Department of Astronautical Engineering
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Nanook Hardware Documentation

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NANOOK HARDWARE DOCUMENTATION

1. INTRODUCTION

Nanook is a robot made by NASA summer interns in a bootcamp led by Michael Comberiate (NASA-Mike). Three robots (Nanook, Penguin 1 and Penguin 2) were developed to explore a remote terrain, while challenging communication protocols, large data transference, and ability to work in harsh environments.

According to P. Stakem [1], the goal of the project was “to assemble a networked team of autonomous robots to be used for three-dimensional terrain mapping, high-resolution imaging, and sample collection in unexplored territories.” The mothership (Nanook) was responsible for locating their auxiliary robots (Penguin 1 and 2) based on sphere detection (each auxiliary robot had unique spheres placed at their top). They tracked an area sending stitched successive images to the control center, where high-level strategy was decided and sent as commands to the robots. The robots are semi-autonomous requiring a minimal command from the control center.

A lot of incredible pioneer work was done during the few weeks of the NASA Engineering Bootcamp, but a good documentation about this project was not developed concomitantly.

Almost five years after the end of Nanook’s project, a reverse engineering project is being developed to document it. Characterized by “taking apart an object to see how it works in order to duplicate or enhance”[2] it, a reverse engineering project allows the reconnaissance of the entire system and its characterization for further consultancy and implementation by establishing the adequate documentation.

2. POWER SYSTEM

Nanook’s power system is composed of two important circuits. The first one is the batteries circuit, which provides power to all the systems in the robot. The second one is the power converter system, which is fed by the batteries system and then distributes appropriate voltage levels for all the other systems (+24V, +12V, or +5V).

2.1 BATTERIES CIRCUIT

The are four 12V batteries. Each side is a set of two batteries connected in series to provide a total of 24V. The two set of batteries is connected in parallel to provide 24V to the power converter circuit. The 24V power cables (VCC and GND) go to the main gray box as a red and a black wire. These wires go to the power converter board.

Figure 01 - Batteries and their connections inside the batteries box

Also, the batteries are connected to a switch, so the system is able to alternate between the charger connection and the connection that goes to the power converter board and provide power to the robot. A circuit diagram is shown below.

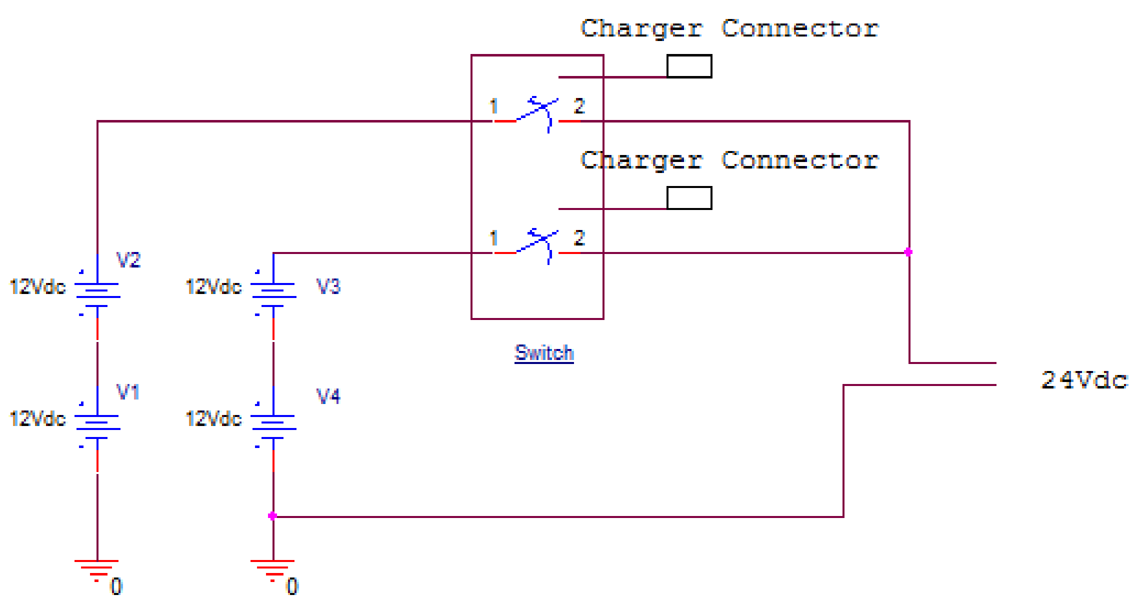


Figure 02 - Schematic of the batteries circuit.

Doing a deep hardware inspection, we detected that both blue batteries are swallowed and need to be replaced, as the figure below is showing.

Figure 03 - Swallowed battery inside the batteries box

2.2 POWER CONVERTERS CIRCUIT

The input to the power converter board is +24V that comes from the batteries. In this board, the voltage level from the battery is converted to 12V and 5V in the WPN20R24S12 and WPN20R24S05, respectively. In addition, the +24V wire is divided in two wires using tape. These components are obsolete now. After the converters, the VCC goes to a fuse. There is one for the 5V, one for the 12V, and two for the 24V wires. The 5V power is identified in the board with the letter “J” and goes to the yellow connector marked with “5”. The 12V power is identified in the board with the letter “M” and goes to the blue connector marked with “12”. Both 24V wires goes to red connectors after passing through the fuses. The figure showing the back side of the power converter board is showed below.

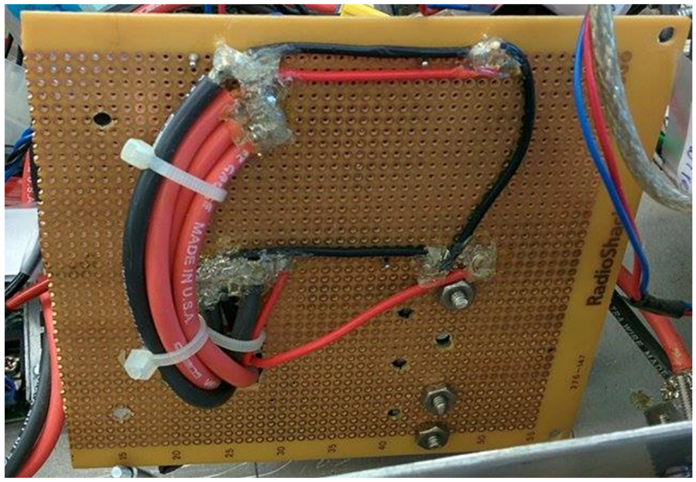


Figure 04 -.Bottom of the power converter circuit board

3. MOTHERBOARD CONNECTIONS

The motherboard has eight USB connections, but just six USBs are being used to control the system. The other two USBs were probably kept unused in order to leave USB ports for flash drives or other support devices. The USB ports have been named by the following notepaper, which came attached to the main box cover. The picture of the paper is showed below:

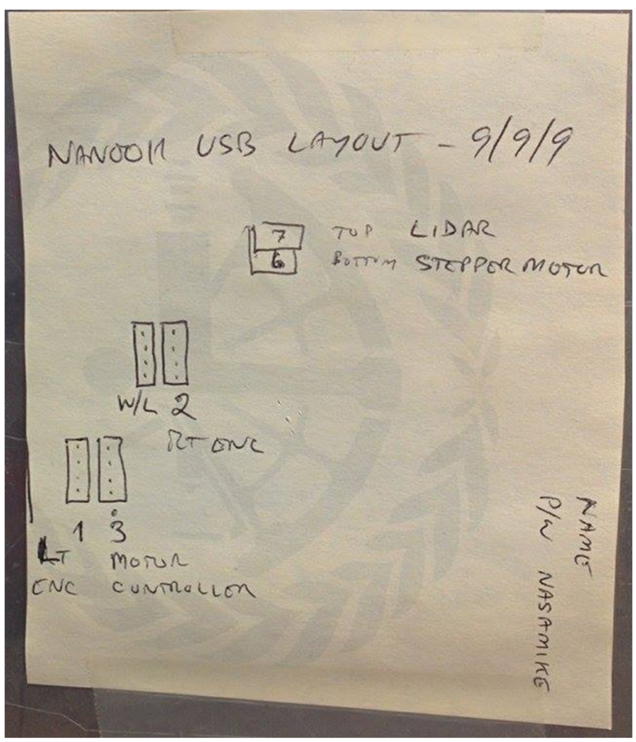


Figure 05 – Paper note with the USB connections' names

In order to facilitate the USB connections comprehension, there is a table below displaying where each motherboard USB connection leads.

Table 01 - USB Connections

From	Mid-connections	Final Destination
USB1	RS232 connector	AD4-B-S Left
USB2	RS232 connector	AD4-B-S Right
USB3	CP2102 (USB/UART converter)	SABERTOOTH 2X25
USB4	--	Wi-Fi Adapter
USB5	NOT USED	
USB6	RS232 connector	LIDAR Stepper Motor System
USB7	RS232 connector	LIDAR (green connector)
USB8	NOT USED	

USB 1 and 2 are part of the DC Motor Feedback System and are responsible for receiving the encoders' data. However, as the computer does not understand the encoders communication protocol, the AD4-B-S makes the translation into RS232**,** and then the computer receives the data though the USB-RS232 cable that is connected to the RS232 that comes from the AD4-B-S.

USB 3 is responsible for the DC motors control. The Embedded software sends the commands to the USB 3, and then before the commands go directly to the Motor Drive called Sabertooth, they are translated into the UART protocol by the CP2102 (USB/UART converter).

USB 4 connects the motherboard to Wi-Fi Adapter.

USB 6 is responsible for sending commands to the LIDAR Stepper Motor System.

USB 7 is responsible for sharing (sending/receiving) data with LIDAR, using RS232 protocol.

In addition, the motherboard has a flash storage drive and a cooler attached to it. There is a SATA Data connection from the external drive to the motherboard (SATA0). Also, there are SATA Power wires linking the motherboard's power connector with the flash storage drive. This plug is also linked to a 2x2 connector in the motherboard - two GND (black wires) and two +12VDC (yellow wires). The model of the SSD flash storage drive is SNV125-S2/64GB.

The motherboard's power connector receives 24 VDC and convert it to the right pins voltage levels that power up the CPU.

Finally, the outside turn-on button (white button) is also connected to the motherboard.

4. MOTORS CONTROL

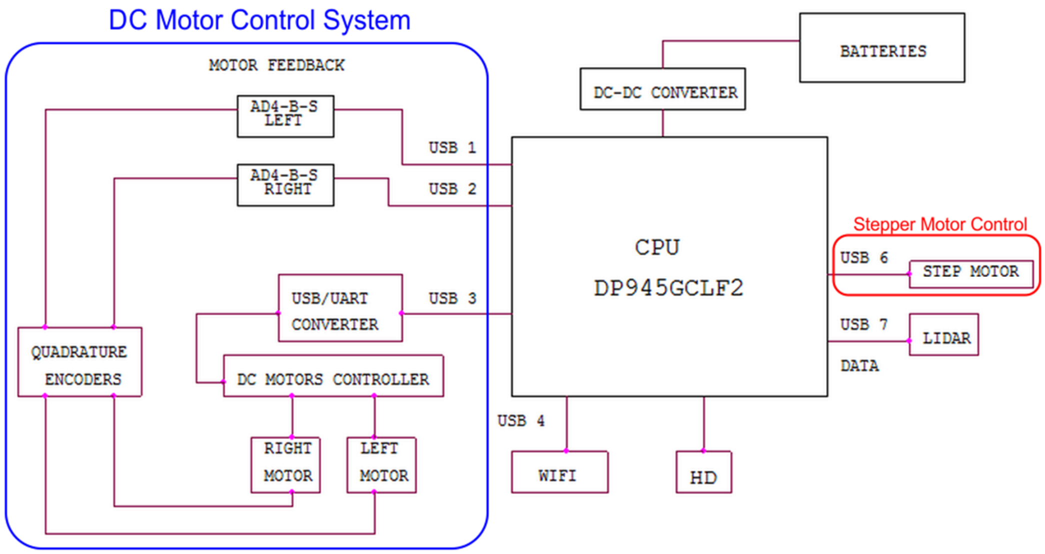


Figure 06 - DC motors control system and Stepper motor in the main schematic

4.1. DC MOTORS CONTROL

4.1.1. COMMAND SYSTEM

The command system of the DC Motors consists basically of USB3, CP2102 and Sabertooth.

The computer software sends the command and the embedded software process the data that comes from the USB4 via Wi-Fi, and then the embedded software sends the respective commands out to the DC motors via USB 3. Since the Sabertooth (DC Motor Driver), just communicates in UART protocol, the USB 3 is connected to the USB-UART converter, called CP2102, in order to make the translation from the USB protocol into UART protocol so that the Sabertooth is able to receive the embedded software command as input.

The Sabertooth receives two wires (a green and a blue one) coming from the CP2102 (a USB/UART converter). In addition, it receives 24 VDC power and ground wires coming from the Converter Board. The Sabertooth's output is composed by two pairs of red and black wires that go to a connector in the border of the main gray box (on the right corner) and go to the motors. Each pair is connected to two DC motors located to the left or right side of the robot.

In order to receive UART signals, the Sabertooth is working on the Simplified Serial Mode. It is possible to visualize this by hardware inspection, since there is a switches board numerated from 1 to 6, as it is visible on the picture below:

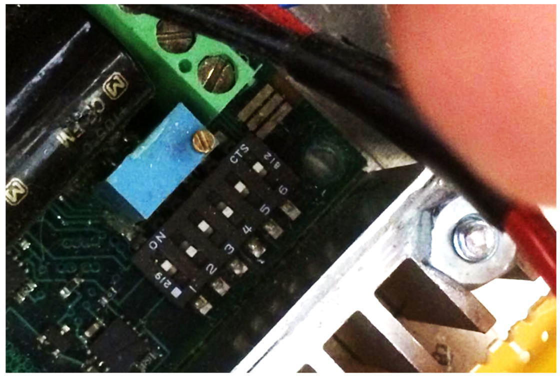


Figure 07 - Switches responsible for selection the mode and baud-rate

Therefore, the switches together with the Sabertooth (DC Motor Driver) datasheet can tell that the DC Motor Driver is working on *Standard Simplified Serial Mode* and 9600 baud-rate.

Selecting the switches 1, 2, and 3 as up, down, and up respectively, it sets the Simplified Serial Mode. Selecting the switches 4 and 5 as down and up respectively, it sets baud-rate as 9600.

Selecting the switch 6 as up, it maintains the standard option, which means the commands are sent as single bytes.

As exposed in the Sabertooth 2x25 Datasheet [3], “sending a character between 1 and 127 will control motor 1. 1 is full reverse, 64 is stop and 127 is full forward. Sending a character between 128 and 255 will control motor 2. 128 is full reverse, 192 is stop and 255 is full forward. Character 0 (hex 0x00) is a special case. Sending this character will shut down both motors.”

An easier way to visualize is below:

Table 02 - DC Motors Control Signals

Motors	Function	Commands in Binary (Hexadecimal///Decimal)
MOTOR 1	Full Forward	0b01111111 (0x7F///127)
	Full Reverse	0b00000001 (0x01///001)
	Stop	0b01000000 (0x40///064)
MOTOR 2	Full Forward	0b11111111 (0xFF///255)
	Full Reverse	0b1000000 (0x80///128)
	Stop	0b11000000 (0xC0///192)

In the Standard Simplified Serial Mode, Sabertooth is able to control two motors (or two sets of motors). Nanook has four motors, two of them are responsible for moving the left side gears and the other 2 are responsible for the right side gears. In this way, Sabertooth can command four motors at the same time, since the control signals are send to the left and right sets of DC motors (two motors each side). For example, the right side commands go to the two right side DC motors, and the left side commands go to the two left side DC motors.

4.1.2. FEEDBACK SYSTEM

The feedback system consists mainly of left and right encoders, left and right AD4-B-S, and also USB 1 and 2.

The feedback data comes from the encoders attached to the DC motors. There are four encoders in total, however two from the front of Nanook are not being used. The feedback data comes from the two encoders from the back of Nanook, left and right side.

There are two sets of colorful small cables which come from Quadrature Encoders attached to the DC motors. They link the DC motors encoders and their respective AD4-B-S (left or right), passing through the MS3106A28-21S connector which is placed on the right corner of the gray box. The quadrature encoder captures the phase position of the DC motors in Channel A and B, and then that information is processed into the AD4-B-S, in which is converted into serial communication (RS232). There are relevant information about AD4-B-S' on their datasheet, for instance, AD4-B inputs from the quadrature encoder. At the table below, it is possible to see their relation.

Table 03 - Relation between Encoder wires and AD4-B-S inputs

AD4-B-S input (Wire number/Color)	Quadrature Encoder Outputs
1/Black	Ground
2/Green	Index
3/Yellow	Channel A
4/Red	+5VDC power
5/Blue	Channel B

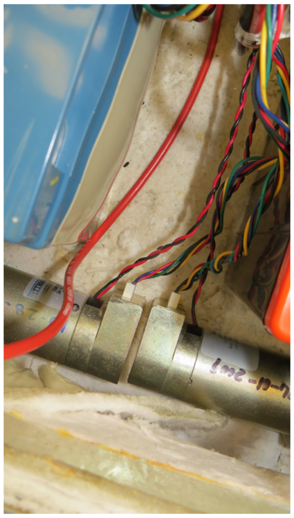


Figure 08 - Encoders

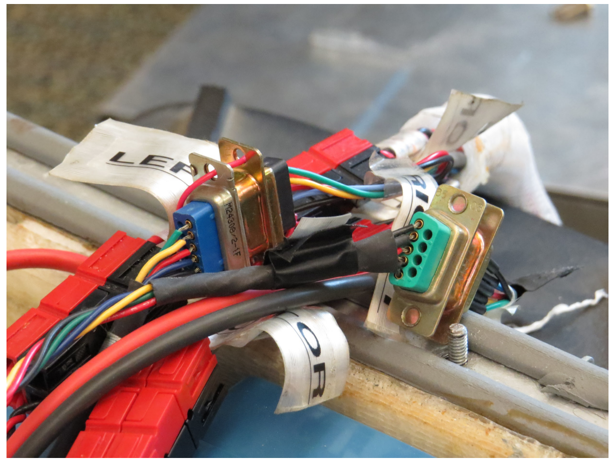


Figure 09 - Cables which leave the battery box

4.2. LIDAR STEPPER MOTOR

In the lateral gray box, there is a circuit to control the LIDAR angle of inspection. In this box, there is a R256 microstepping controller unit with RS232 communication kit. It is used to control the LIDAR stepper motor.

In order to control the LIDAR angle of inspection, the CPU sends signals from the USB6, which are converted to RS232 communication. These signals go into the lateral gray box, where the commands are translated into another protocol called RS485 by a RS232-RS458 converter (which is marked in the pink box in the figure 10). The RS232-RS485 card is plugged to the CPU using a standard male to female DB-9 cable. The RS232-RS485 card outputs an “A” phase and a “B” phase. + 12 VDC power is supplied to both the converter card and R256.

The signals outputted in RS485 communication standard go through the R256 step controller. Then R256 outputs the final 4 signals that go to the step motor. The Red wire is A, Blue is A Bar, Green is B, and Black is B Bar.

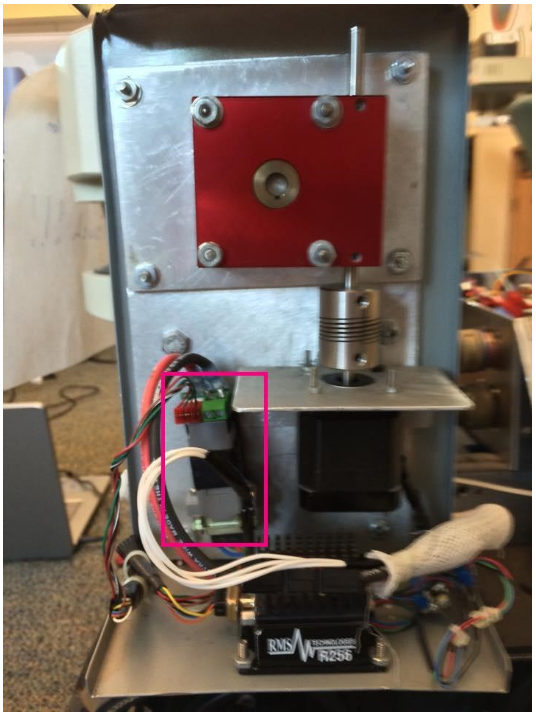


Figure 10 –RS232/R485 Converter

5. LIDAR DATA

For exchanging data between the LIDAR and the CPU, it is necessary to use the RS232 protocol or RS422. In Nanook, it was chosen the RS232 because of the CPU communication. The CPU is connected to the LIDAR though the USB7.

The USB7 is converted into RS232 communication, and then three white wires pass through the connector LJTPQ00RT-15-35S. They come out of the box wrapped by a black net and go directly to the LIDAR box of connections.

By reading the datasheet[6] of the LIDAR, it is possible to have an idea about the LIDAR connections to the embedded computer. Below, as an illustration, there is a picture that explains how to connect to the LIDAR using RS232:

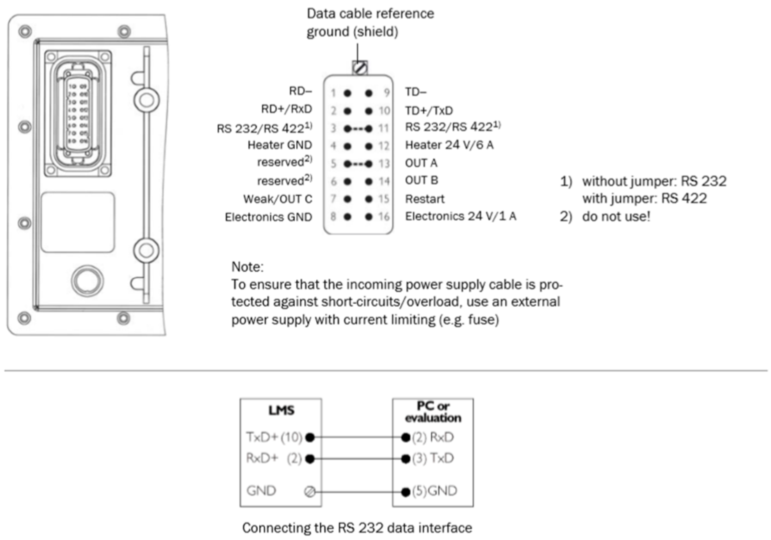


Figure 11 - LIDAR connections [6]

Note that LMS is the same as LIDAR.

6. USELESS DEVICES IN THE BOX

6.1 Parallax

The Parallax motor driver is an obsolete component inside the CPU box. It is not being used anymore, as identified by hardware inspection. However, it still has some wires connected to it and is part of the circuits schematics drawing (attached). There are two wires coming from the power converter board (blue and red wires), and also six other wires coming out of the parallax. These wires come out of the parallax as two red, two green and two black wires, but all of them become white after a connector. Ultimately, they go to a junction of wires not being used.

6.2 Two frontal encoders

As explained in the DC motor control section, only the two encoders in the back of nanook are being used.

6.3 "For hub" connector

From the yellow connector right after the power converter board, which outputs 5 V, there are two wires coming out, one black and one red (both are 5V, even the black one). The black one gets together with another black wire (which this time is a ground) and goes to a connector entitled as “for hub”. The choice of wire colors was not the best as it is confusing and falls off the pattern commonly used by electrical engineers.

7. CONCLUSION

By doing a complete hardware inspection, we were able to track the entire hardware of the robot system. As a result, we developed a schematic using the AutoCad software to documentate the hardware system in a way that anyone can easily understand without having to open any box or decoupling any board. This provides a safer way for people understand and implement changes in the Nanook robot in the future. Additionally, tags were attached to the main parts, so in a possible emergency case that the hardware might be open, it will be possible to quickly identify and follow the main connections in a way that is coherent with the documentation and schematic provided by this work. The schematic file is attached to this document.

8. REFERENCE

[1] Available at <http://www.theoldrobots.com/Pat_Sc.html> Accessed on July 23th of 2015 at 3:45 PM.

[2] Available at <http://searchsoftwarequality.techtarget.com/definition/reverse-engineering> Accessed on July 20th of 2015 at 11:07 PM.

[3] Available at <https://www.dimensionengineering.com/datasheets/Sabertooth2x25.pdf> Accessed on July 3rd of 2015 at 11:43 AM.

[4] Available at <https://cdn.sparkfun.com/datasheets/BreakoutBoards/CP2102_v1.2.pdf> Accessed on July 17th of 2015 at 3:45 PM.

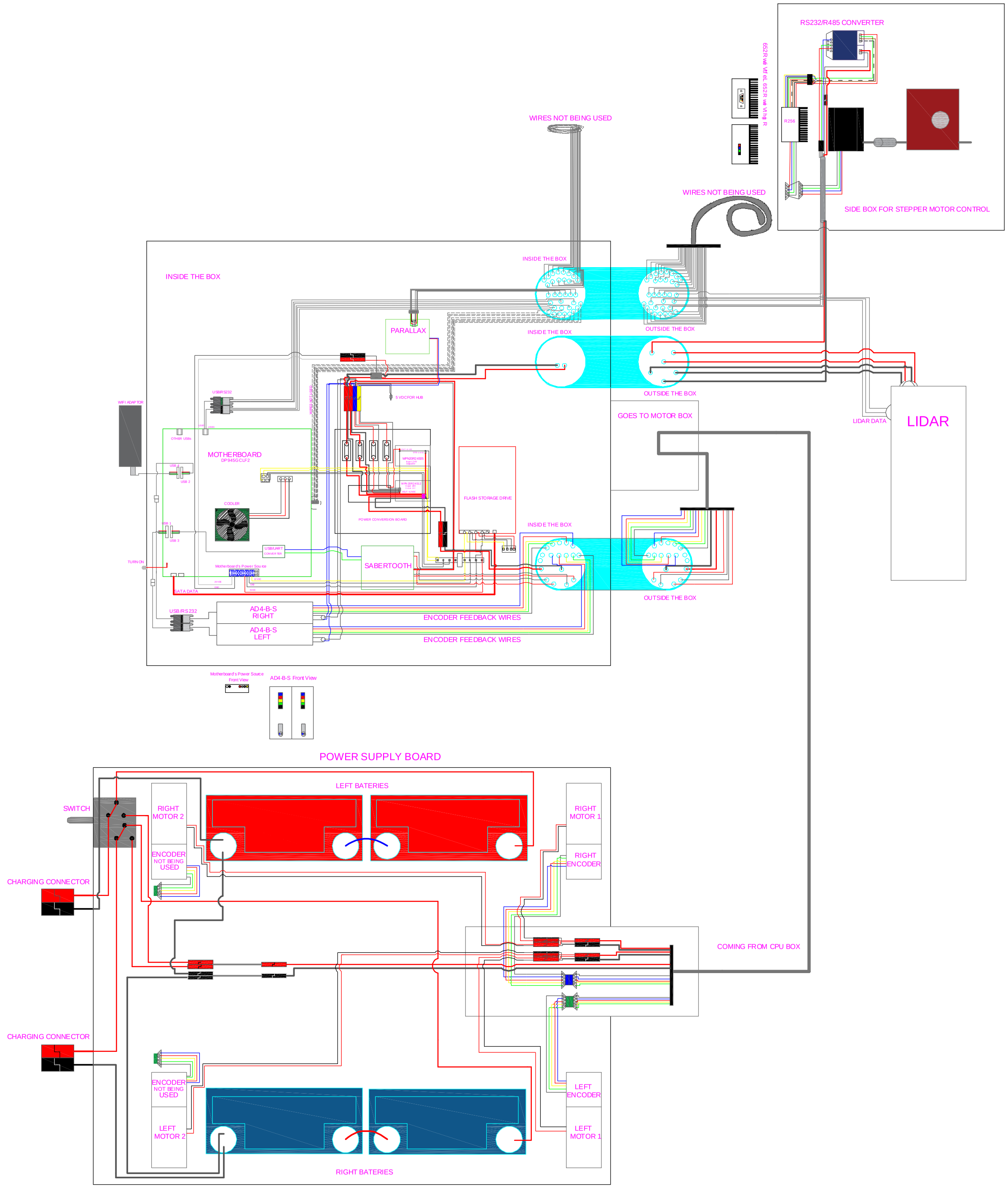
[5] Available at <http://www.digchip.com/datasheets/parts/datasheet/502/AD4-B-pdf.php> Accessed on July 17th of 2015 at 3:45 PM.

[6] Available at <http://sicktoolbox.sourceforge.net/docs/sick-lms-technical-description.pdf> Accessed on July 17th of 2015 at 3:45 PM.

[7] Available at <http://www.farnell.com/datasheets/64131.pdf> Accessed on July 17th of 2015 at 3:45 PM.

ATTACHMENT

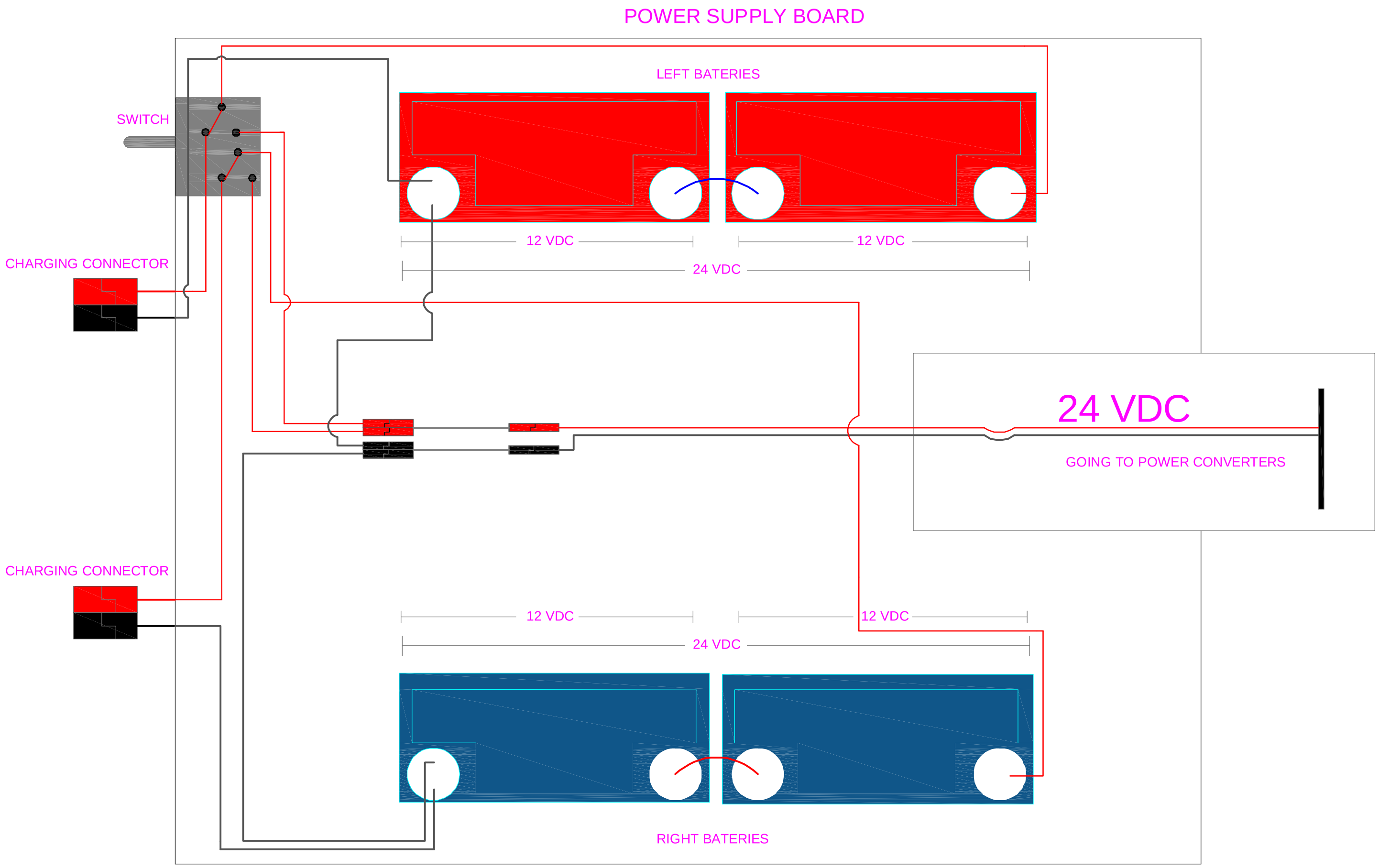
Sub Systems Schematics



LEGEND

NANOOK ROBOT SCHEMATICS
ENCODER WIRES
DC MOTORS CONTROL WIRES
CONNECTORS
24 VDC
12 VDC WIRES THAT GO TO AD4-B-S
5 VDC
12 VDC
FUSES
LIDAR DATA/ STEP MOTOR CONTROL
5 VDC FOR HUB
CONNECTOR FROM INSIDE TO OUTSIDE THE CPU BOX
USB CONNECTOR
DIFFERENT GND SIZES
TAPE
WIRES UNDERNEATH BOARD

CAPITOL TECHNOLOGY UNIVERSITY	Ana Beatriz Prudencio de Almeida Reboucas Thiago Alves Lima Nadson Renan Tome de Sousa	
Title: General Schematics		Description: Diagram of all the circuits in the Nanook robot.
Client: Michael Comberiate		
Drawing: Ana & Thiago	File: Nanook-Schematics.dwg	Board: 1/6
Date: Jul/2015	Software: AutoCAD® 2016	



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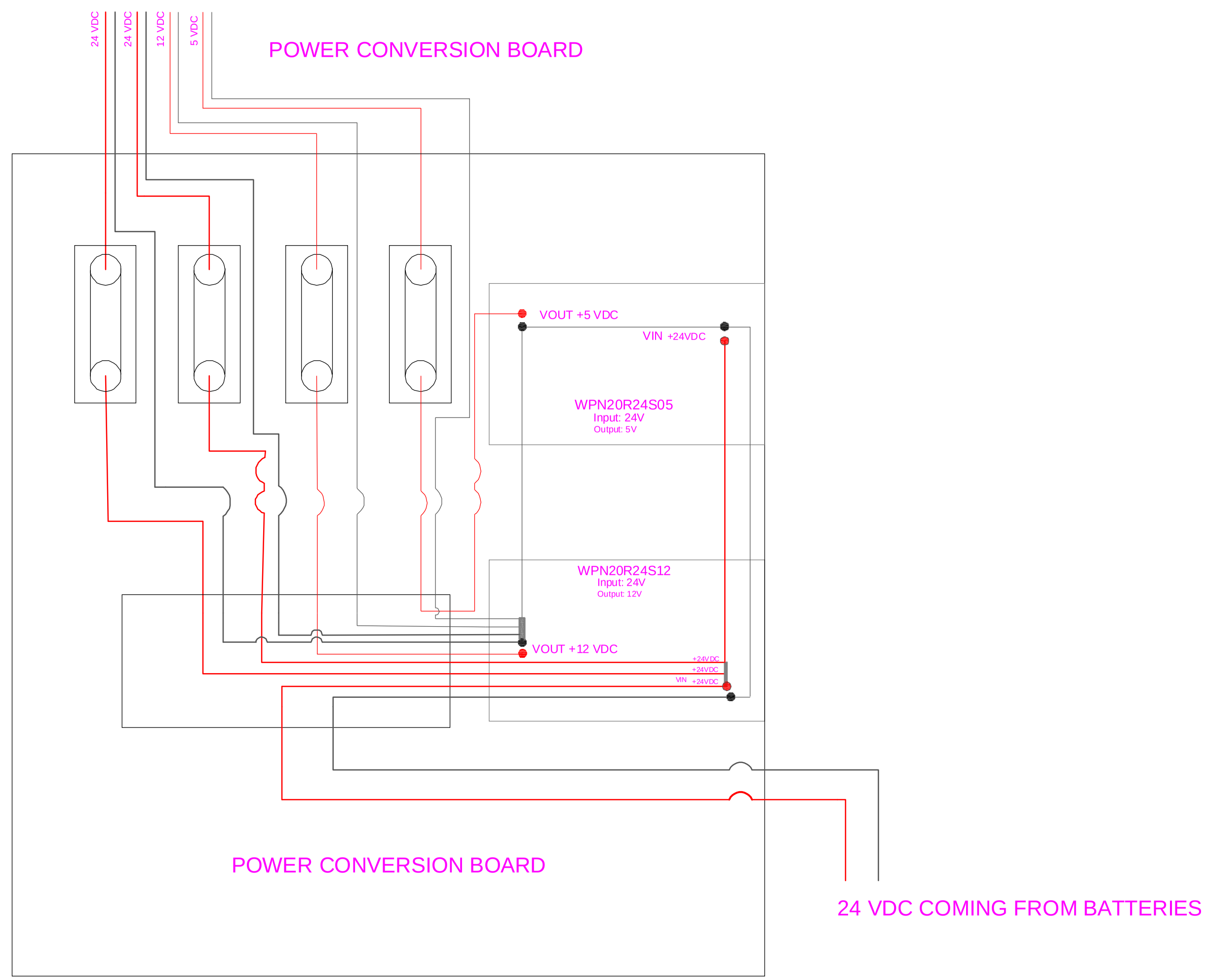
CAPITOL TECHNOLOGY UNIVERSITY	Ana Beatriz Prudencio de Almeida Reboucas Thiago Alves Lima Nadson Renan Tome de Sousa	
Title: Batteries Circuit		Description: Further detail for batteries circuit.
Client: Michael Comberiate		
Drawing: Ana & Thiago	File: Nanook-Schematics.dwg	Board: 5/6
Date: Jul/2015	Software: AutoCAD® 2016	



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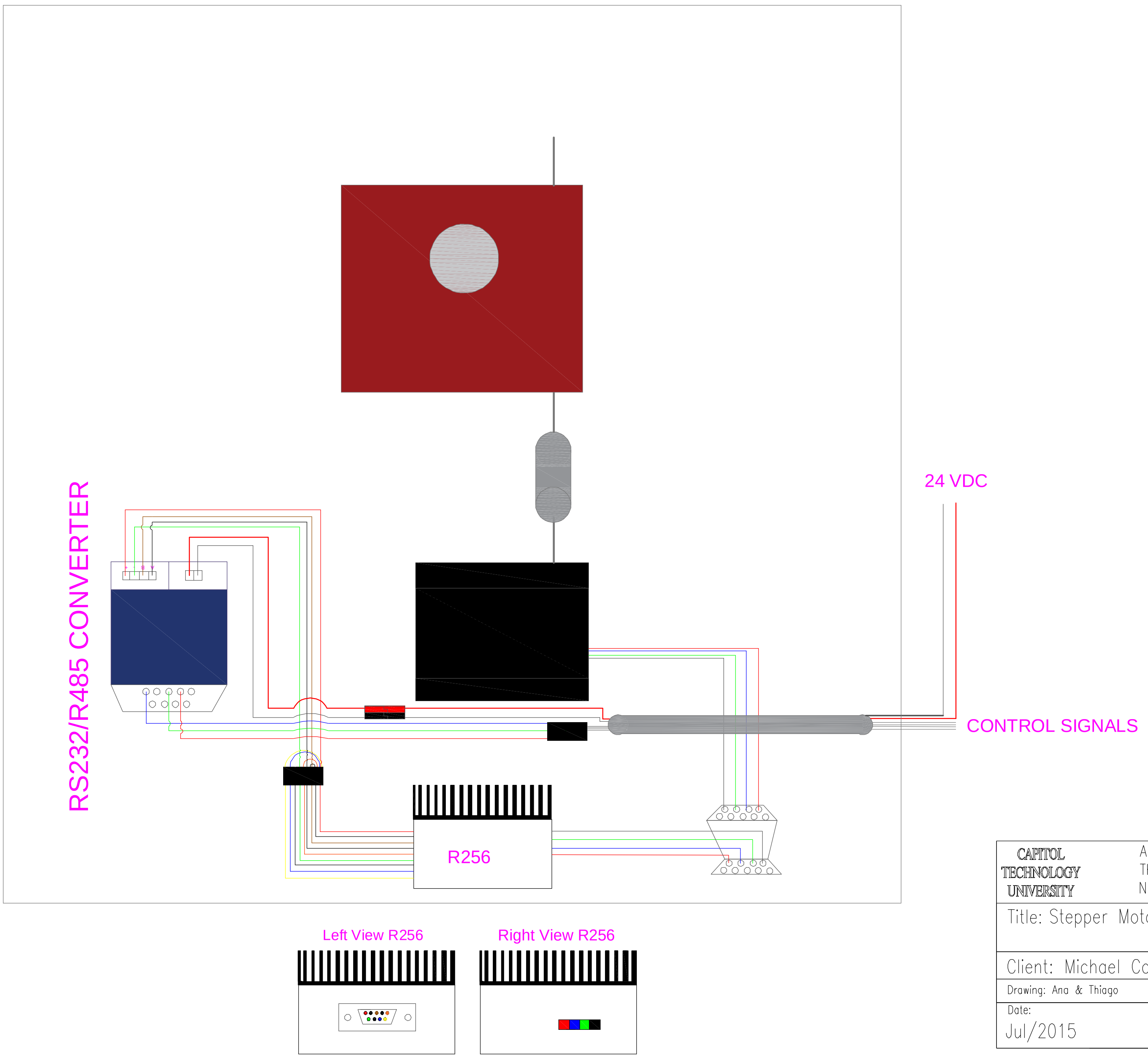
	TAPE
	WIRES UNDERNEATH BOARD

CAPITOL TECHNOLOGY UNIVERSITY	Ana Beatriz Prudencio de Almeida Reboucas Thiago Alves Lima Nadson Renan Tome de Sousa	
Title: Power Converter Circuit		Description: Further detail for power converter circuit.
Client: Michael Comberiate		
Drawing: Ana & Thiago	File: Nanook-Schematics.dwg	Board: 4/6
Date: Jul/2015	Software: AutoCAD® 2016	

SIDE BOX FOR STEPPER MOTOR CONTROL



LEGEND

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CAPITOL TECHNOLOGY UNIVERSITY

Ana Beatriz Prudencio de Almeida Reboucas
Thiago Alves Lima
Nadson Renan Tome de Sousa

Title: Stepper Motor Circuit

Client: Michael Comberiate

Drawing: Ana & Thiago

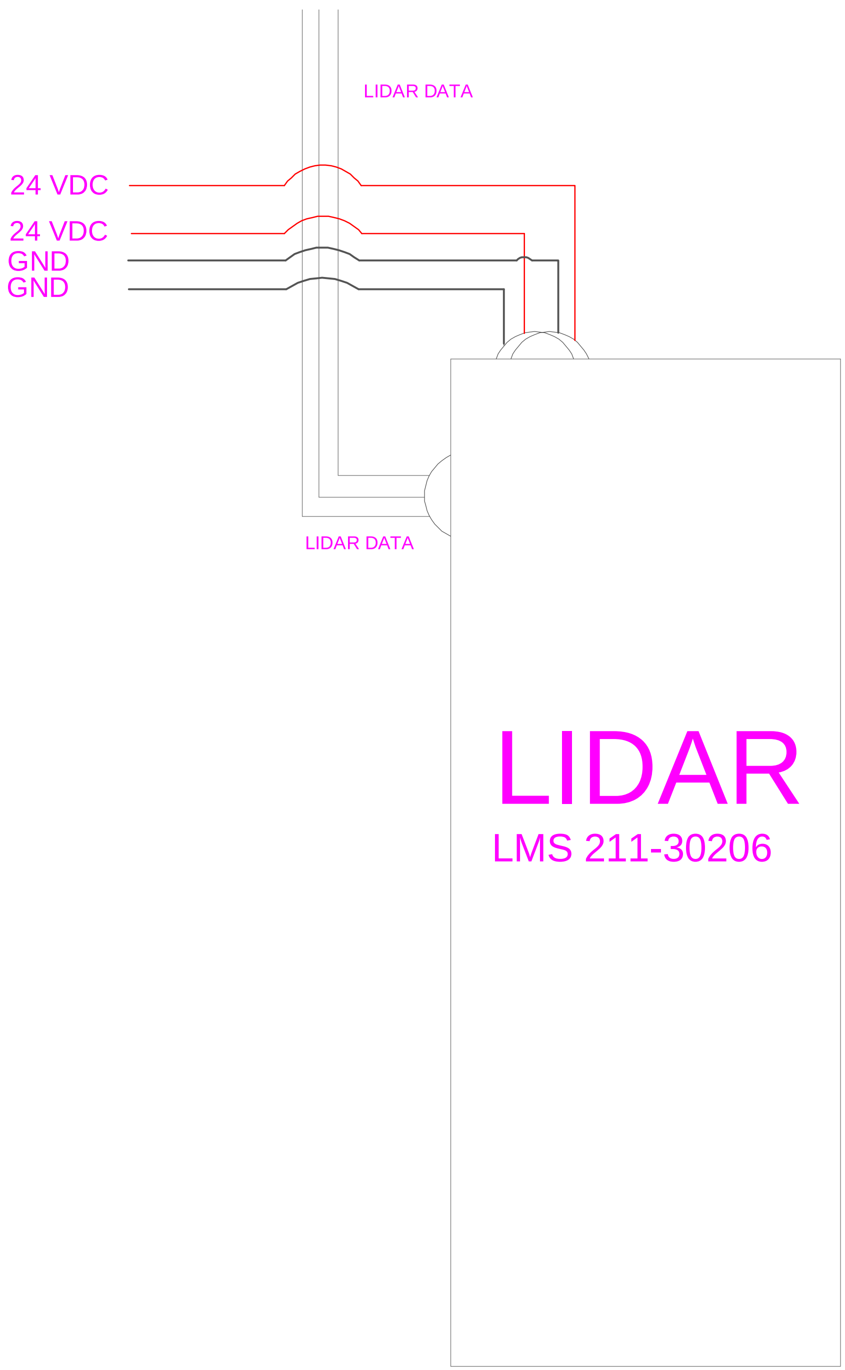
File: Nanook-Schematics.dwg

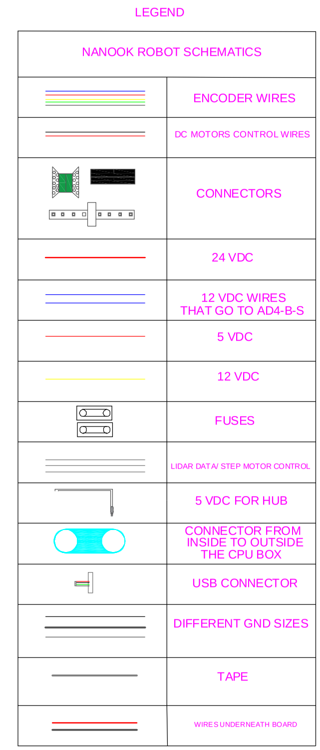
Date: Jul/2015

Software: AutoCAD® 2016

Description: Further detail for lidar step motor circuit.

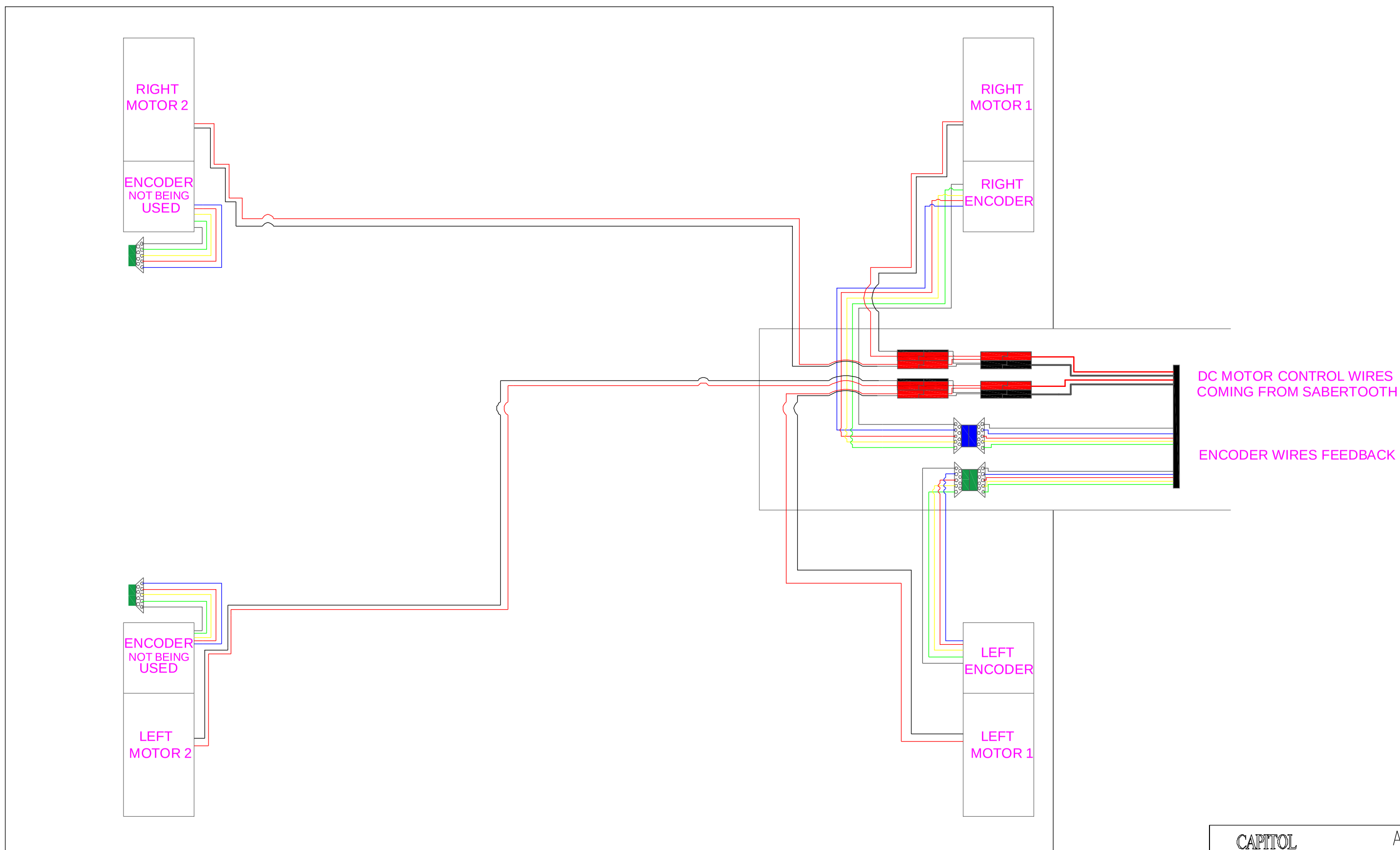
Board: 2/6





CAPITOL TECHNOLOGY UNIVERSITY	Ana Beatriz Prudencio de Almeida Reboucas Thiago Alves Lima Nadson Renan Tome de Sousa	
Title: Lidar Circuit		Description: Further detail for lidar circuit.
Client: Michael Comberiate		
Drawing: Ana & Thiago	File: Nanook-Schematics.dwg	Board: 3/6
Date: Jul/2015	Software: AutoCAD® 2016	

DC MOTORS CIRCUIT



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CAPITOL TECHNOLOGY UNIVERSITY

Ana Beatriz Prudencio de Almeida Reboucas
Thiago Alves Lima
Nadson Renan Tome de Sousa

Title: DC Motors Circuit

Description: Further detail for DC motors circuit.

Client: Michael Comberiate

Drawing: Ana & Thiago

File: Nanook-Schematics.dwg

Date: Jul/2015

Software: AutoCAD® 2016

Board: 6/6