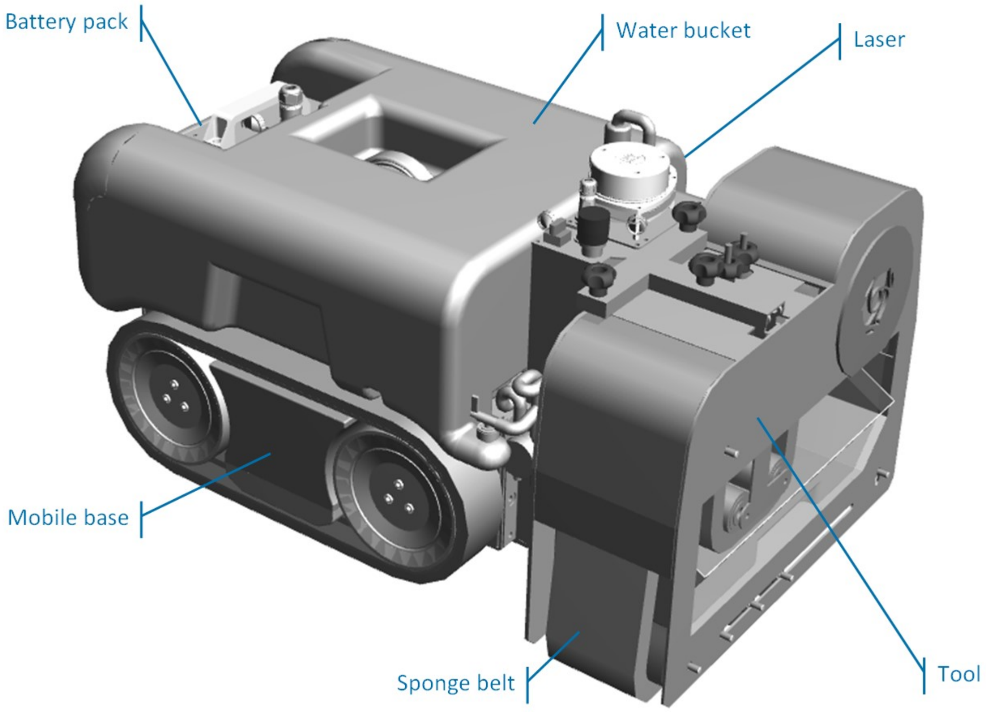


Figure 6: total view of the mechanical design

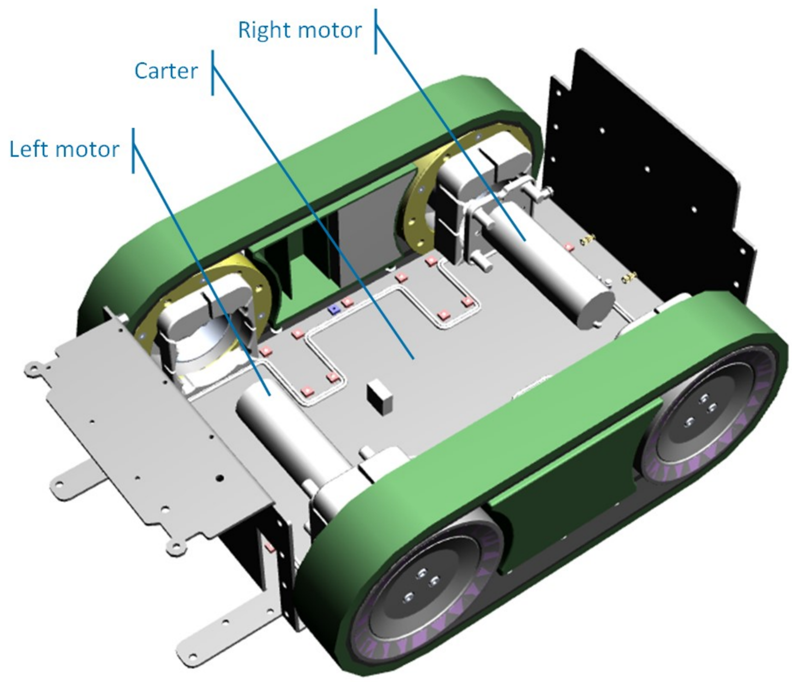


Figure 7: inside view of the mobile base

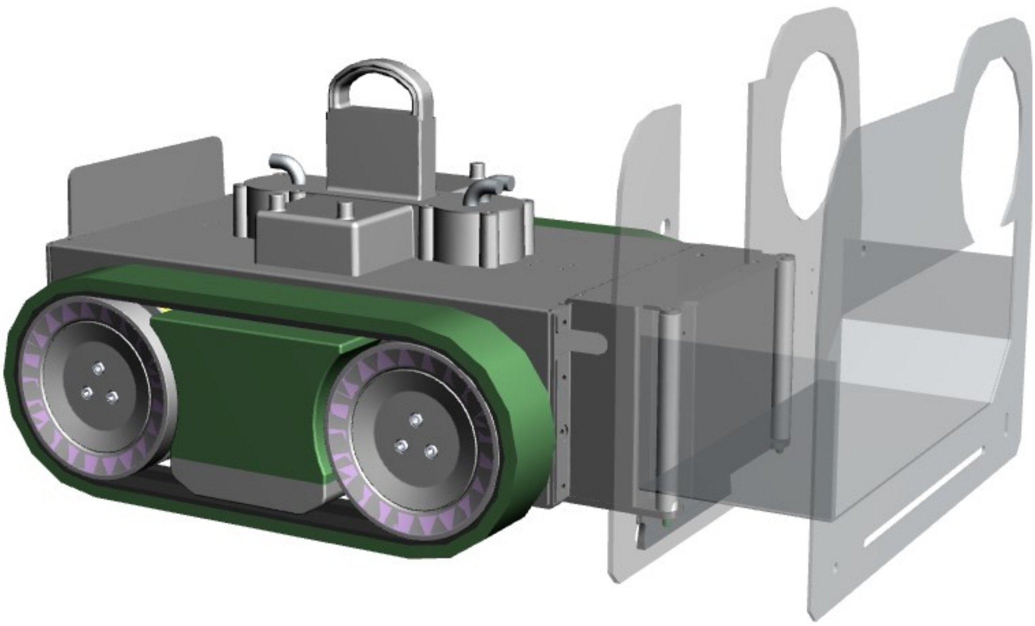


Figure 8: Details of the coupling mechanism between mobile base and tool

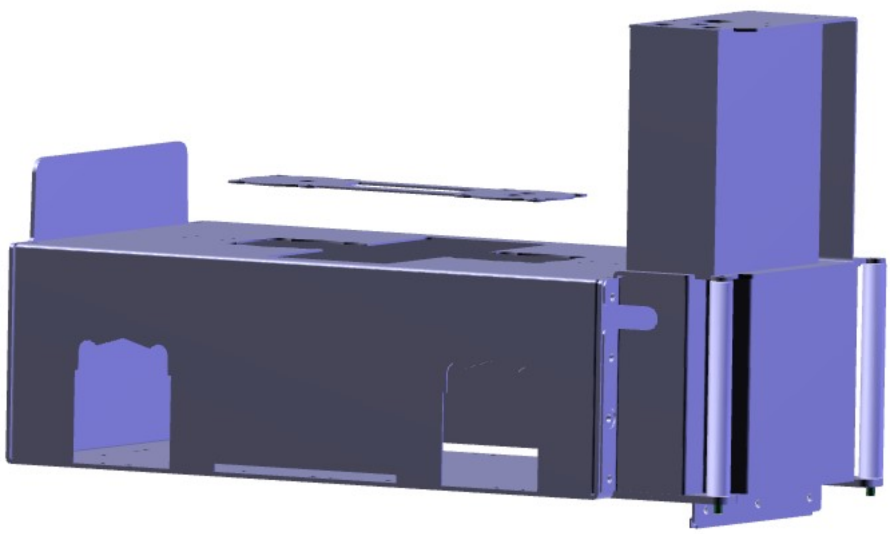


Figure 9: Mechanical frame for integrating components on the mobile base

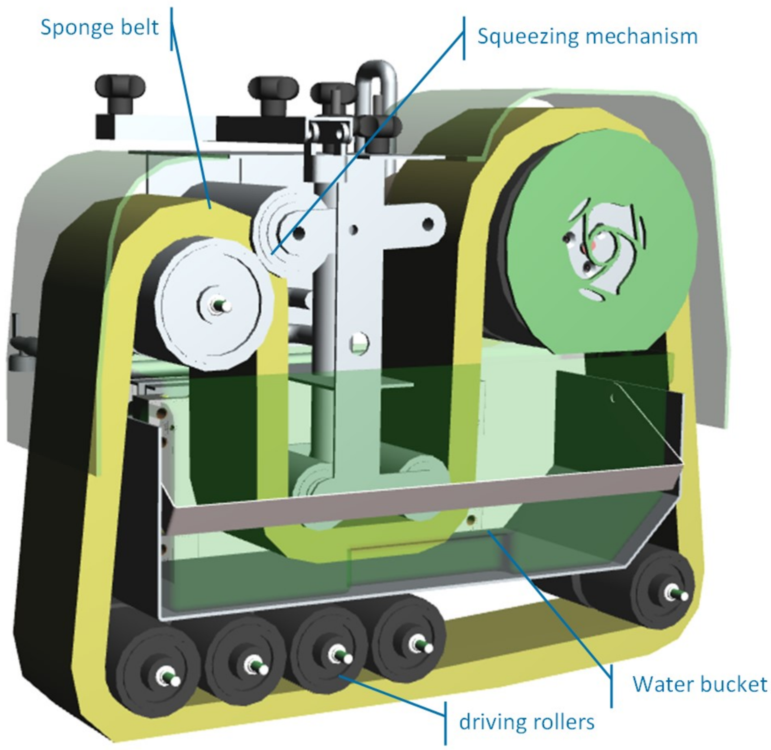


Figure 10: Details of the cleaning tool (frontal view)

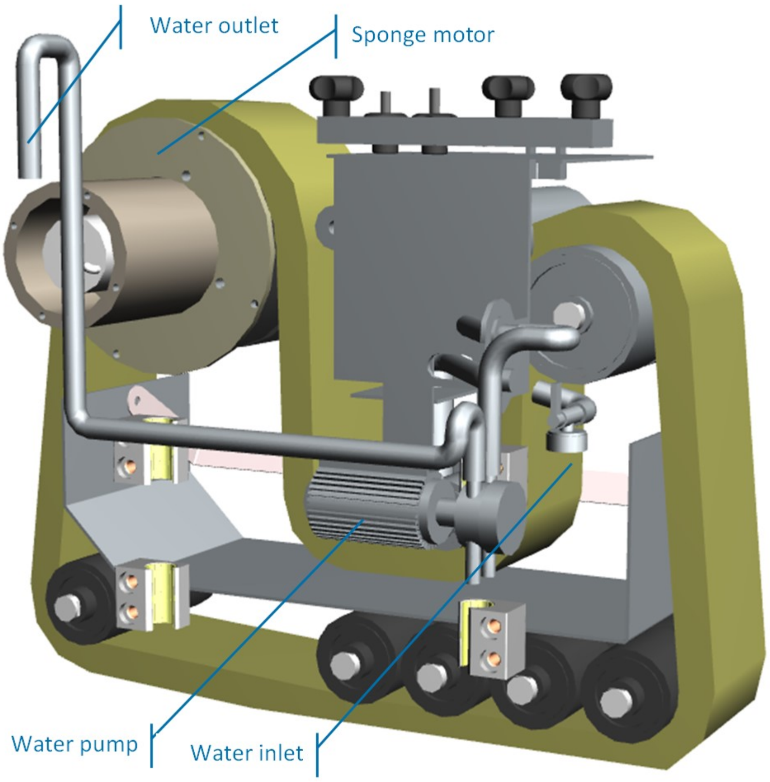


Figure 11: Details of the cleaning tool (rear view)

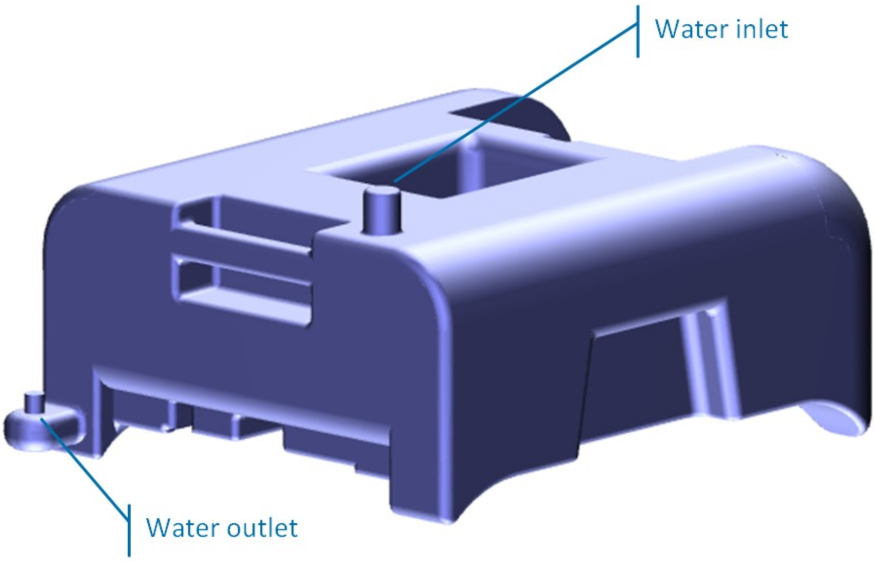


Figure 12: Details of the water bucket

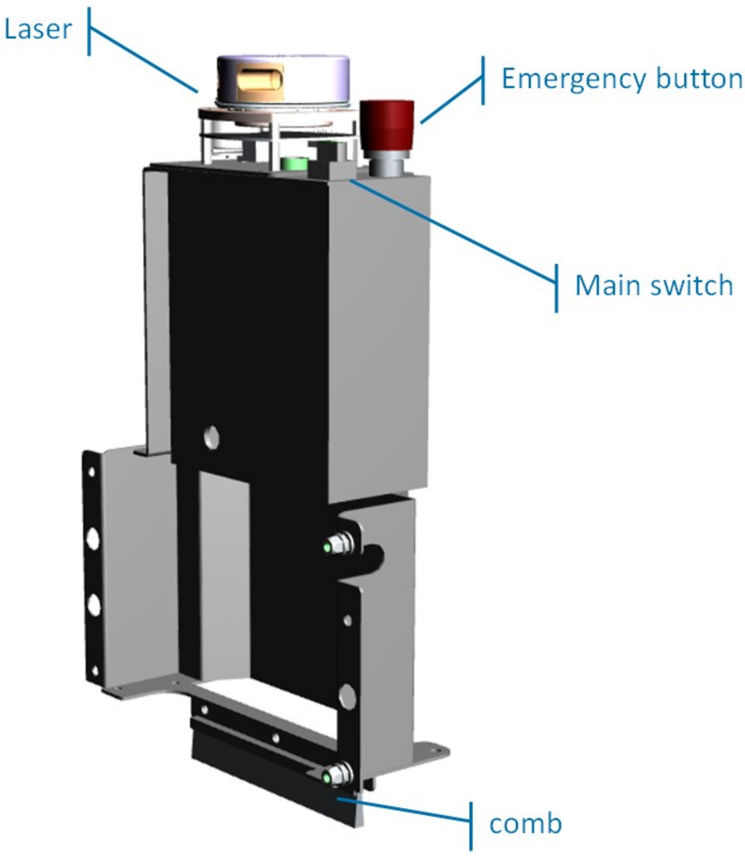
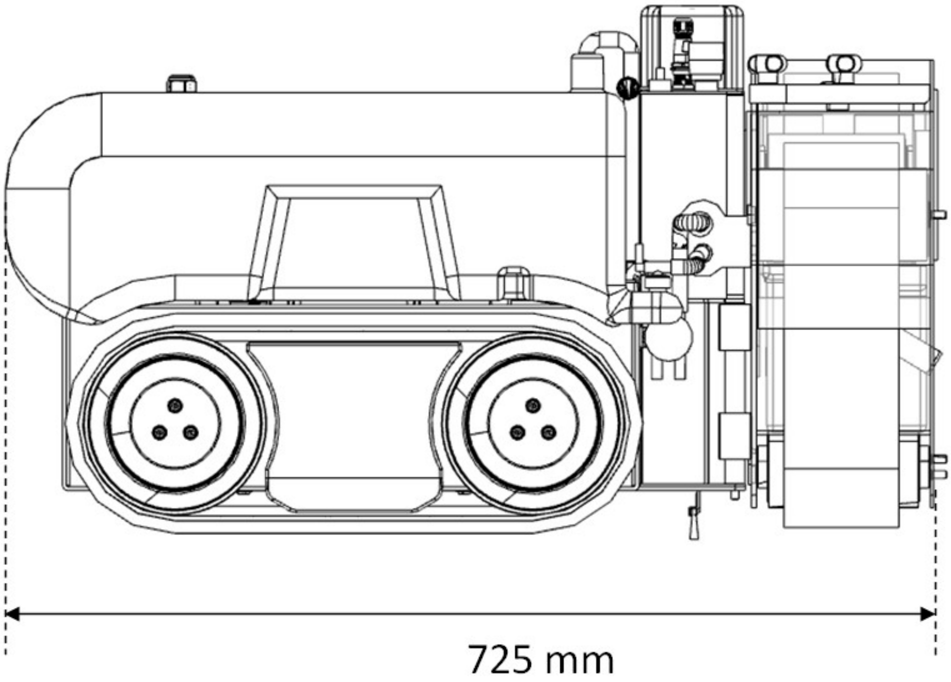
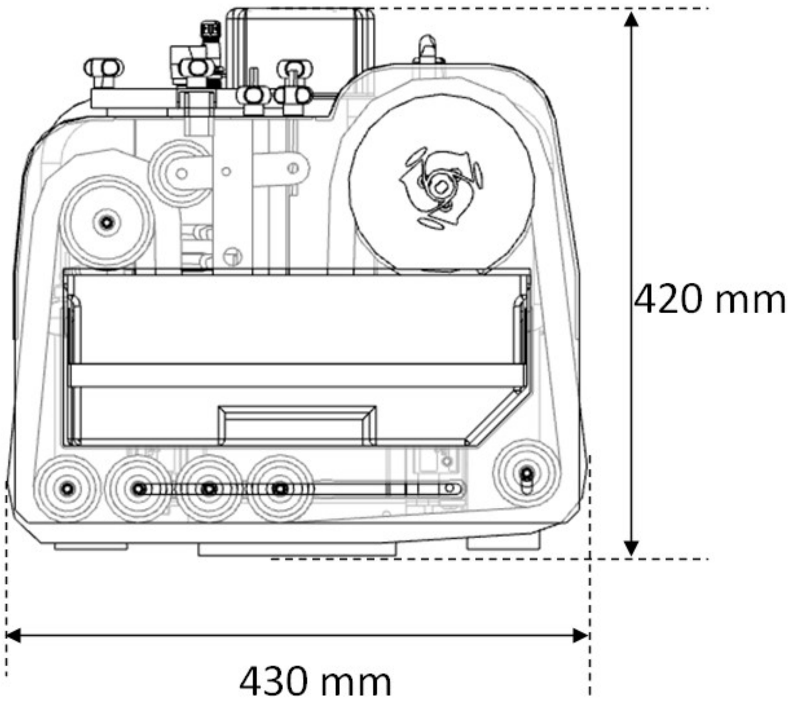


Figure 13: Details of quality control system, HRI devices and laser

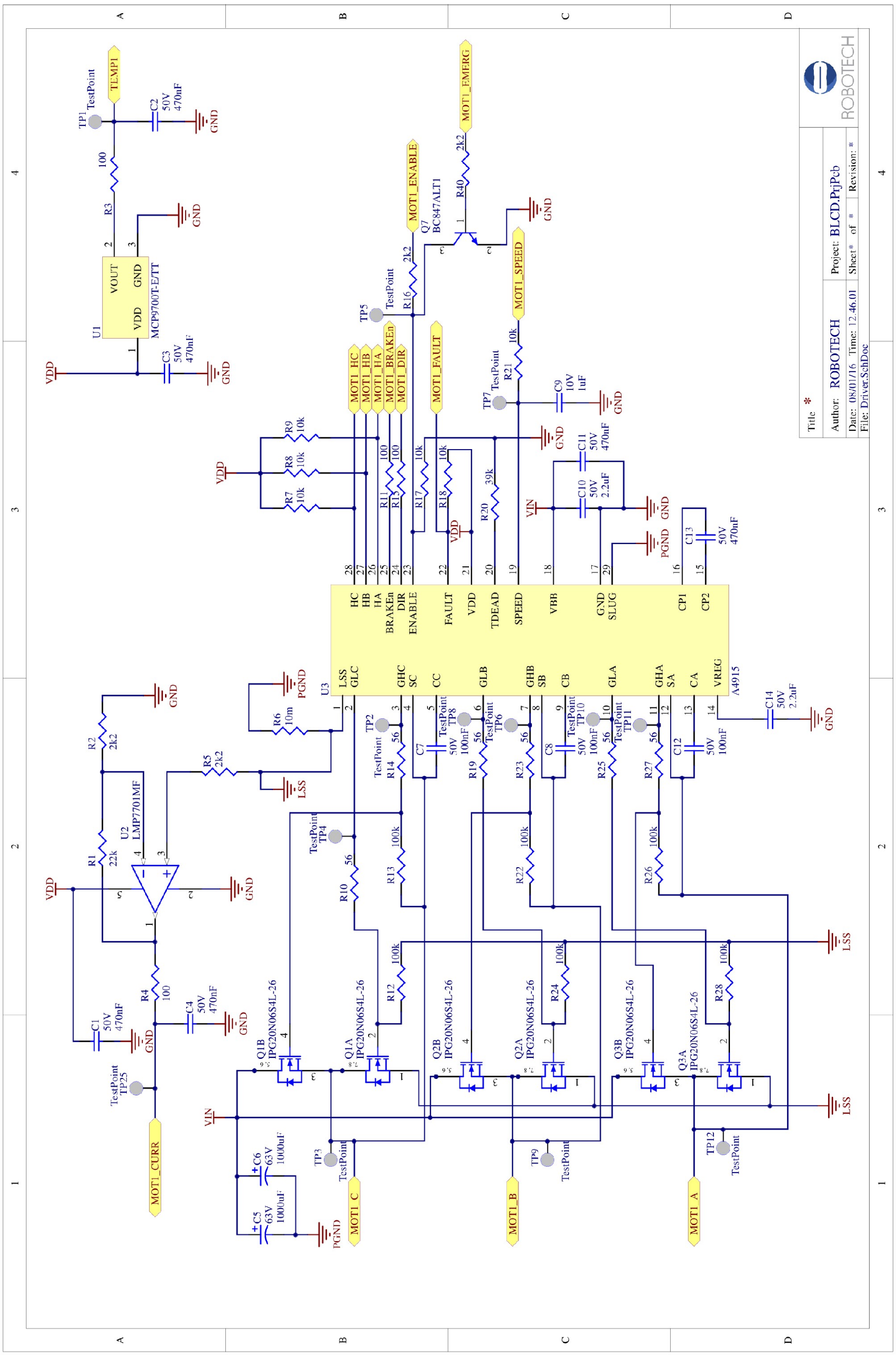
2.1 Robot dimensions

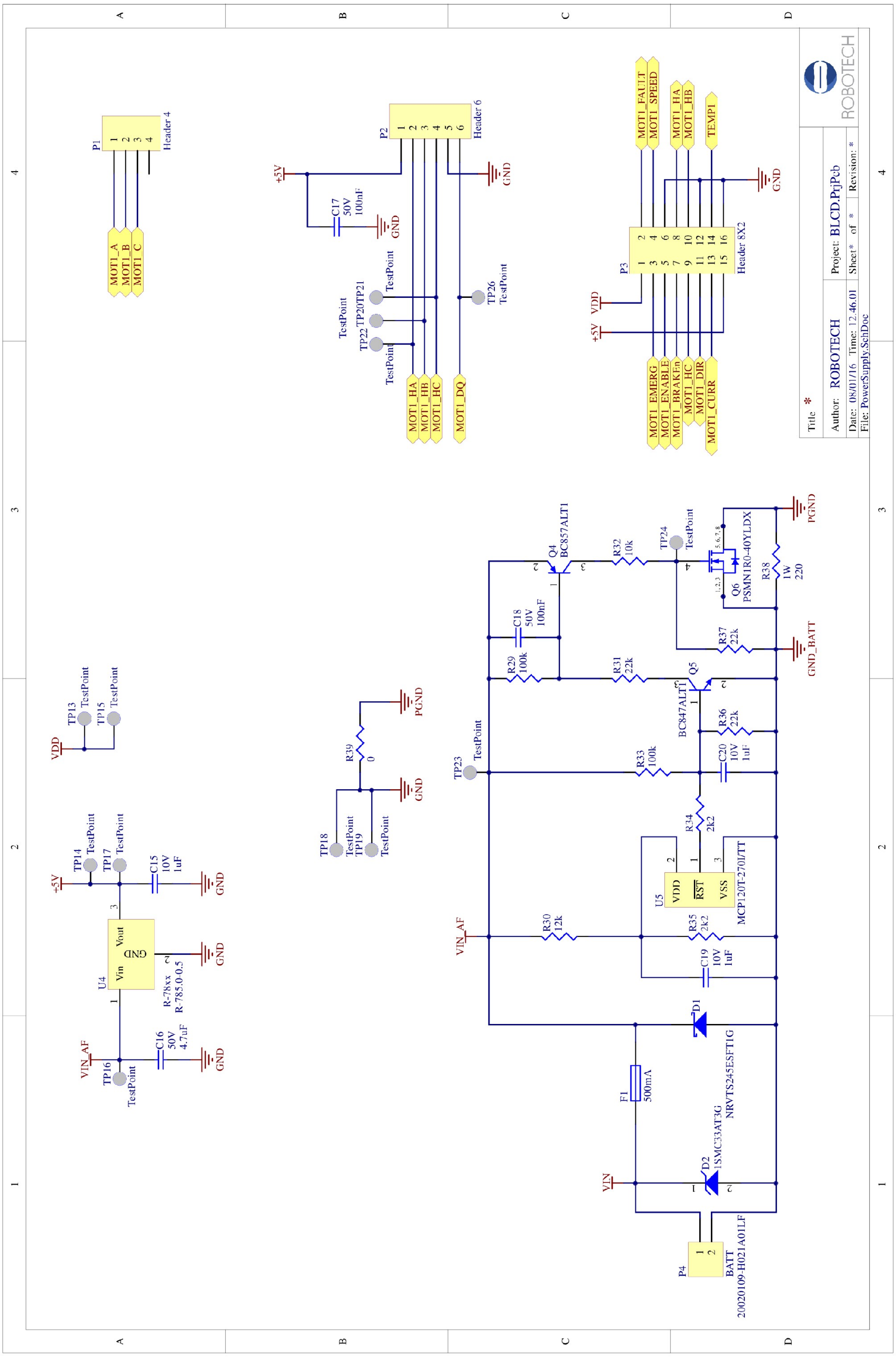




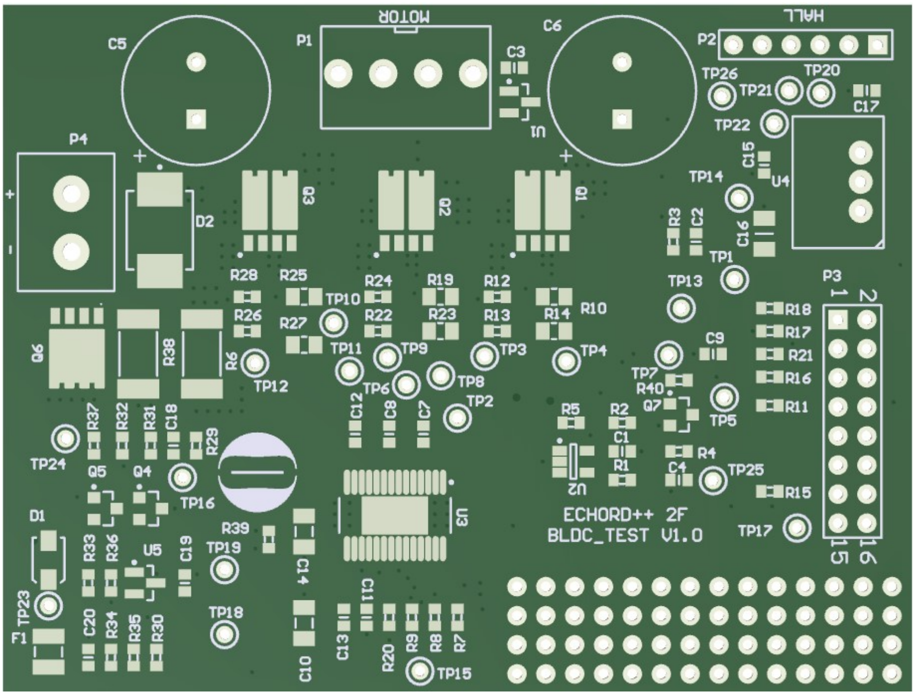
3 Electronics Design

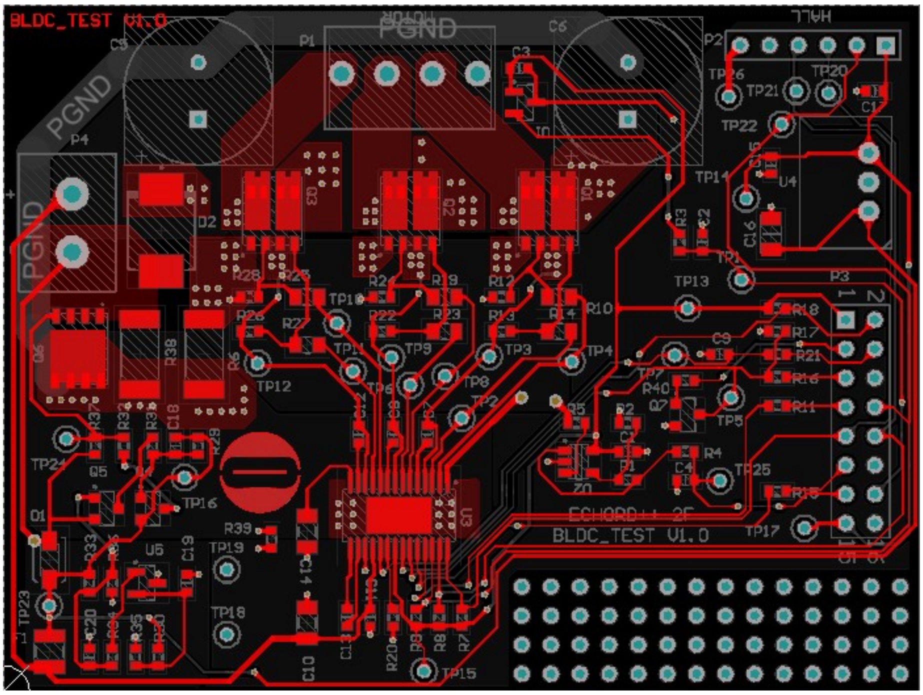
3.1 PCB schematic



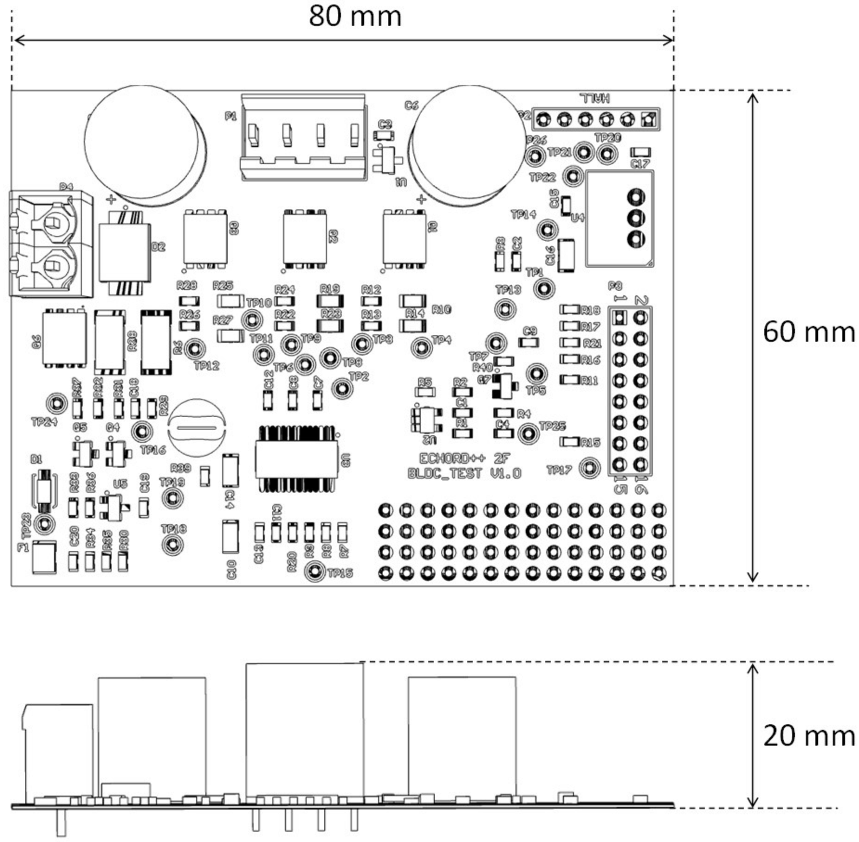

P1
Header 4
MOT1_A
MOT1_B
MOT1_C
P2
Header 6
+5V
GND
C17
50V
100nF
TestPoint
TP22
TP20
TP21
TP26
MOT1_HA
MOT1_HB
MOT1_HC
MOT1_DQ
P3
Header 8X2
VDD
MOT1_FAULT
MOT1_SPEED
MOT1_HA
MOT1_HB
TEMP1
MOT1_EMERG
MOT1_ENABLE
MOT1_BRAKEn
MOT1_HC
MOT1_DIR
MOT1_CURR
ROBOTECH
Title *
Author: ROBOTECH
Project: BLCD.PrjPcb
Revision: *
Sheet * of *
Date: 08/01/16
Time: 12.46.01
File: PowerSupply.SchDoc
TP13
TP15
TP14
TP17
TP16
C15
10V
1uF
U4
Vin
GND
Vout
R-78xx
R-785.0-0.5
C16
50V
4.7uF
VIN_AF
TP18
TP19
R39
0
PGND
TP23
Q4
BC857ALT1
C18
50V
100nF
R29
100k
R31
22k
R32
10k
TP24
Q6
PSMN1R0-40YLDX
R38
1W
220
R37
22k
GND_BATT
Q5
BC847ALT1
R36
22k
R33
100k
C20
10V
1uF
R34
2k2
U5
VDD
RST
VSS
MCP120T-270I/TT
R30
12k
R35
2k2
C19
10V
1uF
D1
NRVTS245ESFT1G
F1
500mA
VIN
D2
1SMC33AT3G
P4
BATT
20020109-H021A01LF

3.2 PCB layout

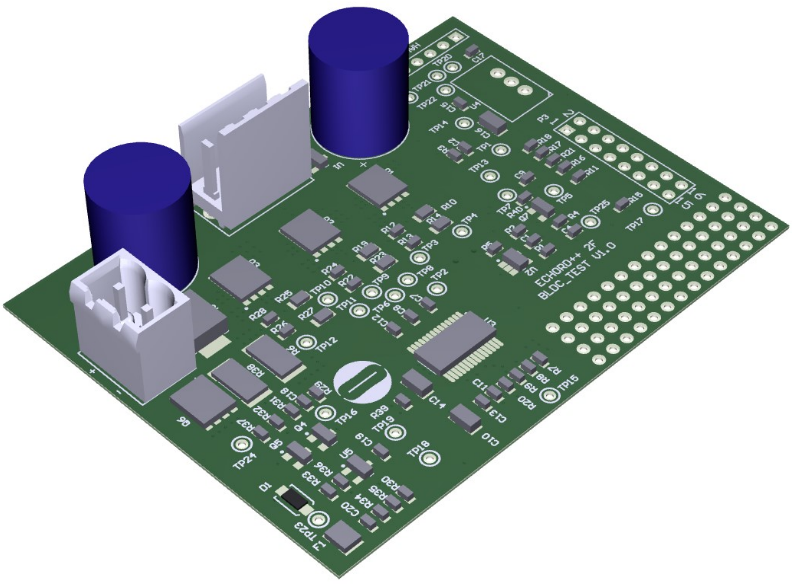




3.3 PCB dimensions



3.4 PCB 3D view

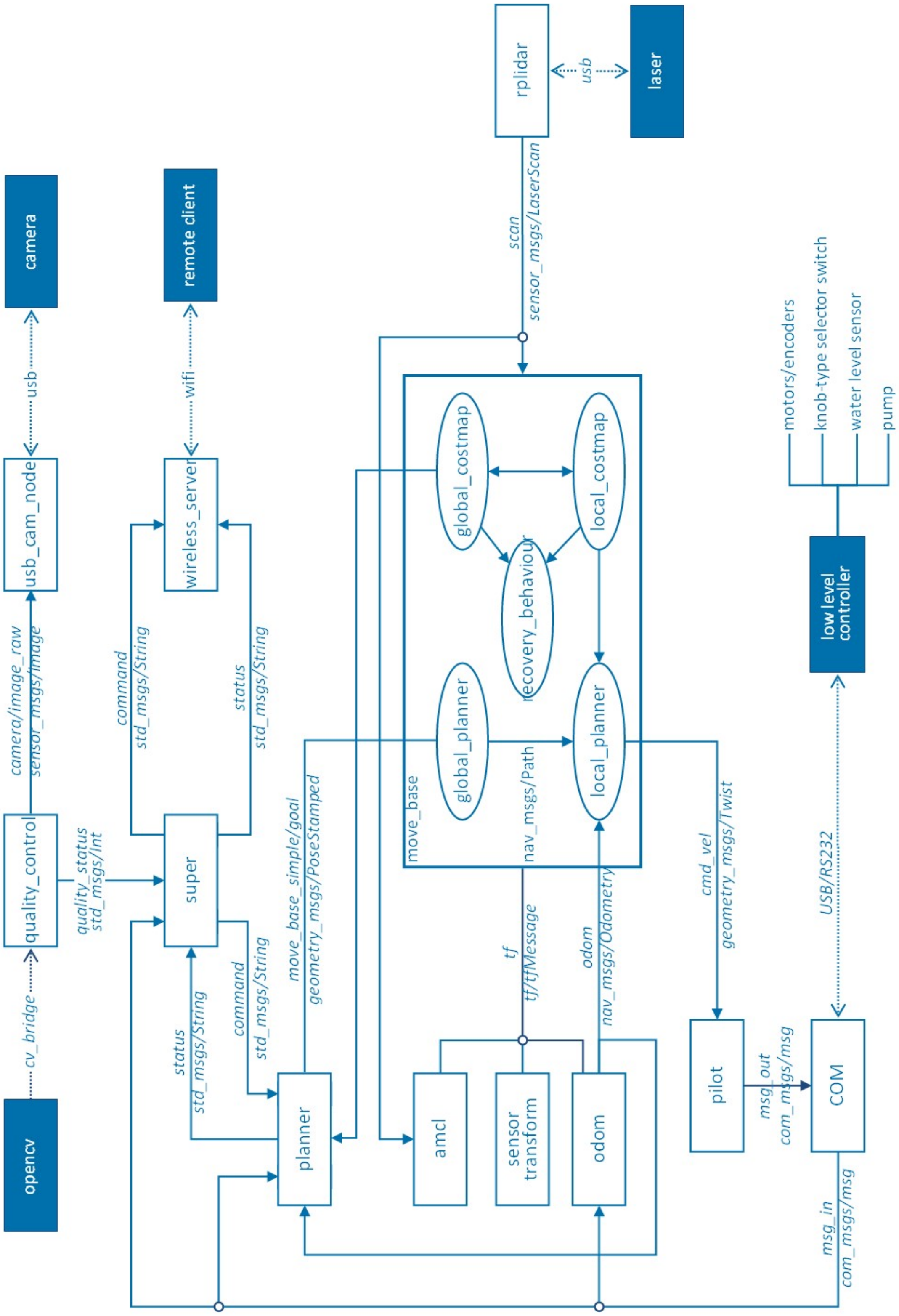


3.5 PCB BOM

Comment	Description	Designator	Footprint	LibRef	Quantity	Value
50V	Capacitor (Semiconductor SIM Model)	C1, C2, C3, C4, C11, C13	C0603	Cap Semi	6	470nF
63V	Polarized Capacitor (Surface Mount)	C5, C6	CAPPR5-13X15	Cap Pol3	2	1000uF
50V	Capacitor (Semiconductor SIM Model)	C7, C8, C12, C17, C18	C0603	Cap Semi	5	100nF
10V	Capacitor (Semiconductor SIM Model)	C9, C15, C19, C20	C0603	Cap Semi	4	1uF
50V	Capacitor (Semiconductor SIM Model)	C10, C14	C1206	Cap Semi	2	2.2uF
50V	Capacitor (Semiconductor SIM Model)	C16	C1206	Cap Semi	1	4.7uF
NRVTS245ESFT1G	Schottky Diode	D1	SOD-123	D Schottky	1	
1SMC33AT3G	1500 W Peak Power Zener Transient Voltage Suppressor, Unidirectional, 2-Pin SMC, Pb-Free, Tape and Reel	D2	ONSC-SMC-2-403-03_V	1SMC33AT3G	1	
500mA	Fuse	F1	14-1210	Fuse 1	1	
Header 4	Header, 4-Pin	P1	AMP 280610-1	Header 4	1	
Header 6	Header, 6-Pin	P2	HDR1X6	Header 6	1	
Header 8X2	Header, 8-Pin, Dual row	P3	HDR2X8	Header 8X2	1	
BATT	Header, 2-Pin	P4	20020107-H021A01LF	Header 2	1	
IPG20N06S4L-26	OptiMOS-T2 Power-Transistor, 60 V VDS, 20 A ID, PG-TDSON-8-4, Reel, Green	Q1, Q2, Q3	INF-PG-TDSON-8-4_V	IPG20N06S4L-26	3	
BC857ALT1	General Purpose Transistor, PNP Silicon, 3-Pin SOT-23, Tape and Reel	Q4	ONSC-SOT-23-3-318-08_V	BC857ALT1	1	
BC847ALT1	General Purpose Transistor, NPN Silicon, 3-Pin SOT-23, Tape and Reel	Q5	ONSC-SOT-23-3-318-08_V	BC847ALT1	1	
PSMN1R0-40YLDX	N-Channel OptiMOS Power-MOSFET, 25 V VDS, 100 A ID, -55 to 150 degC, PG-TDSON-8-1, Reel, Green	Q6	INF-PG-TDSON-8-1_V	BSC009NE2LS	1	
Res3	Resistor	R1, R31, R36, R37	R0603	Res3	4	22k
Res3	Resistor	R2, R5, R16, R34, R35	R0603	Res3	5	2k2
Res3	Resistor	R3, R4, R11, R15	R0603	Res3	4	100
Res3	Resistor	R6	RESC6332M	Res3	1	10m
Res3	Resistor	R7, R8, R9, R17, R18, R21, R32	R0603	Res3	7	10k
Res3	Resistor	R10, R14, R19, R23, R25, R27	R0805	Res3	6	56
Res3	Resistor	R12, R13,	R0603	Res3	8	100k

		R22, R24, R26, R28, R29, R33				
Res3	Resistor	R20	R0603	Res3	1	39k
Res3	Resistor	R30	R0603	Res3	1	12k
1W	Resistor	R38	RESC6332	Res3	1	220
Res3	Resistor	R39	R0603	Res3	1	0
MCP9700T-E/TT	Low-Power Linear Active Thermistor IC, 3-Pin SOT-23, Extended Temperature, Tape and Reel	U1	SOT-23-TT3_N	MCP9700T-E/TT	1	
LMP7701MF	Precision, CMOS Input, RRIO, Wide Supply Range Amplifier, 5-pin SOT-23	U2	MF05A_N	LMP7701MF	1	
A4915	A4915MLPTR-T	U3	TSSOP28-EP_M	A4915	1	
R-78xx		U4	RECOM DCDC	RECOM DCDC	1	
MCP120T-270I/TT	Microcontroller Supervisory Circuit with Open Drain Output, 3-Pin SOT-23, Industrial Temperature, Tape and Reel	U5	SOT-23-TT3_N	MCP130T-270I/TT	1	

4 Software Architecture



The 2F ROS package includes the ROS node managing the robot:

- **super**: this node is the robot supervisor, manages the robot components, get commands for the robot and publishes the robot status from/to ROS topics.
- **com**: this node is the ROS interface to the low level control: writes/reads messages to/from the serial port and gets/publishes these messages from/to ROS topics *"msg_out"* and *"msg_in"*.
- **odom**: this node computes and publishes on the topic "*odom*" the robot odometry estimated on the base of encoder readings.
- **pilot**: this node transform linear and rotational velocity commands in messages for the motor driver. The node gets messages from "*cmd_vel"* topic and publishes the proper message to "*msg_out"* topic.
- **planner**: this node plan trajectories in terms of waypoint to cover the working area on the base of the *global costmap* published by the *move_base* node and the position of the robot in the map. The node publishes goals for the *move_base* node on the topic "*move_base_simple/goal"*.
- **rplidar**: this node acquire laser data from the rplidar laser scanner and publishes the readings on the *"scan"* topic.
- **usb_cam_node:** this node acquire images from the usb camera and publishes them on the "*camera/image_raw"* topic.
- **quality control:** this node perform quality control analysis by comparing images published on the "*camera/image_raw"* topic and by making use of the opencv library by means of the cv_bridge package. The node publishes results of the quality control on the *"quality_status"* topic.
- **wireless_server**: this node is a TCP/IP server and allows remote Ethernet access to the robot. The node gets/sends messages from/to client and publishes/get these messages from/to ROS topics *"command"* and *"status"*.

The architecture is completed by the ROS Navigation stack, AMCL and map server nodes.

4.1 Communication: "command" topic protocol

enable	Enable base motors output
disable	Disable base motors output
speed *v, r*	Set linear v (m/s) speed and rotational r (r/s) speed
moveto x, y, t	Move the base to [x,y,t]
stop	Stop all motors and/or grout removing procedure
sponge on	Start sponge motor

sponge off	Stop sponge motor
pump on	Start pump
pump off	Stop pump
start	Start grout removing procedure
pause	Pause the grout removing procedure (pause base motors, sponge motor and pump)
resume	Resume the grout removing procedure

4.2 Communication: "status" topic protocol

ready	Robot ready
enabled	Base motors output enabled
disabled	Base motors output disabled
moveto x, y, t	Moving robot to [x,y,t]
moveto completed	Base at goal
moveto failed	Moveto failed
speed v, r pose x, y, t	robot linear (v) and rotational (r) speed and position x, y, t (m/s, r/s, m,m,rad)
sponge on	Sponge motor on
sponge off	Sponge motor off
pump on	Pump on
pump off	Pump off
started	Grout removing procedure started
paused	Grout removing procedure paused
completed	Grout removing procedure completed
battery v	Battery level v (volts)
water l	Water level l (%)
quality q	Results of the quality control procedure (%)
emergency button on	Emergency button raised
emergency button off	Emergency button pressed
error *[error message]*	Error

4.3 Communication: UART protocol

Communication protocol with Low Level Control board

Serial port parameters:

- Baud rate: 115200
- Data bits: 8
- Parity: none
- Stop bits: 1

Commands:

enable: [e]	e ∈ {0,1}	enable (1) or disable (0) motor outputs
brake:*[b]*	b ∈ {0,1}	enable (1) or disable (0) motor brakes
setduty: *[dl]*, *[dr]*	dl ∈ [0,100] dr ∈ [0,100]	Set left (dl) and right (dr) motor duties
setsponge: *[d]*	d ∈ [0,100]	Set sponge motor duty (d)
pump: [p]	p ∈ {0,1}	start (1) or stop (0) pump
status	-	Status request

Status messages

motor*[m]* status: enable=*[e]*; fault=*[f]*; brake=*[b]*; dir=*[d]*	m ∈ {1,2,3} e ∈ {0,1} f ∈ {0,1} b ∈ {0,1} d ∈ {0,1}	1 motor left, 2 motor right, 3 motor sponge 1 motor enabled, 0 motor disabled 1 motor error, 0 motor regular 1 brake disabled, 0 brake enabled motor direction
hall*[m]*: *[h]*	m ∈ {0,1,2} h ∈ [0,100]	Hall effect sensor position (h): 1 motor left, 2 motor right, 3 motor sponge
level: *[l]*	l ∈ [0,100]	Water level sensor status: 0 empty, 100 full
selector: *[s]*	s ∈ {0,1}	Selector position: 0 ON, 1 START
emergency_button: [e]	e ∈ {0,1}	Emergency button status: 0 open, 1 closed

ANNEX
MECHANICAL DESING (PDF 3D)