Robotics project

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First progress report

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List of requirements

The present document discusses the design choices that are to be implemented for the robotic system to perform as this list of requirements states.

1. Functional requirements

1.1. **Electromechanics:**

a) The robot shall be able to move freely on a plain surface.
b) The robot shall be contained in a chassis robust enough to carry all its components around.
c) The robot shall be powered by a portable power supply.

1.1.1. Chassis:

a) The chassis shall be lightweight enough to move efficiently, and heavy enough to exert traction to the floor surface.
b) The chassis shall have enough space to fit all the required sensors, actuators and processing and communicating devices.
c) The chassis shall have at least two levels, the lower level for mounting the locomotion sub-system, and the upper level(s) for attaching the electronic parts.

1.1.2. Locomotion:

a) The robot shall be impulsed by a locomotion system that can move consistently over a plain surface.
b) The locomotion system shall give the robot the capacity to trace straight and curved trajectories and to rotate around its own axis.

1.1.2.1. Locomotion actuators:

a) The locomotion actuators shall have a torque capable of propulsing the whole system once it is mounted on the chassis.
b) The locomotion actuators shall be powered by a DC power supply.

1.1.2.2. Locomotion drive:

a) The locomotion shall be controlled by a drive circuit capable of providing the power that the actuators may demand.

b) The drive shall let the actuators move at different velocities and directions independently.

1.1.3. Power supply:

a) The robot shall have a single power supply that provides it with the right amount of DC current and voltage.
b) The power supply shall be portable and shall fit within the chassis.

1.1.3.1. Battery:

a) The battery shall be rechargeable and shall not exceed the dimensions of the robot chassis.
b) The battery shall last enough time for the robot to complete its task with one charge.

1.1.3.2. Regulation circuits:

a) The power supply shall have one or more regulation circuits that provide each electric and electronic component with the current and voltage it needs.

1.1.3.3. Power supply connectors:

a) Every electric and electronic circuit shall have a specific connector or adapter that allows it to connect to the power supply.

1.2. **Electronics:**

a) The robot shall operate autonomously and wirelessly.
b) The robot shall have the ability of scanning its surroundings without directly interacting with the obstacles. It shall, in fact, avoid them.
c) The robot shall compute its trajectories and take decisions based on the information gathered from its surroundings.
d) The actions of the robot shall be coherent with and faithful to the instructions it computes.

1.2.1. Sensors:

a) The robot shall be able to map its surroundings based on sensing information.
b) The robot shall be aware of the dimensions of the obstacles it encounters and the distance from them.

1.2.1.1. Vision sensor:

a) The robot shall be able to sense the room in three

dimensions, that is: width, height and depth.
b) The vision sensor shall provide readings with good resolution, and at a sampling frequency that does not compromise the velocity of the mobile robot.

1.2.1.2. Distance sensors:
a) If needed, the robot shall navigate the room aided with distance and presence sensing.

1.2.2. On-board computer:
a) The robot shall have a processing device that is able to compute the sensed information and make decisions based on it.
b) The computer shall have a wireless network interface.

1.2.2.1. Operating system:
a) The PC of the robot shall run an operating system that is suitable for performing SLAM.
b) The operating system shall enable wireless communication.
c) The operating system shall be robust and trustworthy.

1.2.3. Embedded controller:
a) The robot shall have a stable behavior while performing trajectories.
b) The robot shall have feedback from its actuators and shall correct itself if necessary.

1.2.4. Communication:
a) The robot shall be able to connect to a Local Access Network.
b) The robot shall be able to establish a wireless communication with an external endpoint for programming, monitoring and for displaying relevant information.
c) The existence of the wireless interface shall not compromise the proper behavior of the robot.

2. Performance requirements

a) The robot shall construct a map of its surroundings with enough precision that, once it finishes its exploration, it is able to return to its starting position based on the constructed map with an absolute error of 15cm.

2.1. **Electromechanics:**

2.1.1. Chassis:

a) The system shall be light but able to carry an additional payload of 10 kg.
b) The chassis shall handle a manometric pressure of at least 5000 N/m2 without deforming or breaking.

2.1.2. Locomotion:

2.1.2.1. Locomotion actuators:

a) Each motor of the robot shall be capable of applying over 20kg/cm of torque. This feature shall allow the robot to perform the required functional movements.

2.1.2.2. Locomotion drive:

a) The robot shall be able to move at a mean linear velocity of 0.5m/s.
b) The robot shall be able to rotate at an angular velocity of 1 rad/s.

2.1.3. Power supply:

2.1.3.1. Battery:

a) The battery shall provide 11.1V DC, 3800mAh with over 2 hours for nominal operation.

2.1.3.2. Regulation circuit:

a) The regulation circuit shall provide a constant voltage of 5V to 7.4V and a current of at least 3A to the electronic components.

2.2. **Electronics:**

2.2.1. Sensors:

2.2.1.1. Vision sensor:

a) The sensor in its mapping functions shall map at least 85% of its environment. The area in which the robot is expected to navigate and map is a 3D space with a surface of 5x5 meters and a height of 40 centimeters. The camera shall be able to provide at least 10 images per second.

2.2.1.2. Distance sensors:

a) The distance sensors shall be able to at least detect and send signals when the object in front of the sensor when the distance between the robot and the object is 10 centimeters or more.

2.2.2. On-board computer:

a) The embedded computer be a 64-bit quad core with a frequency of 1.2GHz so the response of the system is accurate and fast for performing its processes.

2.2.3. Embedded controller:

a) The controller shall guarantee the stability of the system in all its functions assuring that the system never deviates from its settling points with a maximum error of 10%.

b) The feedback signal from the actuators shall have a resolution of at least 1000 readings per revolution.

2.2.4. Communication:

a) A fully integrated WiFi (802.11g) system with dual serial communication channels supporting both UDP and TCP/IP protocol shall comprise the communication of the subsystems.

3. Top-level technical requirements

3.1. Implementation constraints:

a) The **X80 Dr Robot Inc: WiFi 802.11** platform shall be used as the basis for building the mobile robot.

b) The **R200 RealSense** camera shall be implemented as the computer vision system that enables the robot to sense and analyze its environment.

c) The system shall run on the subsystem **ROS Kinetic**.

3.2. Mass:

a) The whole system shall weigh less than 5kg.

3.3. Volume:

a) The dimensions of the robot shall not exceed 40x40cm of each side and 30cm in height.

3.4. Power consumption:
a) Roughly, the system shall not consume more than 100W.

3.5. Cost:
a) The total cost shall not exceed 63,862 MXN. More details in the *Budget* section.

3.6. Safety:
a) The robot shall not represent a threat against the user or any other person that might interact with it.
b) If used correctly, the robot shall not damage any goods or the room itself while being in operation.

Mechanical design

The proposed solution to meet the design requirements stated in the last advance is to incorporate the X80 - Dr Robot Inc: WiFi 802.11 robot. Its mechanical features are:

- Weight: 3.5 kg, aiding in the accomplishment of requirement **3.1a** (*The whole system shall weigh less than 5kg*). The combination of the on-board PC, stereoscopic camera and power regulator does not exceed 1.5 kg.
- Dimensions: diameter of 38 cm and height of 25.5 cm, fulfilling requirement **3.2a** (*The dimensions of the robot shall not exceed 40x40cm of each side and 30cm in height*).
- Two DC motors with 22 kg·cm torque each, fulfilling requirement **2.1.2.1a** (*Each motor of the robot shall be capable of applying over 20kg/cm of torque*).
- A maximum linear speed of 1 m/s according to its manufacturer, fulfilling requirement **2.1.2.2a** (*The robot shall be able to move at a mean linear velocity of 0.5m/s*). Given the information about the maximum linear velocity and the robot's diameter, it is possible to estimate an angular velocity for the case where one wheel is run at its maximum driving velocity and the other one, being the center of the described circle, is stopped. Since $\omega = \frac{v}{r}$, the expected angular velocity is 2.63 rad/s, which also exceeds requirement **2.1.2.2b** (*The robot shall be able to rotate at an angular velocity of 1 rad/s*).
- The X80 is built in such a way that its three chassis stages remain parallel to the floor, since its three wheels are level. This means that there is enough space distributed in the robot to place any additional component needed, including the higher voltage battery considered for the project, fulfilling

requirements **1.1.b** and **1.1.1b-c**. It also means that this robot operates well on a flat surface, referring to requirements **1.1a** and **1.1.1a**.

The X80 is illustrated with a couple of its measurements in Fig. 1. This schematic was obtained from the X80 Manual [1].

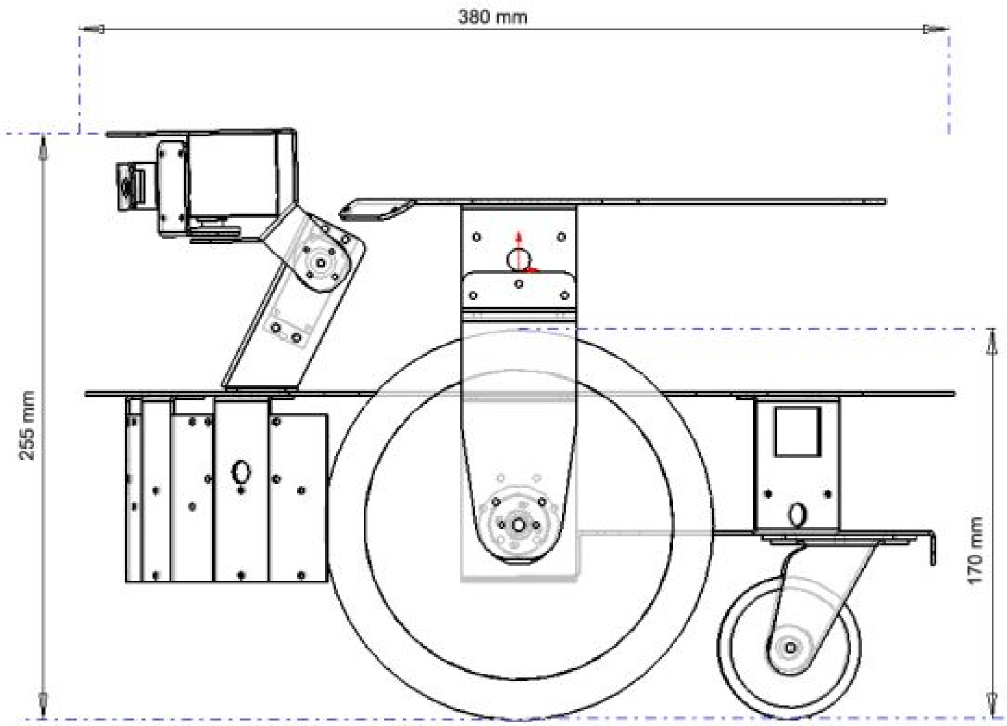

Fig. 1 X80 mechanical design

To attach the stereoscopic camera to the chassis, an additional assembly was needed. A mobile base actuated by servomotors already exists on the robot. The conditions for the camera mount were simply to have the correct measurements to be attached via four screws onto the metal base and to have enough clearance with the pentagonal top piece so the camera wouldn't collide with it when rotated. The measurements taken on both metal pieces are shown in Fig. 2. The units are mm.

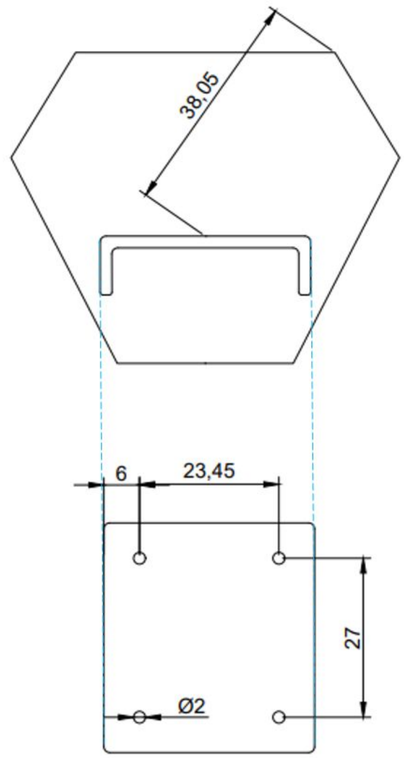

Fig. 2 Measurements to satisfy for the camera mount

Although a mount was designed for the Intel RealSense SR300 3D camera, the camera choice was modified to match the specifications of the assigned embedded PC to the RealSense R200. A team of students who had previously attempted to achieve SLAM on the X80 designed and 3D printed a camera mount that could support the R200. With the exception of a screw that holds the camera at a fixed pitch, the mount is still in very good condition and is currently the one considered to hold the vision system. A CAD drawing created by Duncan Iglesias and used in a previous report [2] is included in Fig. 3.

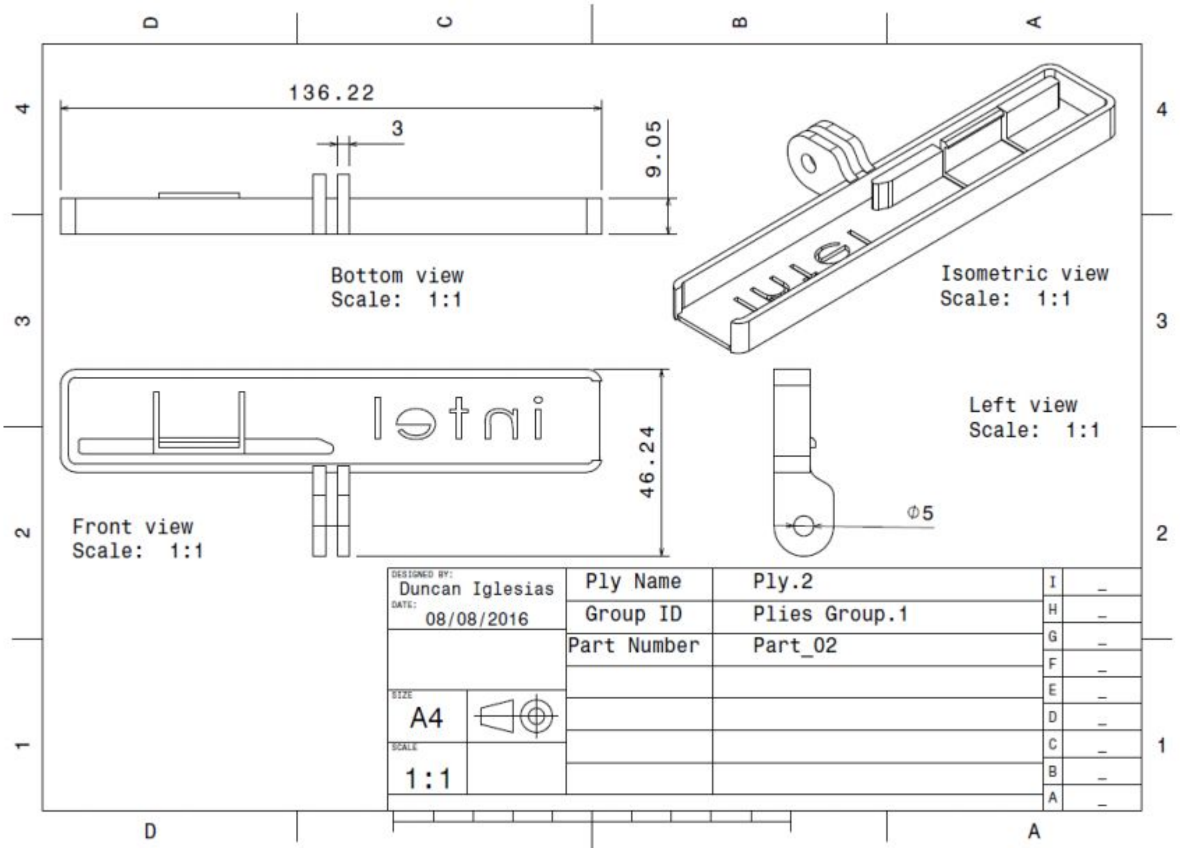

Fig. 3 Camera mount CAD

Fig. 4 shows the embedded PC mounted on the top stage of the X80.

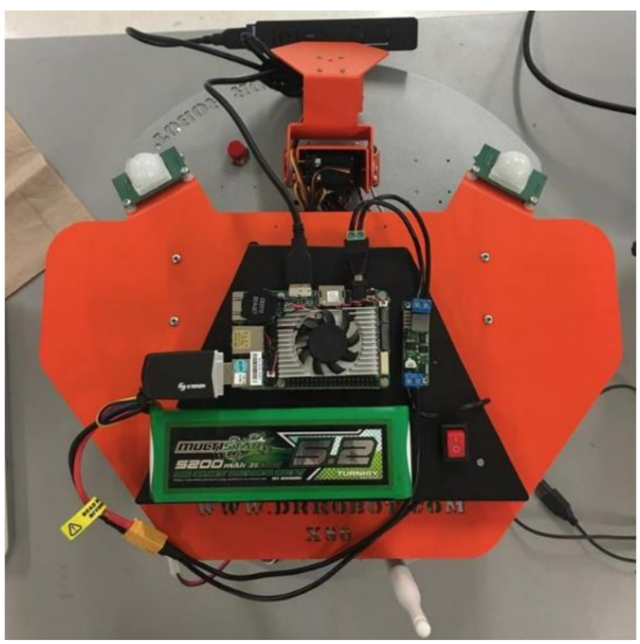

Fig. 4 X80 robot with UP board and battery mounted

Electrical design

Vision sensor

Fig. 5 Intel RealSense R200 camera

As an additional note regarding requirements, the R200 is a stereoscopic camera capable of obtaining three-dimensional information [3], which fulfills requirement **1.2.1.1a** (*The robot shall be able to sense the room in three dimensions, that is: width, height and depth*) and requirement **1.2.1.1b** (*The vision sensor shall provide readings with good resolution, and at a sampling frequency that does not compromise the velocity of the mobile robot*). The use of this device is also a design constraint as specified in requirement **3.1b**.

On-board computer

According to requirement **1.2.2a**, the robot shall have a processing device that is able to compute the sensed information and make decisions based on it. For this purpose the AAEON Up-board was chosen [4].

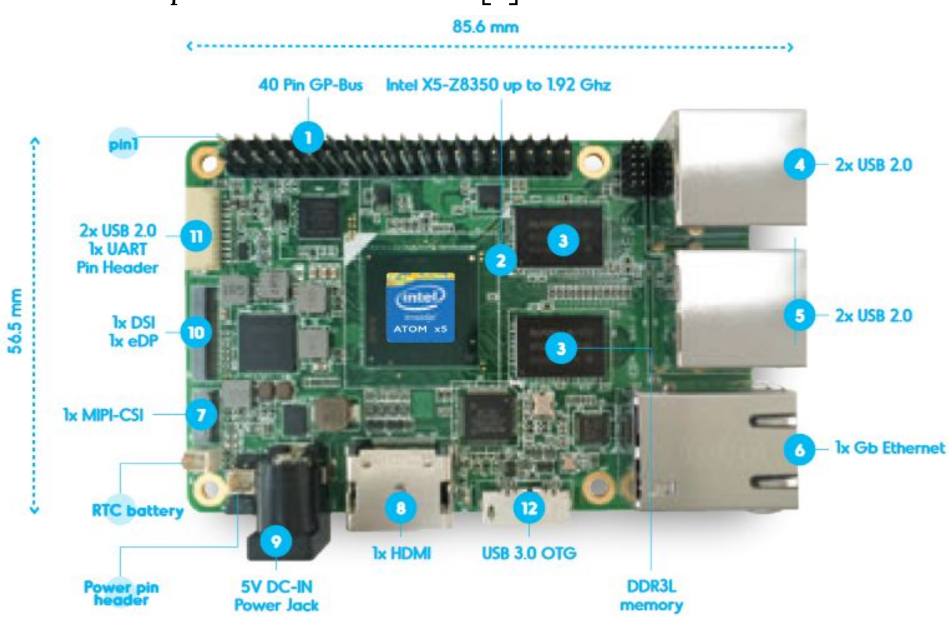

Fig. 6 AEEON Up-board

Its specifications are the following:

- System-on-chip Intel Atom x5-Z8350 quad core processor with a speed of 1.44-1.92GHz.
- 5v DC in @ 4A.
- 2GB DDR3L-1600 RAM.
- 4x UB2.0 & 1x UB3.0 OTG ports.
- Compatible with Microsoft 10, Linux and Android Ubuntu and Marshmallow OS's.

A major reason for choosing this device was its high compatibility with the RealSense R200 camera, which is implementation constraint **3.1b**. Similarly, implementation constraint **3.1c** states the use of ROS Kinetic as the subsystem for the on-board computer, which runs natively on Ubuntu 16.04.6 Xenial. The AAEON Up-board fulfills this constraint, as well as requirement **2.2.2a** (*The embedded computer be a 64-bit quad core with a frequency of 1.2GHz so the response of the system is accurate and fast for performing its processes*). However, this device does not have a WiFi interface, and can only communicate to Internet via Ethernet. This is why a USB WiFi module is required for the board to connect wirelessly to the rest of the system and satisfy requirement **1.2.2b** and **2.2.4a**.

Power supply

As stated in the list of requirements the robot shall be powered by a single portable power supply unit, or battery that delivers DC voltage (requirements **1.1c** and **1.1.3a-b**). The battery that was chosen is shown in Fig. 7.

Fig. 7 Turnigy MultiStar LiPo battery

This battery has an output nominal voltage of 11.1V DC, 5200 mAh, is conformed by 3 cells (3S), and its discharge constant is 10C. These specifications surpass requirement **2.1.3.1a**. The battery is rechargeable and its dimensions are 106 x 44 x 34 mm which does not exceed the robot dimensions. This fulfills requirement

1.1.3.1a (*The battery shall be rechargeable and shall not exceed the dimensions of the robot chassis*). Also, the amount of current that the battery can supply per hour is enough to perform several tests with the robot within an hour (requirement **1.1.3.1b**).

As the electrical design demands that the power supply shall be able to power both the X80 robot and the on-board PC, then power regulators are needed. The voltage regulator proposed to be connected between the battery and the X80 robot has the following specifications [3]:

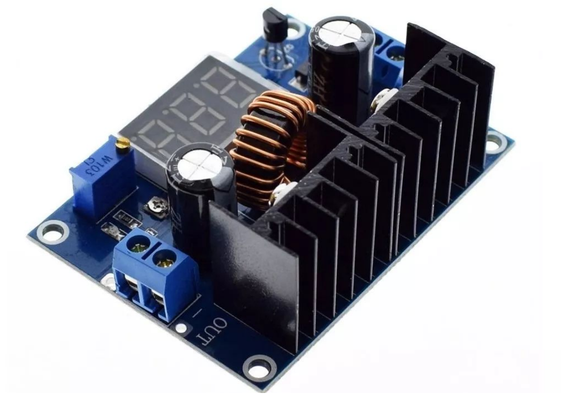

Fig. 8 Step-down voltage regulator

- Product: XL4016.
- Input Voltage: 4~40V DC.
- Output Voltage: 1.25~36V DC.
- Output current: max. 8A.
- Output power: 250 W max.

This regulator will be directly connected to the battery and the output voltage is set to 7.4 V to supply the X80 embedded system, fulfilling requirements **1.1.3.2a** and **2.1.3.2a**.

Similarly, the power regulator chosen for powering the on-board computer has the following specifications [4]:

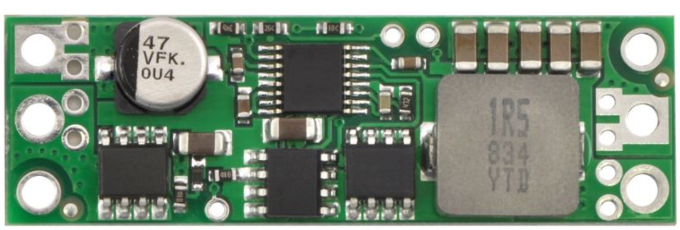

Fig. 9 Step-down voltage regulator

- Product: D15V70F5S3.

- Input Voltage: 4.5~24V DC.
- Output Voltage: 3.3~5V DC.
- Output current: max. 16A.
- Output power: max. 80W.

This component also fulfills functional requirement **1.1.3.2a** (*The power supply shall have one or more regulation circuits that provide each electric and electronic component with the current and voltage it needs*) and performance requirement **2.1.3.2a**. (*The regulation circuit shall provide a consistent voltage of 12V and a current of at least 3A to the electronic components*).

Power supply connectors

From requirement **1.1.3.3a**, every electric and electronic circuit shall have a specific connector or adapter that allows it to connect to the power supply. To meet the requirement a cable with 1 input and 2 outputs is needed. The input should be connected to the LiPo battery, then the outputs must be connected to the voltage regulators. For the UP board the D15V70F5S3 regulator must have in its output a male DC jack connector so the computer can be powered. For the x80 robot the XL4016 regulator must have in its output a male Tamiya connector so it can be connected to the robot circuit. Fig. 10 details the connections between the components that make up the electrical design.

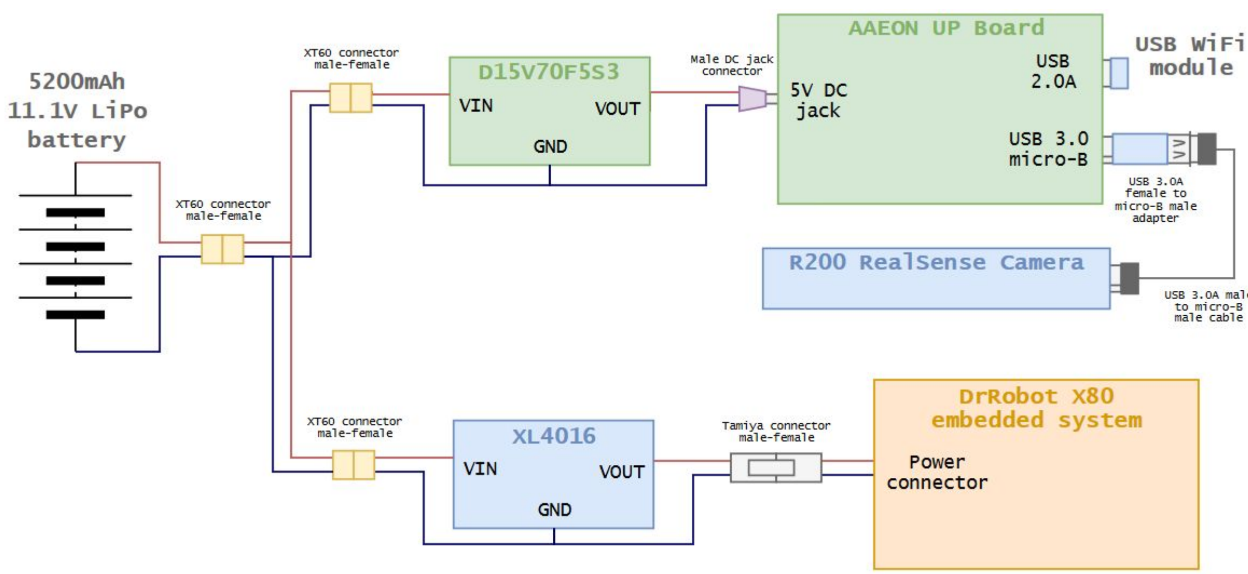

Fig. 10 Electrical design

Software

The robot's software is based on topic publication and subscription to topics with code located in ROS nodes. A computer connected to the same network, but separate from the robot, initiates the process through a publication of a high-level command in a topic. The UP Board receives this event and begins its process. Information about the 3D environment is taken from the R200 to collect a point cloud of the environment. The UP Board, through a different ROS topic, sends motion commands to the X80 in a format that is understandable by the embedded controller. This is done through a library published by Dr Robot. The UP Board also needs to keep a register of the state and actions of the robot to aid its localization through dead reckoning. Additional information from the map can later be used as well. While all this happens, the result of the map can be visualized in the remote computer with the help of the Rviz software. By following this behaviour, the system would satisfy functional requirement **2a**.

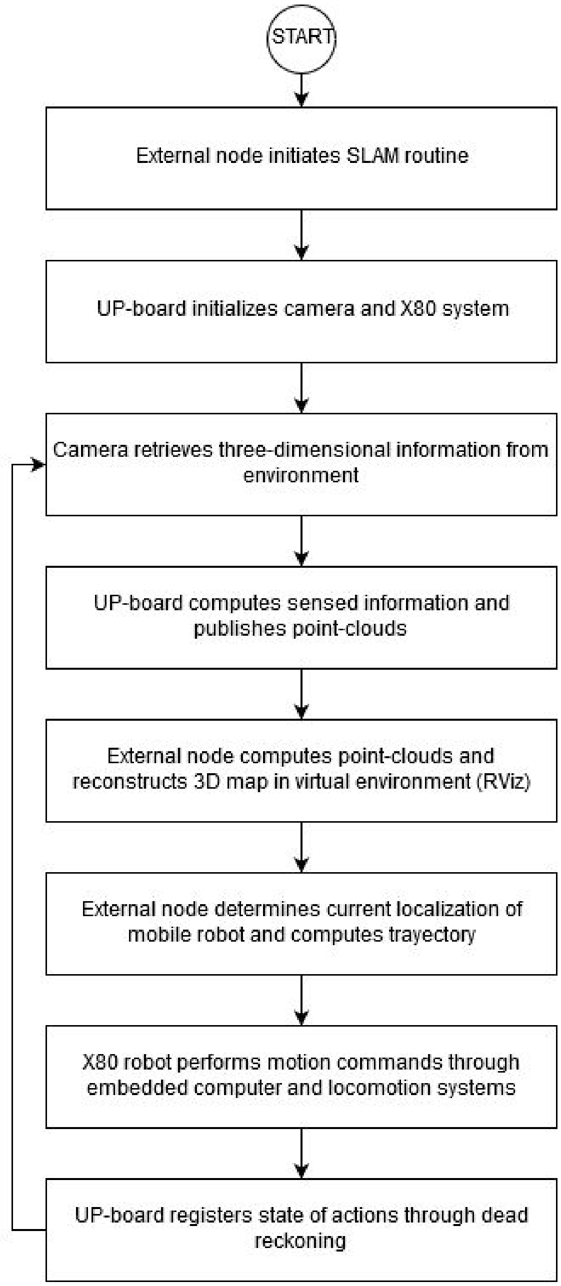

Fig. 11 Behavioural flow diagram for the SLAM robotic system

The proposed topics to pass categorized messages between devices are shown as annotations next to the arrows in Fig. 12. This diagram depicts the wireless connections between the nodes on the system, which would satisfy performance requirement **2.2.4a** as well (A *fully integrated* WiFi (802.11*g*) *system with dual serial communication channels supporting both* UDP *and* TCP/IP *protocol shall comprise the communication of the subsystems*).

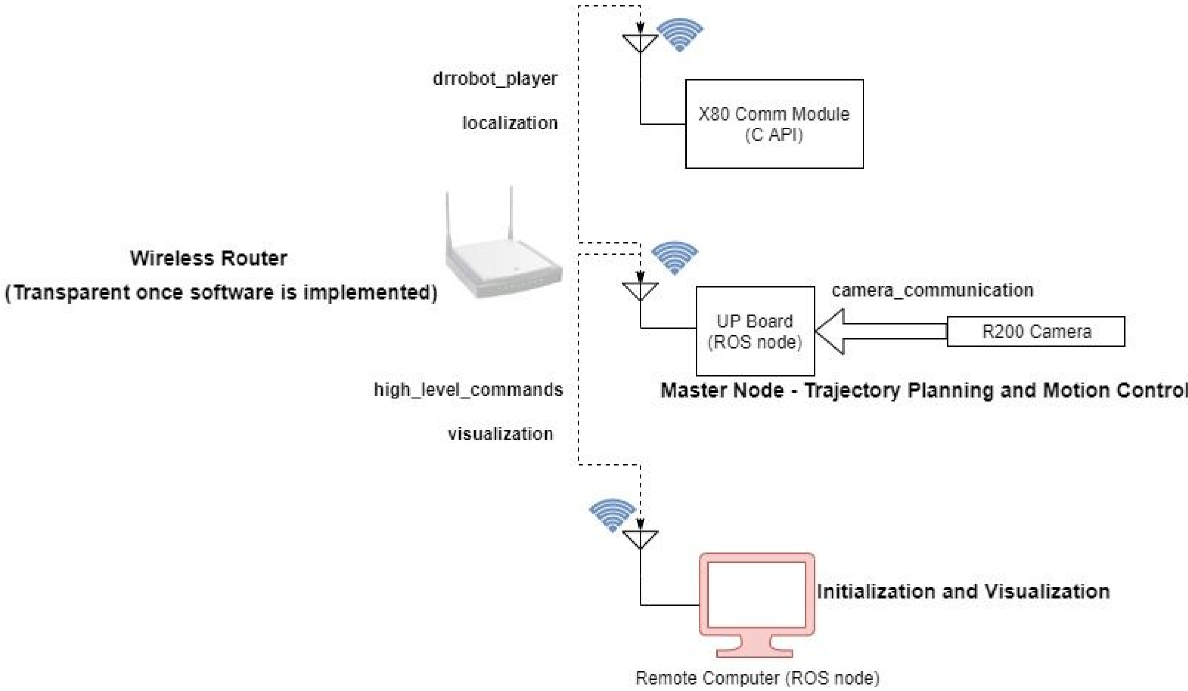

Fig. 12 ROS nodes and topics for message passing

Implementation and Testing

The whole system is to be implemented in subsystems, mainly electromechanical and electronic/software, which by meeting the requirements stated before can perform the expected behaviour. A detailed breakdown of these subsystems is presented in Fig. 13.

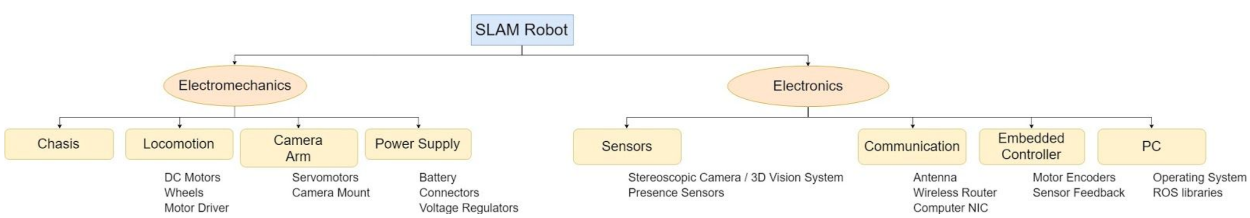

Fig. 13 Robot subsystems breakdown

Testing methodology

The methodology to perform the testing process would be functional oriented given the circumstances and characteristics of this project, in this case the developer of each unit will be the one in charge of testing its contribution to the system. The proposed methods for testing are to be performed in the following order:

Unit testing: the process of ensuring that the individual components of the system are functional and work as they were designed to (scripts, programs, circuits, mechanical elements). For this project, the low-level testing applies mainly to the electrical and computing elements:

- Measure the voltage delivered individually by each regulator when hooked up to the LiPo battery.
- Test the wireless connectivity of the UP Board by either a ping or request of a web resource.
- Initialize ROS and display node information by running the command *rosnode* in the UP Board.
- Being able to observe one image taken from the R200 camera in any computer, operating system and software.

Integration testing: The project is designed to be component oriented. Then the integration testing is the process of integrating units to create modules or components that are designed to perform specific tasks or activities. The modules can be generally grouped into electric, electromechanical and computational subsystems. The important tests to make as integration advances are:

- Ensure there is proper communication through the publication and subscription of the UP Board and a static computer to a topic. A message should be passed by the computer and processed by the UP Board with ROS code.
- Although the mechanical part of the X80 is practically assembled and functioning from factory, a test of its feedback and control algorithms must be performed by tracing a square or otherwise known trajectory through specified distances. The robot must return to its starting point by mere use of its installed encoders with an error of at most a few centimeters.
- The test described above should yield similar results if done with all the equipment contributing with its weight on the robot. This would confirm that it is suitable to fully support itself and perform additional actions.
- Test the electrical system by feeding all the electronics with a single LiPo battery. The voltage and current must be measured at the output of the battery and at the regulators to make sure the power needs of the electronics are satisfied.

System testing: The functionality of the software is tested from end-to-end as a black box in order to evaluate the functionality of the whole system.

- The external computer must be able to send a simple, top-level command to start the entire sequence of mapping, navigation, or both. In this way, the precise functionality of the subsystems has a black-box appearance to the user.
- Place the robot in a small variety of scenarios (such as a straight corridor, a room with boxes and a room without obstacles) and read the decision taken by the evaluation of the existing map and the image viewed at a certain moment. This could be visualized by the publication of messages through a separate ROS topic.

Acceptance testing: This process is used to assess whether or not the final implementation is ready for delivery, in this phase it is recommended to include the final user in the testing process. The system can be considered accepted when the higher-level requirements are met.

- While running the most recent version of the program, the robot is able to stop at a minimum distance of 10cm from objects in its path and does not crash.
- The robot is made to return to a starting position by its own program. This position is at most 15cm away from where it began.
- The tests will be done in closed spaces with static obstacles that are already present or placed by the team. The expected size of the room for testing is around 5 x 5 meters. At the end of the test, the generated map should have few missing spaces, in order to satisfy the requirement of mapping 85% of the space where the robot is located.
- Through observation of the robot while it operates, we must determine that the steps it takes contribute to the generation of the map and it does not get stuck in a loop, a confined space or simply stops without finishing the mapping.

References

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