ROBOTICS AND MECHATRONICS

Rail-guided ballast tank inspection robot, Hardware infrastructure analysis and enhancement

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BSc Report

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Introduction

This thesis is the result of a bachelor assignment which marks the end of the study electrical engineering at the University of Twente. This assignment is done for the Robots and Mechatronics group at the University of Twente which deals with application of modern systems and control methods to practical situations. The assignment originates from project 'RoboShip' as a part of the project 'SmartBot' which has been worked on independently by several companies and institutes including the University of Twente. At this point the robot is in a stage at which all the essential parts of the robot are put together and the work that needs to be done is mainly improvement and making the robot autonomously. Accordingly I got the assignment to analyse the electrical hardware of the robot and search for possible improvements.

Rail-guided ballast water tank inspection robot, Electrical Hardware infrastructure analysis and enhancement.

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***Abstract*— A rail-guided ballast water tank inspection robot from project RoboShip is designed and put together by various companies which resulted in a robot that is still far from efficient and organized. For this project this robot is to be analyzed in order to find improvements concerning electrical hardware. This analysis will contain all the in and outs of every piece of hardware, what kinds of protocols they can be/are using and how much power they consume. The assignment has two main focuses: Firstly, communication between components and secondly the power architecture and a solution for changing batteries. Based on this analysis improvements are made to ensure the hardware is reliable, efficient, well organized and documented.**

I. Introduction

A. Introduction

Present-day Ships have big compartments at the bottom of the ship which can be filled with water to increase the stability of the ship. These compartments are called ballast water tanks and are often filled with seawater. This seawater can be very aggressive for the steel within the tank and therefore the tank needs to be inspected regularly[1]. At the moment half a dozen inspectors are needed to do an inspection of this tank. Because the chambers within this tank and the passages from one chamber to another can be very small, it is a very uncomfortable way of working. Together with the high risk of tripping, bumping against metal or inhaling toxic gasses this work can be dangerous.

Within the RoboShip project[2] a couple of companies and institutes have been working on a robot that does inspections within a ballast water tank. This robot is supposed to autonomously move on rails which are mounted in the tank. This robot will not only make this work easier, but it will also make this work much faster and more efficient.

B. Assignment

For this assignment the electrical hardware infrastructure for the robot will first be analysed to find potential improvements. After this improvements of different parts of the electrical hardware will be made. The focus of this research is twofold:

1) Communication between components: The communication between parts of the robot is very devious. This communication can work with less superfluous hardware and with fewer cables. An example of this are the USB to serial converters. Several components communicate with the main computer through serial communication. Due to the lack of serial ports on the computer, several USB to serial converters are needed to connect all the serial connections. If done right, this can be done with only one smaller hardware piece with only one USB connection. Therefore, the first main part is about the communication between the components.

All the electrical hardware on the robot will be analysed and possible improvements will be made.

2) Power architecture: The robot has two battery packs. One should provide all the power to all the actuators on the robot. Because the actuators can draw a lot of current and can cause a voltage drop on this battery, there is a second battery that provides power for the main computer such that the computer will not power down while the actuators are drawing a lot of current. Since it is not known which part of the robot is connected to which battery and there is at the moment no way to switch batteries without shutting down the computer, an analysis and possibly improvements on the power architecture will be made and a solution for changing batteries is to be found.

Based on this analysis improvements will be made to make sure the electrical hardware is more reliable, efficient, well organized and documented while keeping in mind that there is only a small budget available.

C. Outline

In the next section an analysis will be made with an inventory of all the components of the robot. Based on the analysis improvements will be made and the design of the solutions will be discussed in the design section. The realization of these designs will be reviewed within the results section and the conclusions and recommendations will be stated within the last section.

II. Analysis

A. Inventory

To investigate possible electrical hardware improvements a hardware overview is needed. To get a better overview, the different components of the robot are documented. The following properties of the components are being analysed:

1) Description and associated datasheet.
2) How many times is this device used.
3) Significant parts used by the component.
   - Description of each part.
   - Associated datasheets.
   - Function of each part.
4) What is this components purpose?

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5) How is/can it be connected to other electrical components?
6) What communication protocols does/could it use?
7) How much voltage does it require?
8) How much power does it consume?

The result of this analysis consists communication boards, DC/DC converters, motors and other significant parts and can be found in the table in Appendix A1. This table gives a lot of information about the parts which are used. To get a better overview, it is better to make a diagram. An overview on the communication architecture and the power architecture van be seen in Appendix A2 and A3 respectively. As can be seen in Figure 1 is robot divided in different main parts. These parts are the robot arm, main camera, clamp and the remaining parts. The parts which are not located in the arm, main camera or the clamp are located next to the main computer on the robot. Except for the wireless USB device which is located under the main camera.

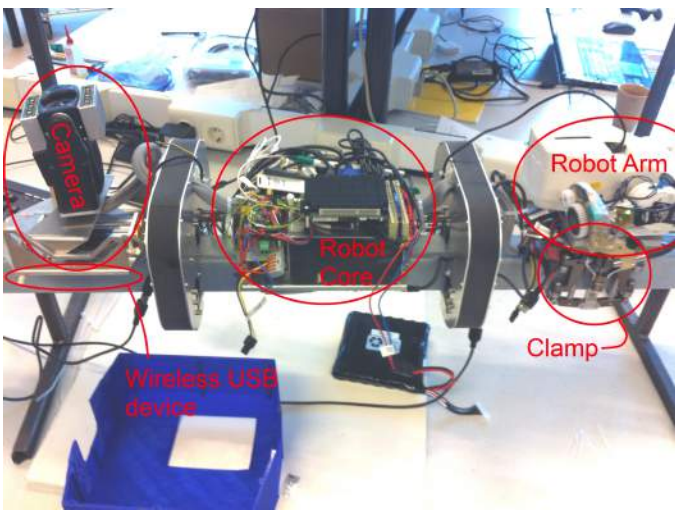

Figure 1. The robot from project RoboShip

B. Functioning of the robot

The robot is mend to be to do inspections inside the ballast tank. To accomplish this it can manoeuvre through the ballast tank using four wheels which are attached on a rail. The robot has two states, a driving state and an inspection state. While being in the driving state, the vehicle can move around in the ballast tank on the rail. When the vehicle reached a point at which the inspection needs to be done, the robot can go to its inspecting state and clamp itself to the rail for stability. When the clamp is set the pan-tilt-unit (PTU) of the camera can be set to an upside position. Using two other motors the camera can be rotated into different direction to inspect the ballast tank while being in the inspecting mode. This camera has several LED's on it to light up a dark environment. When a spot on the wall is observed which needs further measurement, the brain of the robot, the Intel Atom board, send coordinates to the Gumstix after which the Gumstix calculates the correct arm movement and controls the motors on the robot arm. When the robot arm reaches the wall, it can lock itself to the wall using a magnet and do layer thickness measurements using the elcometer. The robot arm also has a camera with which it can take a closer look at the tank.

C. Communication analysis

1) Serial converters: In Appendix A2 is shown that most of the devices are connected via a USB to serial converter to the Intel Atom board. In total four USB to serial converters are required which results in a chaos of wires and converters. Reducing the amount of electrical hardware required to connect all these parts would make the robot a lot more structured and would make it much easier to overlook.

To make the communication less devious, a lot of USB to serial converter could be removed. The Intel board has not enough connections to support all devices. A new computer board or a PCI extension board is needed with multiple serial connections on it. The robot needs at least eight serial connections to control all the actuators as can be seen in Table I. Most computer boards do not have eight serial connections even with a PCI extension, buying a new computer board was not an option.

TABLE I
DEVICES WHICH USE SERIAL COMMUNICATION

Device	Serial communication	Currently connected to
Wheel driver	RS232	Intel Atom Board
SSH Terminal	RS232	Intel Atom Board
LED Driver	RS232	Digitus USB converter
Battery Monitor 1	RS232	Digitus USB converter
Battery Monitor 2	RS232	Digitus USB converter
PTU	RS232	Digitus USB converter
Clamp Driver	RS485	DFRobot converter 1
Camera Rotation motors	RS485	DFRobot converter 2
Tobi Board	RS232	TTL-232RG converter

A communication bus could be created to reduce the amount of serial connections needed to connect all parts. The wheel drivers already use a bus topology and the same protocol could be used to put other parts on that same bus. Since most of the device can not be reprogrammed to use a bus protocol this is not an option.

Besides this, the main computer uses the Robot Operating System(ROS)[3] which uses nodes to control the different parts. The nodes to control the different actuators use a specific communication channel. A bus topology would require the nodes to share one of these communication channels which requires the nodes to wait on each other. This could create delays and this is not an option.

In order to achieve a more robust, efficient and well organized communication system, the following properties are relevant:

- It should minimize the amount of signal converters.
- It should minimize the amount of wires to connect the devices.
- It should not decrease the maximum baud rate at which the parts can communicate with the Intel Atom board.

The solution will be discussed in the design section.

D. Power architecture analysis

To improve the power architecture an analysis is done on the power architecture. The most significant results of this analysis are shown below.

1) Stable power system: At the moment, there are two Lithium-ion battery packs which provide the power for the robot. The Intel Atom board is connected to the other battery together with the camera rotation motors and the Gumstix which controls the robot arm. The other parts, which are most of the motors, are connected to the other battery. A stable voltage requires to have no parts on the same power line that draw peek current which leads to voltage drops. At the moment there are two motors of the main camera connected to this power line. These two motors can each draw 1.2A[4] which is 2.4A in total and the Intel Atom board can draw a maximum of 0.8A excluding any devices connected to this board[5]. The Traco buck converter providing this power can only provide a maximum of 2.5 A[6] which is not enough when the motors draw maximum current. This was noticeable by a situation which has occurred at which the motors got stuck when trying to reach a certain angle. This resulted in the Intel Atom board to shut down thanks to the voltage drop which presumably occurred.

To determine much current the power lines need to be able to handle for designing a good power architecture, the maximum current drawn by the parts should be estimated. The part which draws the most continuous power is the robot arm because of its many heavy motors. The robot arm has seven motors of which six are Dynamixel MX-106[7] motors which could draw a maximum of 6.3A and one Dynamixel RX-28 motor which draws maximum of 1.2A. Since the motors are never going to reach their maximum power drain as is specified in their datasheet, it is more practical to know the continuous power drawn. To measure the maximum continuous power that the arm motors can draw is when the arm is in a stable 90 degrees angle. The measurement of the current with a 24.3V input was 5.8A maximum. This means that the continuous power which the arm draws is about 140.9W.

The robot arm is fully operational during the inspecting state of the robot. During this state no other motors are used except for the camera rotation motors which draw 14,4W each. The total maximum continuous power drawn from the battery pack is there for approximately 170W. Because the assumption that the battery is empty when it has a potential of 22.5V[1], a maximum of 7.6A continuous current can be drawn from the battery packs. It is save to design a power system that can at least handle this amount of continuous power and current. It is better to design a system that can handle more than that due to the much higher peak power that may be consumed by the robot.

[1] In the code of the battery monitor is assumed that the battery is empty when the total voltage of battery is 22.5V

2) Hot swap of battery packs: At the moment the robot is not able to switch batteries. When a battery is connect before removing the other a short-circuit between the two voltage sources is created which results in a significant current from one battery to the other. This current can be very high because of the voltage difference between a full and an empty battery. This significant amount of current unwanted and needs to be avoided.

A solution would be using a hot swap controller (ADM1177[8]) which can be used to connect and disconnect a battery packs from the load. This IC in combination with a MOSFET can be used to switch between the different battery packs and can be controlled via simple logic. An advantage of this solution is that the robot can switch between battery packs while driving through the ballast tanks autonomously and no physical switching is needed to switch between different battery packs.

Another solution is using diodes to prevent the current from going from one battery to the other. When a new battery needs to be connected to the robot, someone can connect one battery and then disconnect the other battery without the need to turn the computer off. The downside of this solution is that a person has to physically connect and disconnect the batteries. The advantage of this solution is that it is very easy to implement and no program has to be written to switch between batteries.

Whatever solution is chosen, a device has to be connected between the two battery packs and the power line. This means that the solution needs to be able to handle a certain current and voltage. The voltage of the battery packs is approximately 29.5 volt when it is charged, therefore the device needs to be handling at least 29.5 volt. The current is very dependent on which device is connected to it. But it has to be able to handle at least the current calculated in the previous section, 7.6A. In the design section will be shown which solution is chosen.

3) Broken battery monitor: The battery packs consists out of multiple cells which require to be within a certain voltage boundary. If the cells are past these boundaries, the cell could become unstable. Therefore the cell voltages need to be carefully monitored[9] and this is done by battery monitor boards. These boards monitors the individual cell voltages and makes sure that the cells which reach a certain unwanted voltage are discharged. One of these boards was already broken when the robot got to the university. The PCB already had components soldered on places where they should not be. The device also had several burned resistances on it. It is dangerous to connect a lithium ion battery pack without monitoring, it is good to have a solution for this problem.

A measurement was done to find the problem for the broken battery monitor. Pin 27 and 28 of the battery monitor IC LTC6803G-3[10] which are normally used to measure a potential were short circuited. Pins which are used to measure electric potential has to have a high impedance, but measuring the resistance between those pins resulted in a zero ohm resistance. This resulted in the conclusion that this part of the device is broken. Fixing this board is not the main focus of this assignment, there was not much time spend on fixing this board.

E. Organization of cables

As can be seen in Figure 2 the cables on the robot are not organized. Not only are there too many power cables, but also the USB, Serial and other communication lines are too long which results in rolled up cables. Together with the many screw terminals which are used, makes it unordered. Making the wires much more organized will not only make it much less of a mess, but makes it also much easier to work with and easier to oversee.

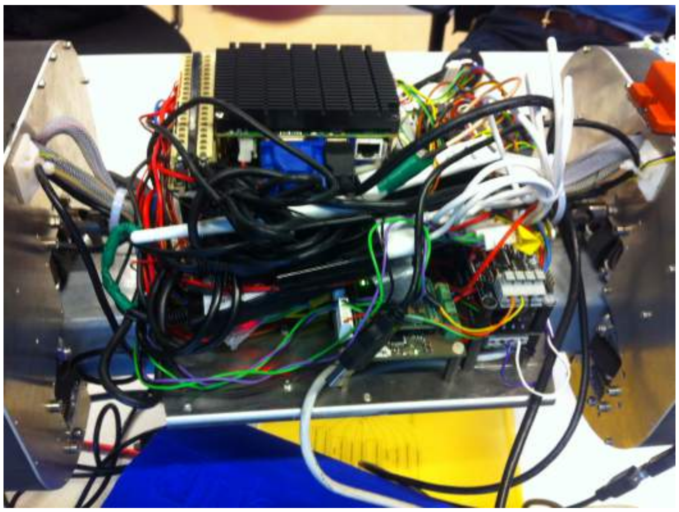

Figure 2. The jumble of cables on the robot

The robot has a very large screw terminal block at which most of the devices are connected to for power. Which can be seen on the left side of the Intel Atom board in Figure 2 A couple of other devices are connected to terminals blocks under the battery monitor boards which also makes it very difficult to oversee the whole system. It would be a improvement when all the power lines are connected such that the terminals are not needed to hack everything together. In the design and result section will be discussed how this problem is taken care of.

F. Power button

To shut down the Intel Atom board correctly, it has to be shut down from within the operating system with a mouse or a keyboard or by connecting with the serial terminal. The Intel Atom board has a power button connection which is not connected to anything. A good improvement of the robot would be a power button which can be pressed to shut down or power up the system. The resulting power designed is discussed in the section design.

III. Design

In this design section the chosen solution and their designs will be discussed. Firstly the designed USB to serial converter will be discussed, secondly a designed power circuit for improving the power architecture will be discussed and finally the design of a power button will be reviewed.

A. USB to Serial Converter

The design requirements for the new USB to serial converter were:

- It should minimize the amount of signal converters.
- It should minimize the amount of wires to connect the devices.
- It should not decrease the maximum baud rate at which the parts can communicate with the Intel Atom board.

Based on these requirements a device was made to provide all the serial communication ports with only one USB connection. This device is a breakout board for the USB Hi-Speed Serial/Hub Module[11] which is an USB to four times serial converter and an USB hub on one module.

The breakout board in combination with the module has four RS232(RS1 to RS4) outputs of which RS1 and RS2 can be changed to RS485 outputs by moving the jumper on JP1 and JP2. With jumper PWRJP can an external power source or power from the upstream USB be selected to provide power for the module and breakout board. When the external power is selected, a OKI-78SR DC/DC converter[12] which was also available can be placed on the DC/DC header to convert power connected to the PWR IN to 5V. When 5V is provided to the power input, a wire can be placed on pin 1 and 3 of the DC/DC header to provide all parts with power.

The breakout board is designed in such a way that multiples of this device can be efficiently stacked onto each other. When stacked, the devices are only 2cm from each other which makes it possible to stack three devices onto each other inside the robot. This property in combination with the small area of the device makes it very compact device. The breakout board has also a USB header at which a female USB connector can be connected to connect the next board in the stack to the previous device.

The designed USB to serial converter is shown in Figure 3 and Figure 4. More images and schematics can be found in Appendix B.

The designed breakout board also has a red and green LED for each serial communication channel which lights up when data is send or received respectively. In this way the data send and received by different devices are observable for easier debugging.

A solution with eight or more communication channels could be made. But because this requires to make a PCB with one or multiple FT4232H USB to serial converters[13] which makes the PCB relatively large and designing the PCB a time consuming task. The current design has a very small cover area which makes it a better solution for the current robot which has limited space.

B. Power circuit board

1) Hot swap of battery packs: Because switching batteries while driving through the ballast tank is not required, the solution with the IC and the MOSFET has no more

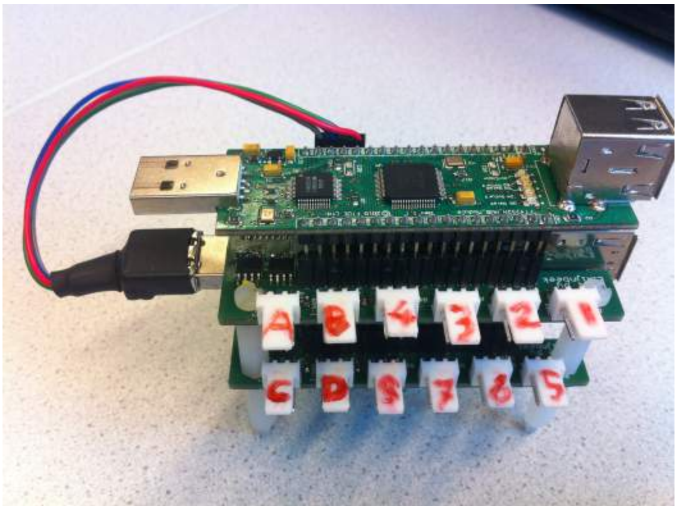

Figure 3. Designed USB to serial converter, connector side

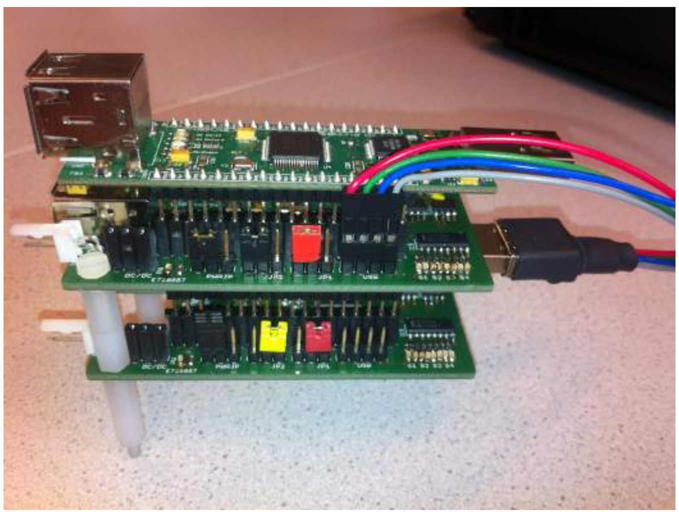

Figure 4. Designed USB to serial converter, jumper side

advantages. Besides that, switching between batteries autonomously would require the robot to have two battery packs for each power line, which is in total four batteries. At the moment there is no space for two more batteries. Therefore the solution with the diodes is chosen.

The diodes which are going to be used need to have a few requirements. The requirements are stated below.

1) It should be able to handle 29.5V.
2) It should easily be able to handle a continieous current of 7.6A.
3) As low as possible forward current voltage drop.
4) It preverably has to be available at Farnell or RS-components.

The diode MBR4045PT[14] is chosen which are two Schottky diodes in one package. Each diode can handle 45V and 20A which should be sufficient for this application. The metal-semiconductor junction ensures that the forward voltage drop is relatively small such that a minimal amount of power is wasted by the diode.

One of this device is used for each power line, therefore two of these devices implemented in total. The anodes are connected to the batteries and the cathodes are connected to all the devices to provide them with power.

2) Stable power source: To avoid that the parts which controls the robot shut down when motors draw to much current, all the motors are connected to one battery. All the other parts are connected to the second battery. In this way the Intel Atom board and the Gumstix wont shut down when the motors draw too much current. In the initial situation the camera rotation motors were connected to the same DC/DC converter as the Intel Atom board. Because there was a not connected DC/DC converter available, the Intel Atom board and the camera rotation motors can separately be connected to its own DC/DC converter. In this way the Dynamixel motors which also need 12V can be connected to the other power line.

From the datasheet of the Intel Atom board it is known that it requires 12V and draws a maximum of 0.8A without peripherals. A maximum of 3A can be drawn from the 5V peripherals, which means that the total power consumption of the Intel Atom board with a 12V to 5V DC/DC converter efficiency of 77% [2] is at most 29.08 Watt (2.42A on 12V). The Dynamixel motors for camera rotation both use max 1.2A which is in total 2.4A on 12V.

$$12V \cdot 0.80A + \frac{5V \cdot 3A}{0.77} = 29.08W \qquad (1)$$

Both the buck converters to 12V can handle this amount of current, it does not matter which converter is connected to which devices when you look at available current. But because the Intel Atom board draws current continuously, the converter with the highest efficiency would be the best option for the Intel Atom board. According to the datasheet the TRACO DC/DC converter has an typical efficiency of 91% and the other DC/DC converter, the IDD-936160[15] [16], has a efficiency between 80% and 95%. The TRACO converter was chosen for the Intel Atom board based on the comparison between the average of the given values for the IDD converter and the typical efficiency of the TRACO converter.

The new overview of connections between devices is shown in Appendix A5

3) Designed power circuit: The TRACO buck converter is soldered on a experiment print together with power connectors and the two Diodes. The circuit board is made in such a way that the battery monitors can be mounted on top of the board such that the space inside the robot is used efficiently. The connectors[17] for power which can handle up to 2.5A are soldered such that the devices can be connected to a specific power line. The Molex connectors chosen for this application are non-reversible and all connectors have the

[2]The actual DC/DC converter efficiency on the Intel Atom board could not be found. This is the minimum typical efficiency found in the six available 12V to 5V DC/DC converters at Farnell. The average of those six was 82% (15-07-2015)

grounded wire on the same side such that no mistakes can be made while connecting the devices.

All the devices in the front part of the robot are connected to this board. The motors which are located on the back side of the robot can be connected to the small power hub in front of the robot which is also connected to the power circuit. For the power hub extra thick wires are used (16 AWG) such that it can handle the large amounts of current(13A) [18] that is reqiured by the robot arm motors. The power line from the battery to the hub and from the hub to the robot arm are either soldered or connected via a screw terminal since the connectors used for other devices cannot handle the amount of current that the robot arm needs.

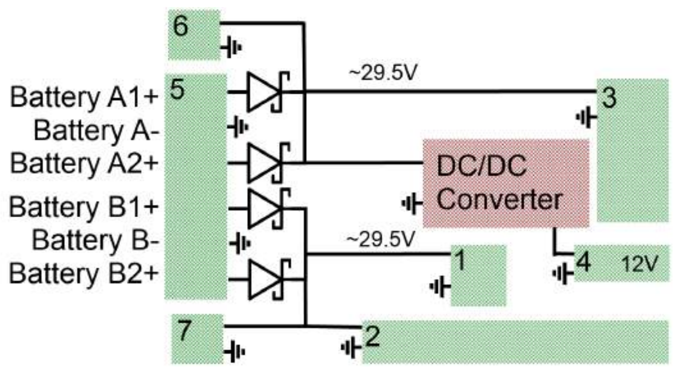

Figure 5. Schematic of the designed power circuit

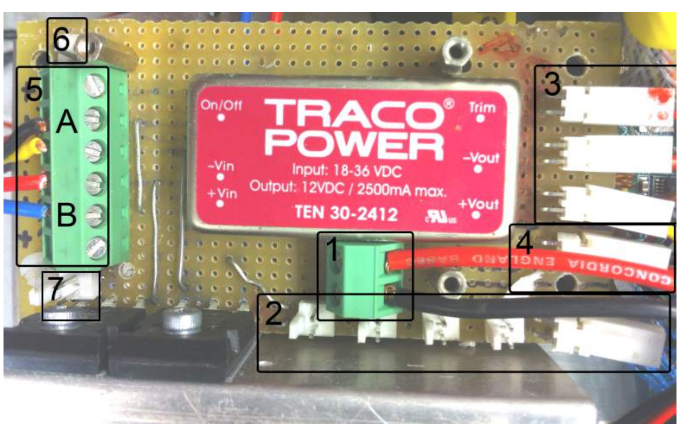

Figure 6. Realization of the power circuit

The schematic of the designed power circuit board is shown in figure 5 and the final realization is shown in figure 6. The power hub can be connected on the screw terminal labelled with the number one. The other motors are connected to the connectors at two. The other devices can be connected to the connectors labelled with the number three and the Intel Atom board can get its power from connector four which provides 12V using the TRACO DC/DC converter. The battery monitor boards can be mounted on top of the circuit and can be powered by connecting them to the connectors labelled with the number six and seven. The reason for placing those connectors on the shown places is that is very close to the power inputs of the battery monitor boards.

The Diodes are mounted on the device in such a way that the metal frame of the robot can be used as heat sink. Isolation plates are used to prevent the diodes from shortcutting with the case.

C. Power button and indicator LEDs

A power button with two indicator LEDs was designed for turning on and off the Intel Atom board. The connector can be connected on the Intel Atom board to the two by three male header with the arrow on the connector pointing upwards. This power button makes it possible to shut down the robot properly without screen and keyboard or mouse attached to the computer. When shut down the computer can be turned on by pressing the button again just like a normal power button. The red LED is turned on when the computer is also on. The orange LED turns on when the memory of the computer is being used. In Figure 7 is the six pin header shown at which the power button and the LEDs should be connected. The corresponding pin layout can be found in Table II

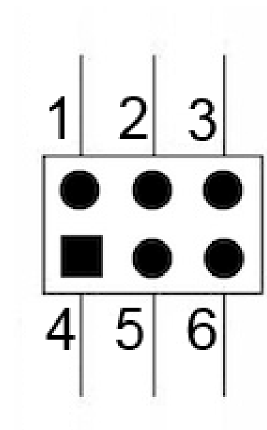

Figure 7. six pin header on the Intel Atom board

TABLE II
POWER BUTTON AND LEDS HEADER PIN LAYOUT

Pin	Connected to
1	Power LED+
2	HHD LED+
3	HHD LED-
4	Power Button
5	Power LED- and Power Button
6	Reset Button(Not Connected)

IV. RESULTS

A. Communication between components

The new USB to serial converter is made twice and mounted on top of each other. This created eight new serial connection of which two are used to communicate using RS485. The new device makes room for five other USB devices which can be connected to this part. All the devices which need serial communication are connected to the USB to serial converter stack.

Due to this new device, the other four USB to serial converters could be removed from the robot which makes the robot much easier to oversee. Removing the four USB to serial converters made the USB hub obsolete. The remaining devices which were connected to this hub are now connected to the new device. All the devices can now communicate with the Intel Atom board via the new USB to serial converter. The lights on the device which indicate when data is send or received makes the robot more convenient to work with when trying to communicate with the parts of the robot.

All wires have been shortened to the proper length and have been equipped with connectors and labels for convenience. The new USB to serial converter has been provided with numbers for the RS232 channels and letters for the RS485 channels. All the devices are connected and the software has been changed to understand the new changes. The communication ports within the software which normally are called ttyUSB0 till ttyUSB7 are named after the devices which are connected to the associated communication channels using the udev software package. The associated file which defines the names for this program is shown in Appendix E. The physical port at which the device is connected is shown in Table III together with the associated channel name within the software.

TABLE III
CONNECTED DEVICES AND ASSOCIATED DEVICE NAMES

Number	Interface	Devices Connected	Software name
1/A	RS232/RS485	Wheels	ttyUSBwheels
2/B	RS232/RS485	PTU Faulhaber motors	ttyUSBptu_faulhaber
3	RS232	Battery monitor 1	ttyUSBbattery1
4	RS232	Battery monitor 2	ttyUSBbattery2
5/C	RS232/RS485	Dynamixel Camera Rotation	ttyUSBptu
6/D	RS232/RS485	Clamp	ttyUSBclamp
7	RS232	not connected	ttyUSBnotconnected
8	RS232	Camera LED's	ttyUSBleds

B. The power architecture and the solution for changing batteries

The devices are now connected to the battery in such a way that the Intel Atom board is not dependent on current drops of the motors. The batteries can be swapped without shutting down which makes the robot much more reliable.

Due to the new power circuit the terminal blocks could be removed together with a lot of wires. Also by this improvement made the robot much better to oversee. Making this power circuit at which all the devices can be connected made the large terminal block obsolete. Also a lot of wires which were connected to this terminal block could be removed because most of the devices are on the front side of the robot where the new power circuit is in the contrary to the terminal block which was located at the back side of the robot. There were also three terminal blocks used to connect some other devices to the other battery pack. Removing those by connecting all the devices to the power circuit board made the robot terminal block free. The loose terminals which were removed are shown in Appendix D. Because the large terminal block has been removed, the Wi-Fi and Logitech USB modules could be placed under the Intel Atom board. All this makes the robot much more organized.

Photos of the organized result can be seen in Appendix D.

V. CONCLUSION & RECOMMENDATIONS

A. Conclusion

The robot has been analysed and the results are documented. The robot is working like it did before the improvements in this research. All the hardware can communicate with Intel Atom board with only one device and no more keyboard, mouse, computer screen or terminal is needed to shut down the robot which makes the robot much more efficient since is uses less hardware to accomplish the same thing.

A lot of wires and terminals have been removed and labels have been added which makes the much easier to oversee and well organized.

By reorganizing the power architecture and the fact that batteries can be changed anytime without shutting down the robot makes the robot much more reliable. This is all done without any malfunctioning parts of the robot, which makes it an overall improvement of the hardware architecture of the robot.

B. Recommendations

The battery monitor was not fixed during this project. Because battery monitoring can be important in the future, it is recommended to find a solution for the broken device currently on the robot. It is worth trying to replace the broken ic on the monitor board. There are devices that are not on the metal frame where the Intel Atom board is also located. Recommended is that these devices are or removed because they are not used like the USB RFID reader and the wireless USB transceiver, or move them also on the metal frame next to the Intel Atom board. If done right, a metal frame could be created to use this space much more efficiently.

C. References

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Appendix A.1: Hardware inventory

The PCB's, motors, converters and other significant parts can be found in Table A1.1, A1.2, A1.3, A1.4 respectively. The batteries used can be seen in Table A1.5.

Table A1.1: PCBs on the robot

Nr.	Name	#.	Type	Significant Connections	Significant Parts	Supply	Note
B1	Intel Atom Board	1	MIO-2261	USB,RS232, I^2C or SMBus , Ethernet	Intel Atom N2800 1.86GHz	12v, Min: 0.46A, 5.52W, Max: 0.80A, 9.6W	The main computer of the robot.
B2	LED driver	1	Custom made by DFKI	RS-232	ATmega168a, MP232ec	12v	LEDs which provide light for the main camera.
B3	Multipurpose USB-RS232-RS485-TTL Multiplexer	2	DFrobot converter	USB/RS-232/ RS-485/TTL	Several converter IC's	5v, <1W*	Multiplexer supports conversion interfaces among USB, TTL, RS232, RS485, and allows to have one input and multiple outputs.
B4	USB-4xRS232 converter	1	DIGITUS USB to RS-232 converter	USB to RS-232	-FT4232H	5v, ±2,9W*	
B5	Battery monitor	2	Custom made by DFKI	RS-232	ATmega168a, LTC6803G-3 Multicell Battery Monitor, ST32328 (for RS232)	±29v <1W*	One is defect when I started the assignment
B6	Wheels motor driver	4	Faulhaber platine MCDC3003 P RS	RS-232		Max 30v 3A	Uses the standard faulhaber protocol
B7	PTU driver	1	Faulhaber MCBL3002 S RS	RS-232		Max 30v 2A	Uses the standard faulhaber protocol
B8	Clamb module	1	Custom made by DFKI	RS-232	ATmega328a, Maxon, Motor Driver	±29v	Reads the sensor and controls the clamp motor driver

B9	Clamb motor driver	1	Custom made by DFKI	Pin headers		±29v	On top of the clamb driver
B10	Gumstix	1	Overo Airstorm	Gumstix		5v	Can be mounted on Tobi
B11	Tobi	1	-	USB	FT232R	3,3-5v	Breakout board for the Gumstix
B12	Wireless USB transceiver	1	SX-2000WG	USB		5v	
B13	USB to 485 Converter	1	DS_USB-COM485-PLUS2	USB, 485	FT2232H	5v	Converter for the motors on the robot arm.

Table A1.2: Motors used by the robot

Nr.	Name	Amount	Type	Supply	Note
M1	Wheel	4	Faulhaber 2657W024C	Max 32V	Faulhaber Brushless motor
M2	Camera PTU	1	Faulhaber Minimotor SH	None needed, has driver	
M3	Camera rotation	2	Dynamixel RX-28	Input 12-16V (Recommended 14.4V), Standby current: 50mA , Max current 1.2A	Connected with RS-485
M4	Clamp motor	1	Maxon motor 480486	Max 40W	
M5	Robot arm motors	7	6x RX-106 and 1x RX-28	Input 12-16V (Recommended 14.4V), Standby current: 50-55mA , Max current 1.2A (RX-28) 5.2A (RX-106)	Connected with RS-485

Table A1.3: Power Converters used by the robot

Nr.	Name	Amount	Type	Power	For
C1	Buck converter	1	TRACO POWER TEN 30-2412	30W 18-36v to 12v 2,5A 91% eff. 120mV ripple	For the Intel Atom board and the camera rotation motors
C2	Buck/Boost converter	1	IDD-936160	60W 9-36v to 12v 5A min. 80% eff. 240mV ripple	Not connected
C3	DC/DC converter	1	-	±29v to 5v	For the wireless USB board

C4	DC/DC converter	1	-	±29v to 5v	For the Tobi board
C5	DC/DC Converter	6	PTN78020	30W 15-36v to 12-22v 6A 96% eff.	Converters for all the robot arm motors.

Table A1.4: Other significant parts

Nr.	Name	Type	Connection	Supply
Z1	Logitech controller receiver	Logitech Nano receiver	USB	5v, 2,9W*
Z2	Wifi Adapter	TP-link TL-WN722n	USB	5v, 4,8W*
Z3	Xsens	MTI-300-2 A5G4	USB	4.5-34V or 3V3 (675-950 mW)
Z4	RFID	SCL3711	USB	5v <1W*
Z5	Main camera	Procilica GE2450C	UTP/FTP	-
Z6	Arm camera	-	USB	5v
Z7	Elcometer	Elcometer 456	USB	5v, 2,2W*
Z8	USB Serial Converter	TTL-232RG	USB 232	5v, 50mA
Z9	USB Hub	Belkin F5U259-ME 7 ports	USB	5v
Z10	Magnet	ITS-PE 3529		12v 28W

*measured by measuring current drawn from battery

Table A1.5: Batteries

Name	Amount	Type	Specs
Battery	4(2 connected at a time)	7s2p konion2250V3	4,5Ah 116Wh 29,5v

All the datasheets and other found information of the components are organized in a hardware directory.

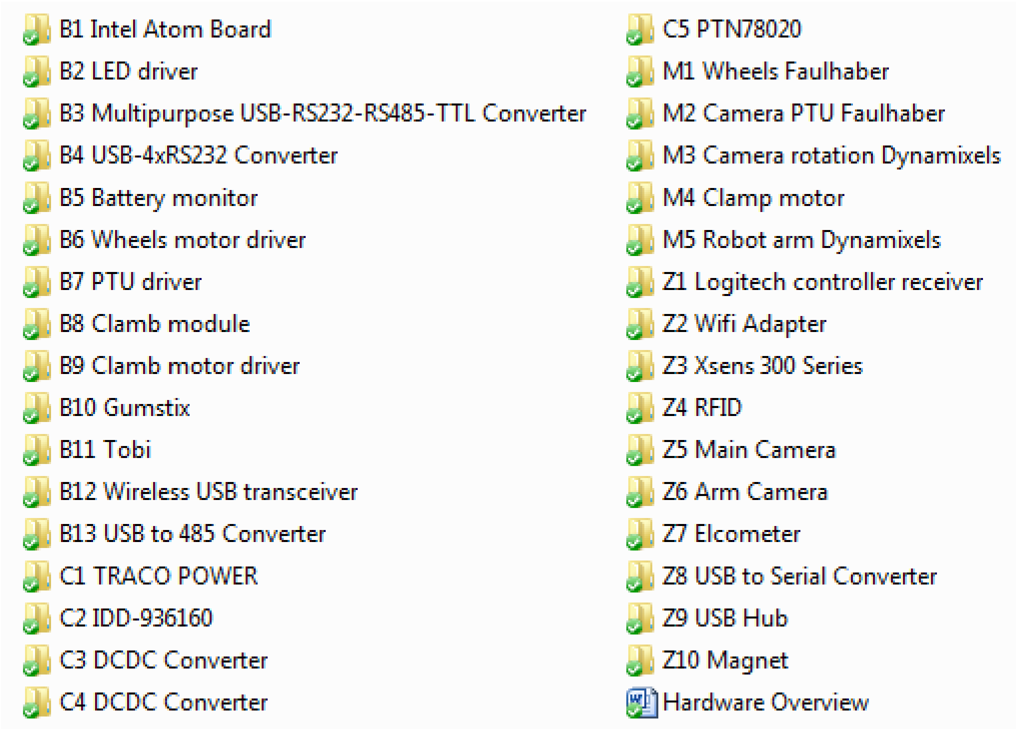


Figure A.1: The hardware directory with information

Appendix A.2: Communication overview old situation

In this Figure A.2 can be seen how all the parts of the robot are interconnected at the begin of the assignment.

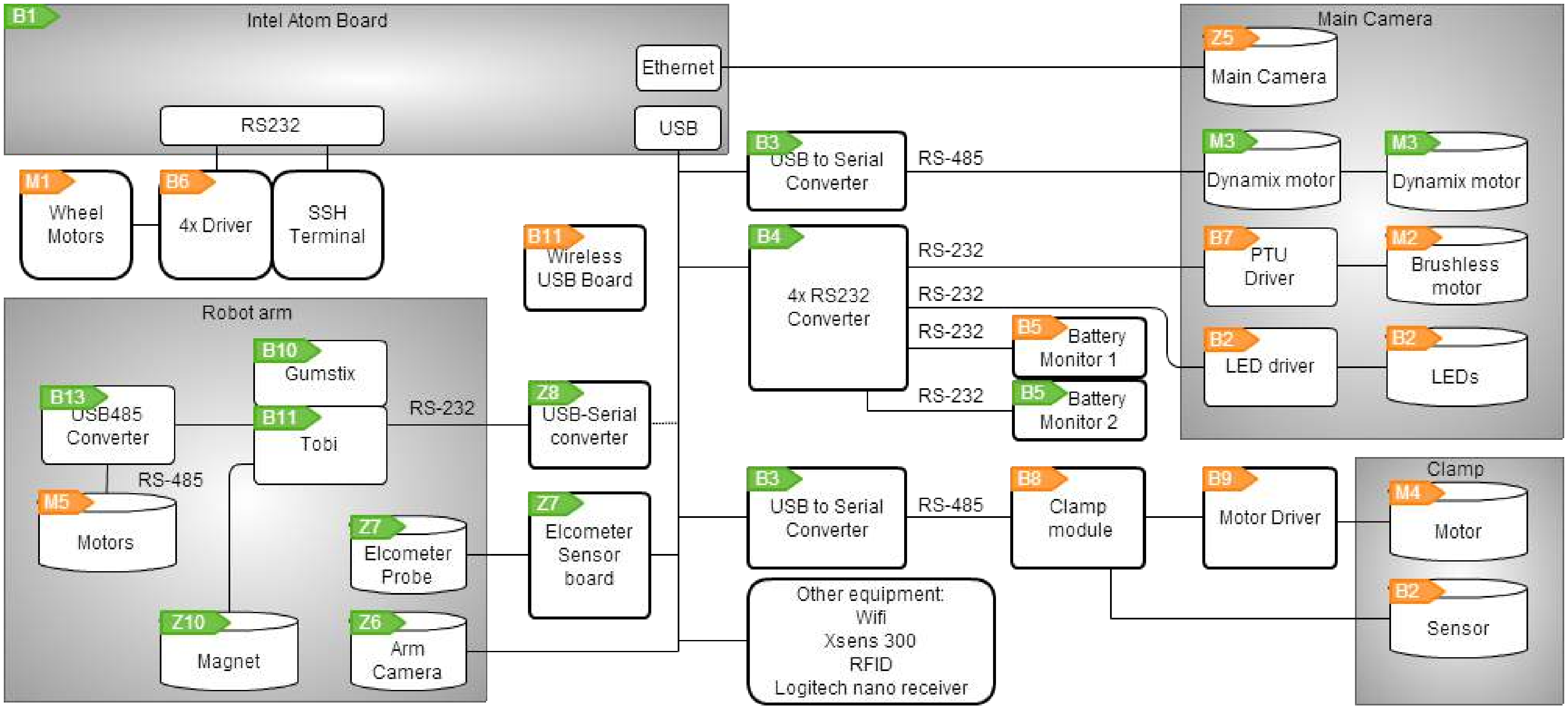


Figure A.2: Communication architecture of the robot.

Appendix A.3: Power architecture overview old situation

In Figure A.3 can be seen how the devices are distributed over the power cells. Here can you see that the Camera rotation motors of the PTU are connected on the same buck converters as the Intel Atom board. The high peek current of the motors resulted in a reset of the Intel Atom board due to a lack of available power. There was also a not connected serial converter on the robot which worked perfectly.

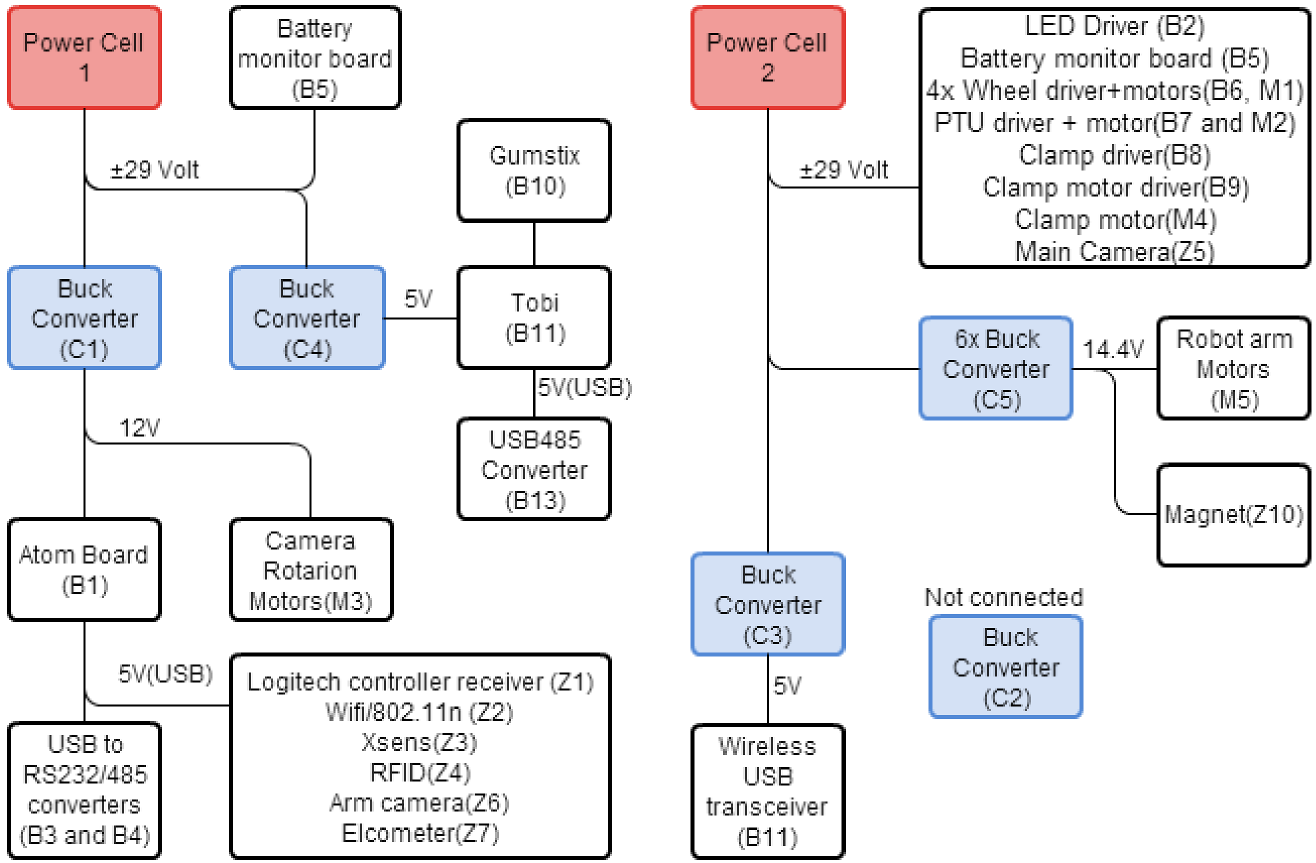


Figure A.3: Power architecture of the robot

Appendix A.4: Communication overview new situation

In Figure A.4 can be seen how the components of the robot are connected after the rework. You can see that all the serial connections are connected to the new USB to Serial converter. The USB hub and four USB to serial converters could be removed because of this rework.

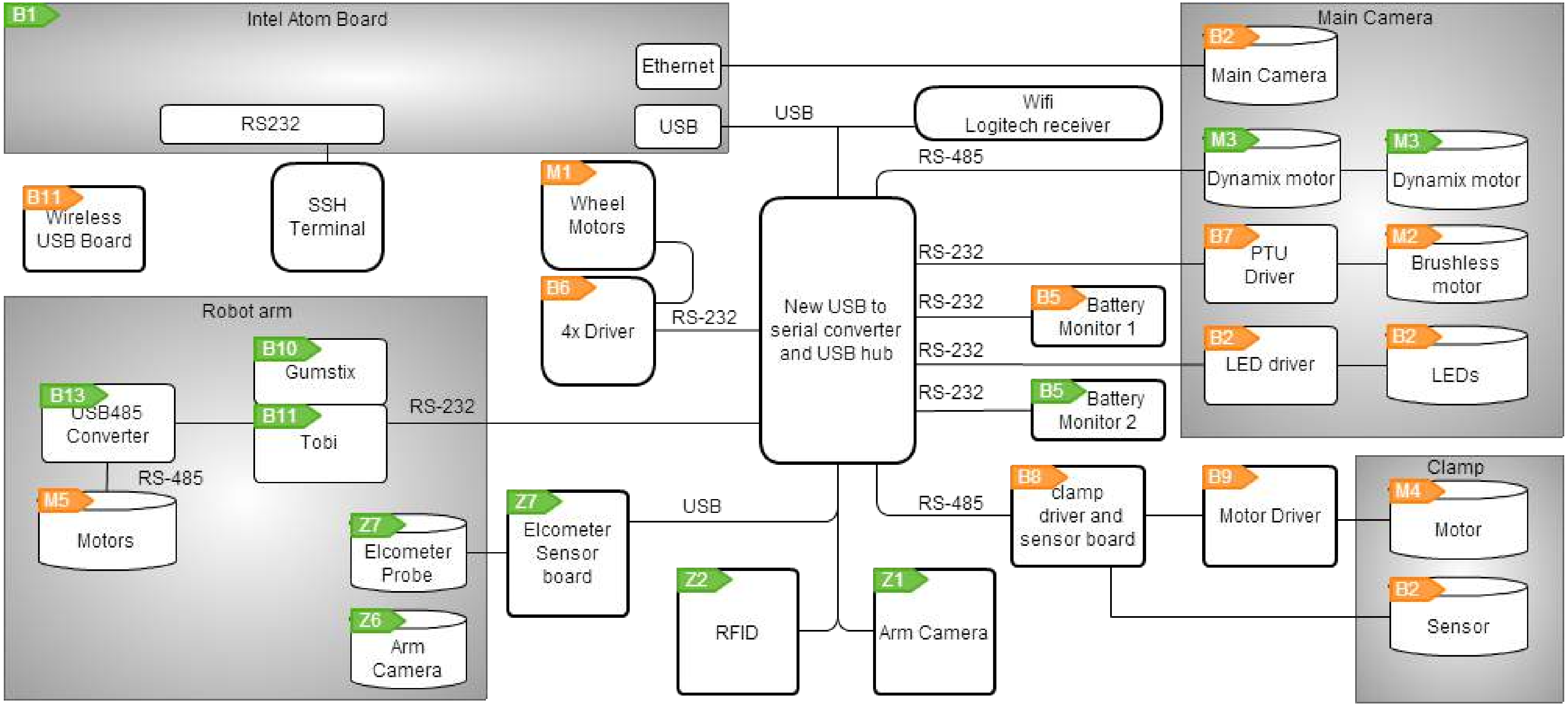
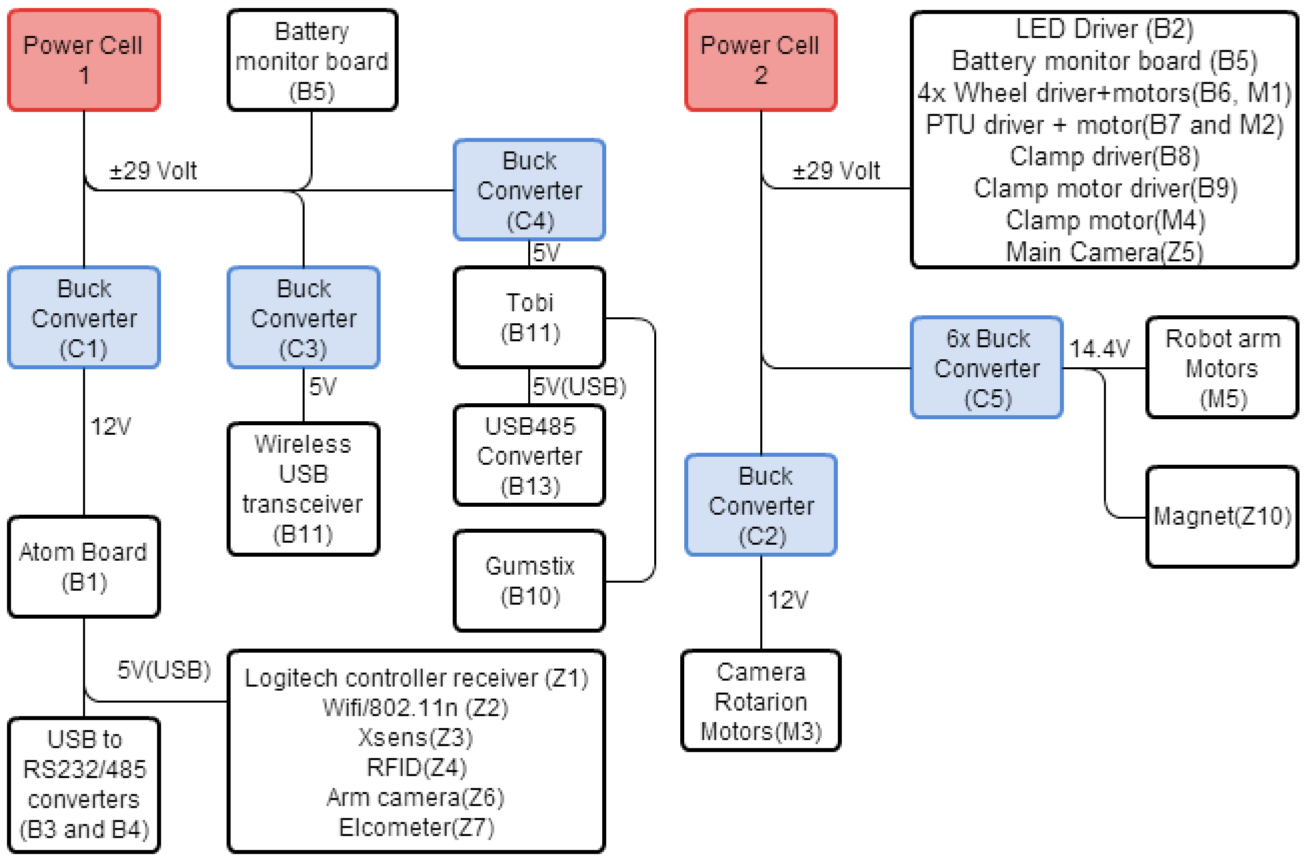


Figure A.4: Communication architecture of the robot after the rework.

Appendix A.5: Power architecture overview new situation

In Figure A.5 can be seen how the power is distributed over the different devices. No motors are connected to the first power cell such that the voltage on the first battery is stable. The not connected DC/DC converter is now used to provide power for the camera rotation motors.



Appendix B.1: USB to serial converter schematic

The schematic of the new USB to serial converter can be seen in Figure B.1. In this schematic can be seen that the signals are converted by either the MAX232 IC's to a RS232 signal of by the MAX481 to a RS485 signal. The device also has a 74HC595 shift register that drives the LEDs.

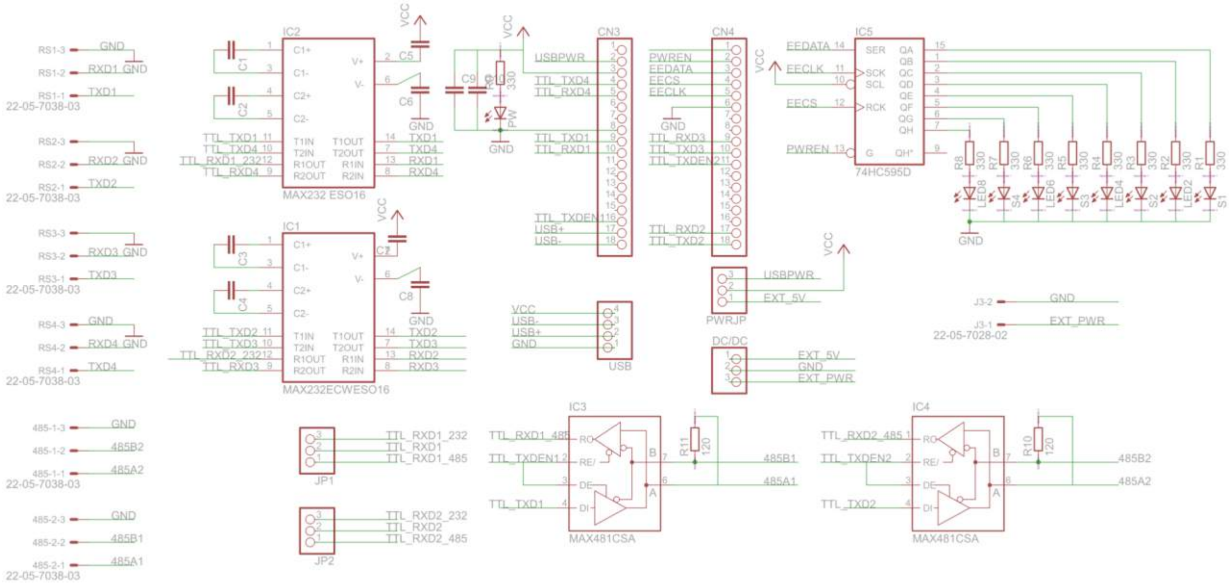


Figure B.1: Schematic of the new USB to Serial converter

Appendix B.2: USB to serial converter results

In Figure B.2 and B.3 can be seen how the result of the new USB to serial converters looks like. In Figure B.2 can be seen how the connectors can be connected. The A, B, C and D connectors are for RS-485 and the 1 till 8 numbers are for the RS-232 connections.

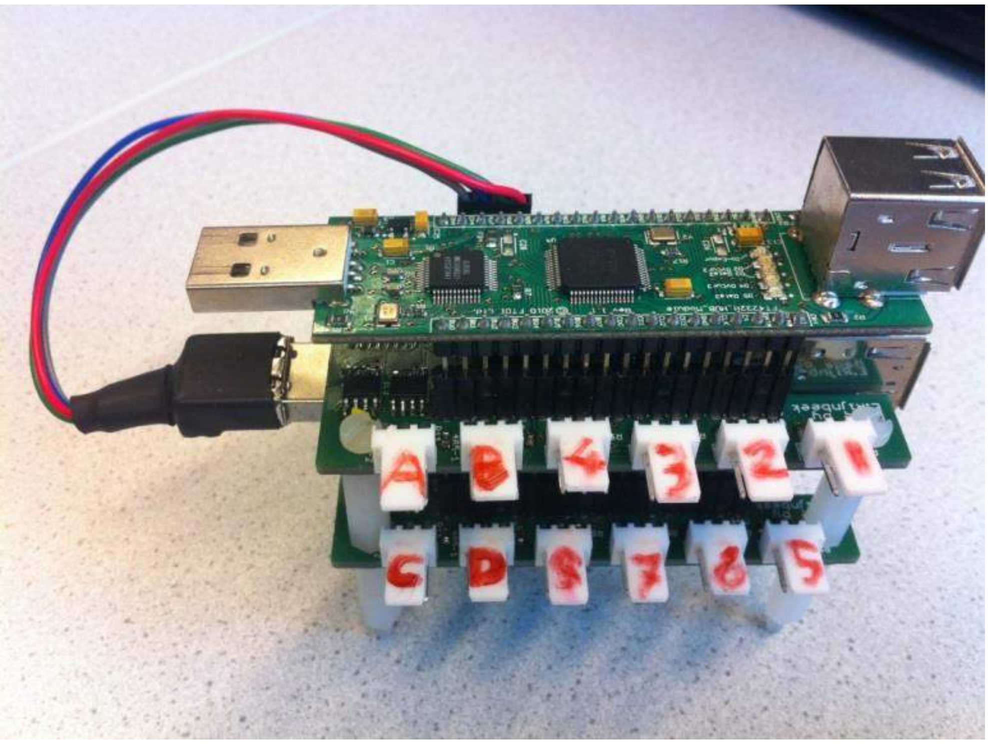


Figure B.2: Designed USB to serial converter, connector side.

The other side is shown in Figure B.3. At the far left of the device is a possible power input connector such that the device can be provided with power whenever the USB input can not handle the amount needed by the USB and serial devices. The three pin female header next to the power connector is for a DC/DC converter which can provide the device with 5V output when the power input is higher than 5V. When the power input is already 5V, a wire can be connected from the first and third pin of the female header.

Next to this header is a LED that lights up if the device is provided with power. Next to this header is a jumper called PWRJP which can be used to select a power input. When the jumper is on the left side of the 3 pin header, the downstream USB power is chosen as power input. When the right side is chosen, the external power is selected.

Next to this jumper JP1 and JP2 which can be used to select the proper serial output. When JP1 is connected on the right side, a RS485 connector A can be used instead of RS232 connector 1. Connector 1 can be used if the jumper is on the left side. This also holds for JP2 which switches between B and 2. For the lower board can JP1 and JP2 also be changed to select C instead of 5 and D instead of 6.

Next to the jumper is a header which can be used to connect a USB cable. This cable can be used to connect the next USB to serial converter on the stack. The USB header of the lower USB to serial converter is still unused and could be used to connect other devices.

At the far right side of the device are eight LEDs which light up when data is send of received. The eight LEDs are divided into four channels with each two LEDs. The far left light lights up red when data is send on channel 1 or A. When data is received by the channel 1, the second LED lights up green. This holds also for the third and fourth LED which indicates data send or received for channel 2 or B. The same holds for all the other channels and LEDs.

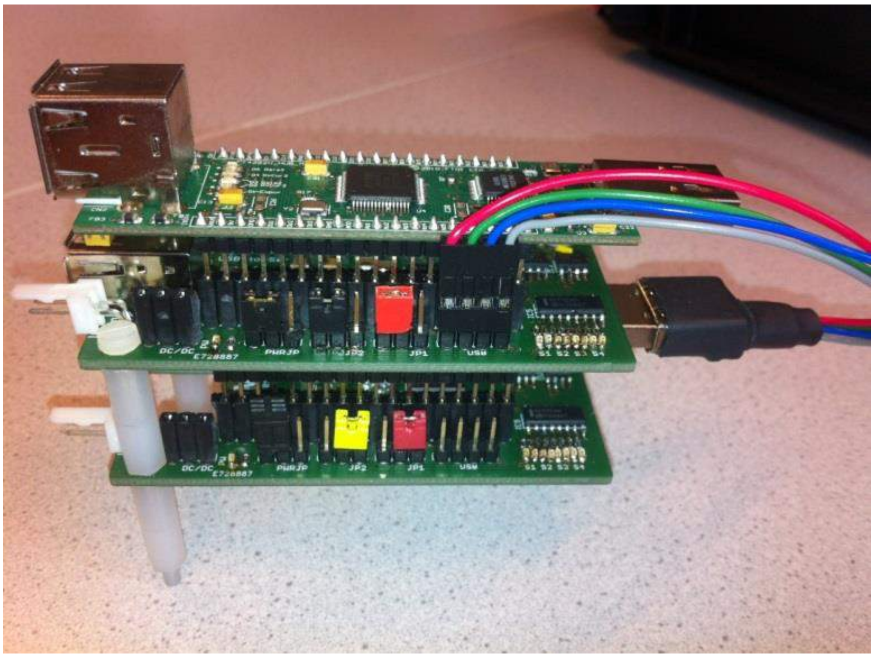


Figure B.3: Designed USB to serial converter, jumper side.

Appendix C: Power circuit

The design of the power circuit can be seen in Figure C.1 and the realization of this design can be seen in figure C.2. The battery which can be between 18 and 36V can be connected to connector five. The positive side of the battery for the motors can be connected to either Battery B1+ or Battery B2+. The negative side of the battery can be connected to Battery B- which is connected to ground. The other battery can be connected in the same way at Battery A inputs.

The devices which need to be connected to battery B can be connected to the five connectors which are located in the indicated region marked with the number two. The robot arm can be connected to the screw terminal marked with the number 1. The other devices which are connected to the other battery can be connected to the three connectors located in the region marked with the number three. The Intel Atom board which requires 12V can be connected to connector four. The battery indicators which are stacked on this device can be connecter to connector six or seven.

The diode ensures that there is no current between batteries that are connected at the same time such that the batteries can be switched while the robot is still provided with power.

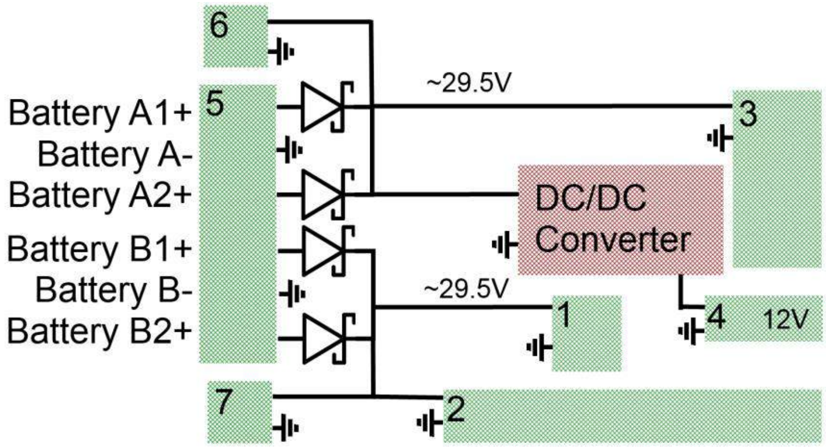


Figure C.1: Designed power circuit.

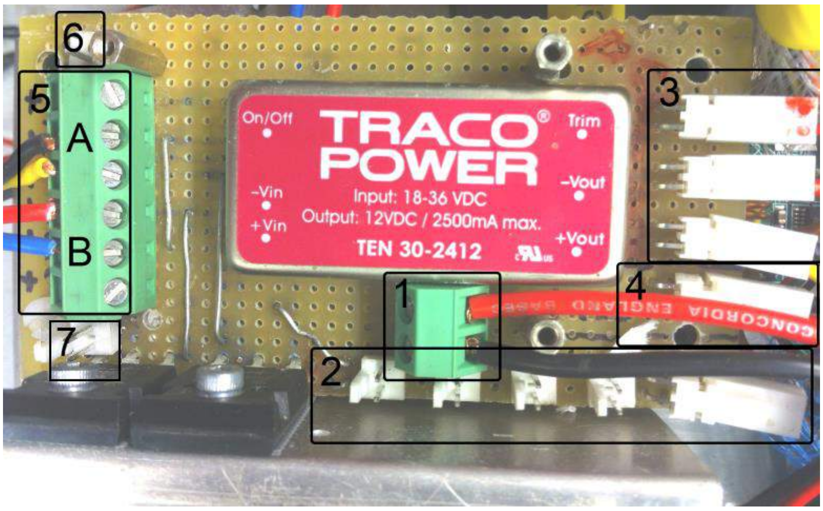


Figure C.2: Realized power circuit.

Appendix D.1: Photos

In the Figure D.1 a collage can be seen of how the robot looks like before the improvements.

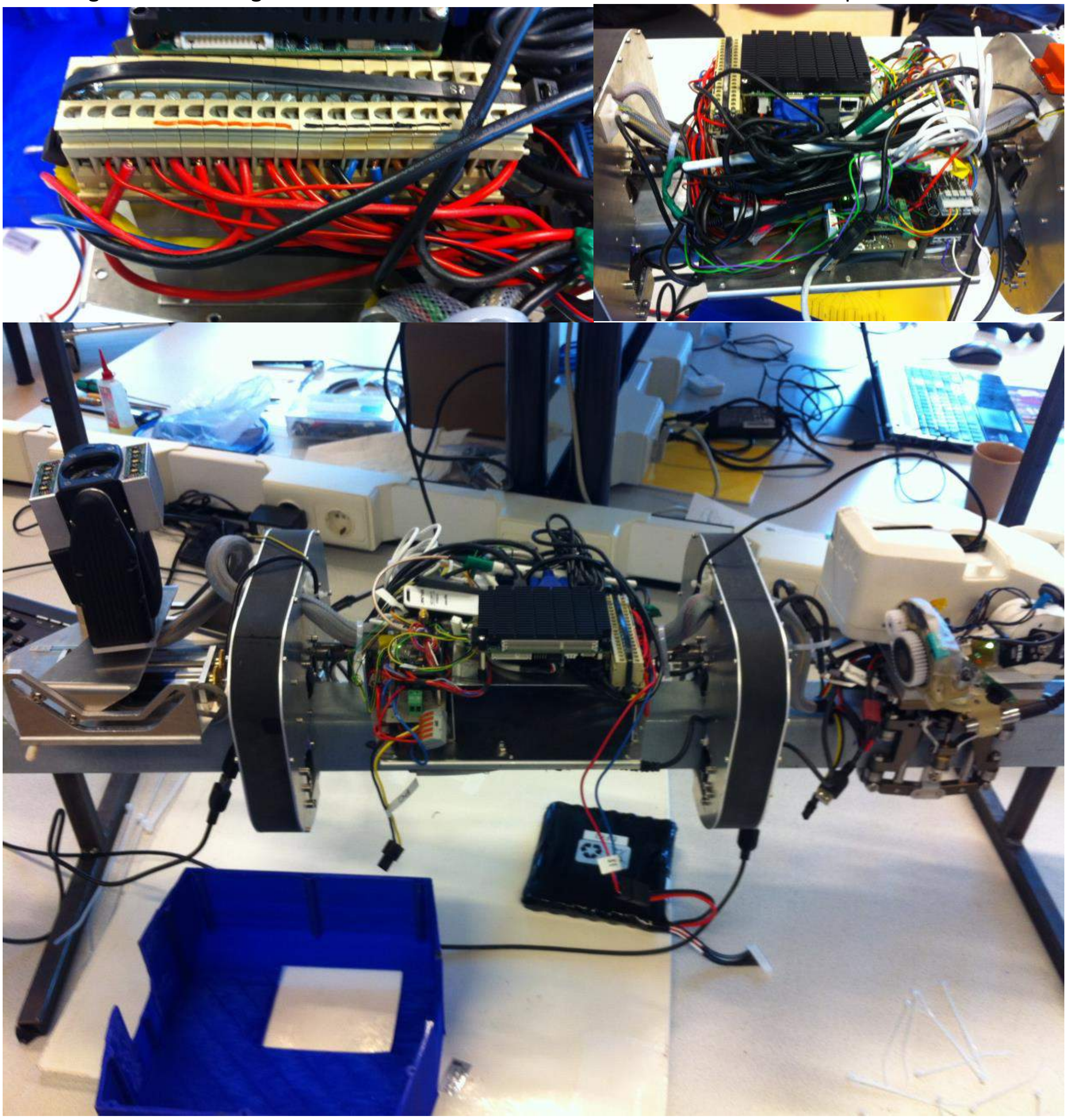


Figure D.1: Collage of the robot before the improvements.

In Figure D.2 can be seen how the robot looks like after the improvement. Four USB to serial converters, the large screw terminal, three smaller terminals and a lot of wire are removed.

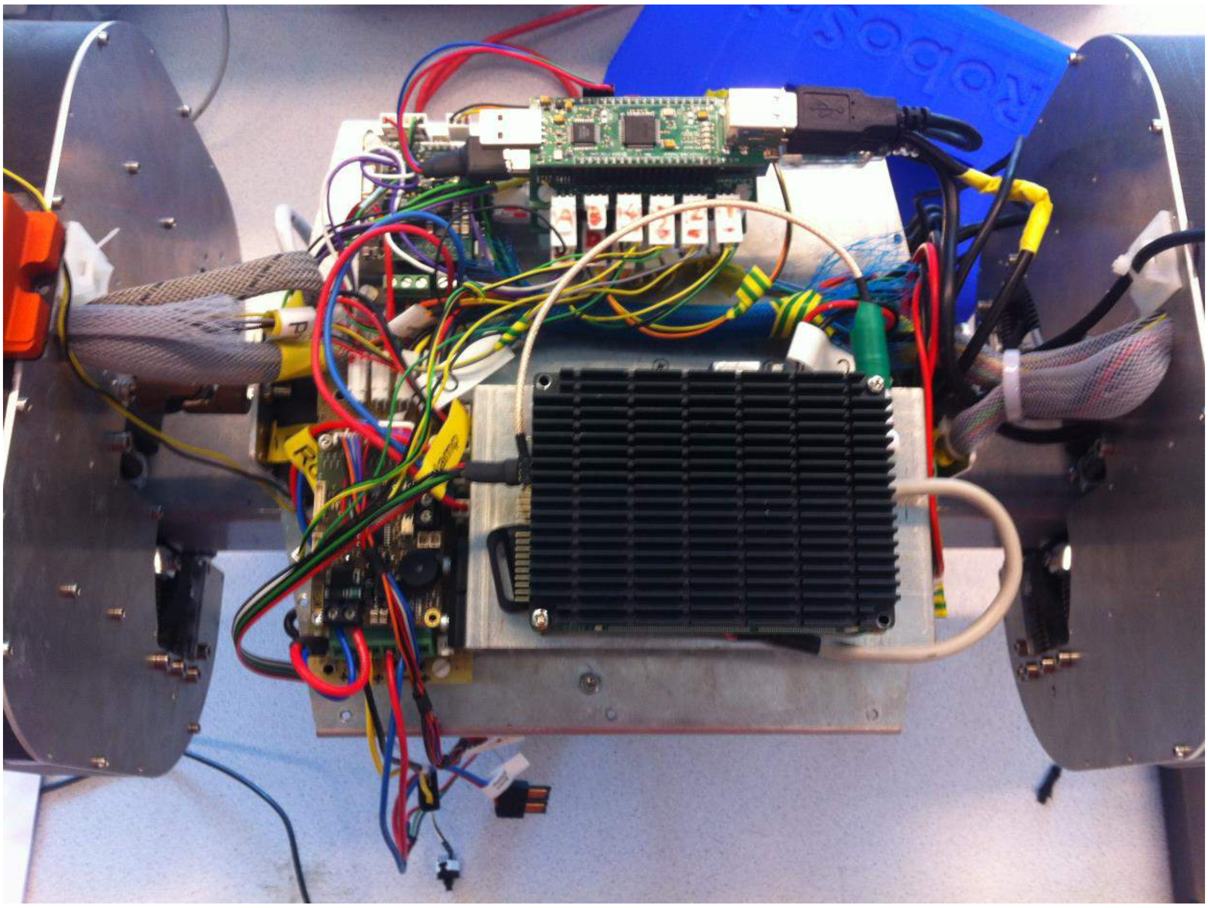


Figure D.2: The robot after al the improvements.

Appendix E: Udev Rules code

This is the code which has been used as rules such that devices within the software are given a name such that they are recognizable.

```
#This file is located in /etc/udev/rules.d
SUBSYSTEMS=="usb", ATTRS{serial}=="0000:00:1d.7",
ENV{.LOCAL_serial}="$attr{serial}"
SUBSYSTEMS=="usb", ENV{.LOCAL_ifNum}="$attr{bInterfaceNumber}"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX52BT",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="00",
SYMLINK+="ttyUSBwheels",  MODE="0660"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX52BT",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="01",
SYMLINK+="ttyUSBptu_faulhaber",  MODE="0660"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX52BT",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="02",
SYMLINK+="ttyUSBbattery1",  MODE="0660"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX52BT",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="03",
SYMLINK+="ttyUSBbattery2",  MODE="0660"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX53JK",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="00",
SYMLINK+="ttyUSBptu",  MODE="0660"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX53JK",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="01",
SYMLINK+="ttyUSBclamp",  MODE="0660"

#SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX53JK",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="02",
SYMLINK+="ttyUSBnotconnected",  MODE="0660"

SUBSYSTEMS=="usb", ATTRS{serial}=="FTYX53JK",
ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6011",
ENV{.LOCAL_serial}=="0000:00:1d.7", ENV{.LOCAL_ifNum}=="03",
SYMLINK+="ttyUSBleds",  MODE="0660"

SUBSYSTEM=="tty", ATTRS{idVendor}=="0403", ATTRS{idProduct}=="6001",
ATTRS{serial}=="FTXK98F5", SYMLINK+="ttyUSBgumstix"
```