Robotics project

Prof. Alf Kjartan Halvorsen

Design requirements document

Marcos Eduardo Castañeda Guzman
A01372581@itesm.mx

Gerardo Uriel Monroy Vázquez
A01372286@itesm.mx

Emmanuel Hernández Olvera
A01371852@itesm.mx

09/09/19

Table of contents

Problem definition

A robotic system that performs Simultaneous Localization And Mapping (SLAM) within a closed room is to be designed and built. SLAM is concerned with the problem of building a map of an unknown environment by a mobile robot while at the same time navigating the environment [1]. The 3D map built by the robot is not expected to comprise structures higher than the robot itself neither inaccessible areas (i.e. narrow passages or stairs).

Proposed solution

The solution being considered consists in using an existing robotic module that has already been purchased and is currently located in the campus laboratories, and adapt its hardware to hold a vision system that enables the robot to receive and process stereoscopic video. The robot uses a differential drive, has a wireless connection through WiFi and is battery-operated, which makes it useful to navigate either remotely controlled or autonomously. For the solution to work, some hardware will have to be built to accommodate the vision system. The SLAM-capable robot can be seen as a collection of mechanical parts coupled with power electronics and low-power electronics for logical control and communication. The required subsystems and subparts are shown in Figure 1.

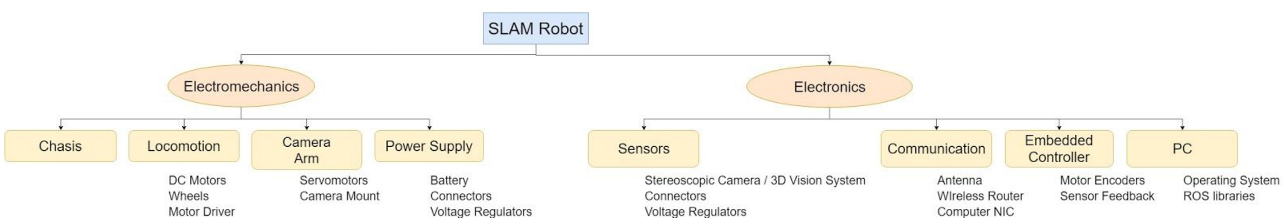

Fig. 1 Robot subsystems breakdown

The interaction between these subsystems and parts is explained in the Interfaces section of this document.

Requirements

1. Functional requirements

1.1. Electromechanics:

- The robot shall be able to move freely on a plain surface.
- The robot shall be contained in a chassis robust enough to carry all

its components around.
- The robot shall be powered by a portable power supply.

1.1.1. Chassis:

- The chassis shall be lightweight enough to move efficiently, and heavy enough to exert traction to the floor surface.
- The chassis shall have enough space to fit all the required sensors, actuators and processing and communicating devices.
- 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:

- The robot shall be impulsed by a locomotion system that can move consistently over a plain surface.
- 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:

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

1.1.2.2. Locomotion drive:

- The locomotion shall be controlled by a drive circuit capable of providing the power that the actuators may demand.
- The drive shall let the actuators move at different velocities and directions independently.

1.1.3. Power supply:

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

1.1.3.1. Battery:

- The battery shall be rechargeable and shall not exceed

the dimensions of the robot chassis.
- The battery shall last enough time for the robot to complete its task with one charge.

1.1.3.2. Regulation circuits:
- 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:
- Every electric and electronic circuit shall have a specific connector or adapter that allows it to connect to the power supply.

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

1.2.1. Sensors:
- The robot shall be able to map its surroundings based on sensing information.
- The robot shall be aware of the dimensions of the obstacles it encounters and the distance from them.

1.2.1.1. Vision sensor:
- The robot shall be able to sense the room in three dimensions, that is: width, height and depth.
- 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:
- If needed, the robot shall navigate the room aided with distance and presence sensing.

1.2.2. On-board computer:
- The robot shall have a processing device that is able to

compute the sensed information and make decisions based on it.
- The computer shall have a wireless network interface.

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

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

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

2. Performance requirements

2.1. **Electromechanics:**

2.1.1. Chassis:
-The system shall be light but able to carry an additional payload of 10 kg.
-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:
-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: The robot shall be able to move at a mean linear velocity of 0.5m/s. The robot shall be able to rotate at a maximum angular velocity of 1 rad/s.

2.1.3. Power supply:

2.1.3.1. Battery:
-The battery shall provide 14.8V DC, 3800mAh with over 2 hours for nominal operation.

2.1.3.2. Regulation circuit:
-The regulation circuit shall provide a consistent voltage of 12V and a current of at least 3A to the electronic components.

2.2. **Electronics:**

2.2.1. Sensors:

2.2.1.1. Vision sensor:
-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:
-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:
-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.

2.2.2.1. Operating system:

2.2.3. Embedded controller:
-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%.

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

2.2.4. Communication:
-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. Mass:
-The whole system shall weigh less than 5kg.

3.2. Volume:
-The dimensions of the robot shall not exceed 40x40cm of each side and 30cm in height.

3.3. Power consumption:
-Roughly, the system shall not consume more than 100W.

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

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

Design, implementation and testing plan

The development of the project is mostly linear, since milestones depend on past advancements. There are, however, two small design phases that can be done separately and early, namely the design of the camera mount and the design of the circuit to ensure adequate power is supplied to all components. The chronogram is shown in figure 2.

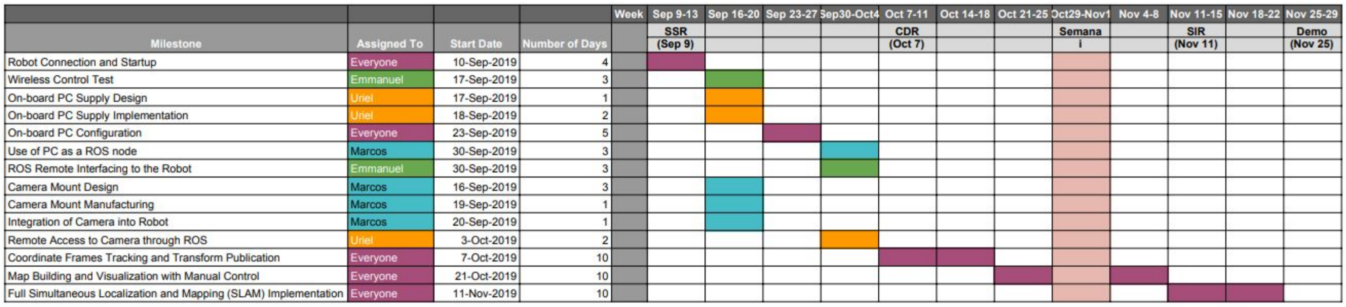

Fig. 2 Project's Gantt chart

The tests to be conducted to verify the completion of certain milestones are the following:

1. Control of the robot through, at least, the built-in application for wireless communication.
2. Correct voltage output and power rating of the battery-sourced power supply. The embedded PC should start and run with this supply.
3. Publication and subscription of the embedded PC to at least one ROS topic in the dedicated network.
4. Status reading and motor/servo motor control from a laptop connected to the same wireless network as the robot, using ROS libraries to send the appropriate commands.
5. Display of the camera information in a remote computer, preferably through a ROS interface.
6. Visualization of a coordinate space in a remote computer where the position and orientation of the robot can be identified, thus showing the correct use of reference frames in the software.
7. Mapping of at least one wall or corner where the visualization shows distinguishable points pertaining to said object with an appropriate scale.
8. The robot being capable to move in some pattern without external input so a bigger percentage of the space is mapped as compared to the test without motion.

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 designed to be performed in the following order:

Unit testing: the process of ensuring individual components of the system are functional and work as they were designed to.

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.

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.

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.

Budget

The estimated budget for this project is depicted in the next table.

Table I. Budget estimation

Element	Cost	Importance
X80 Robot [2]	52762.86 MXN	High
Stereoscopic camera	3600.00 MXN	High
On-board computer	7000.00 MXN	High
3D impression for camera base	200.00 MXN	Medium
14.1V LiPo battery	700.00 MXN	High
Power converter	300.00 MXN	Medium

The total estimated cost of the project is 63,862 MXN.

Internal and external interfaces

Most of the components will interact internally and are mounted on top of the chassis in order to move with the robot. Interfaces that allow access from external devices will mainly be used to monitor the progress of the robot and to send very high-level control signals. Figure 3 is a diagram depicting the interactions among the components.

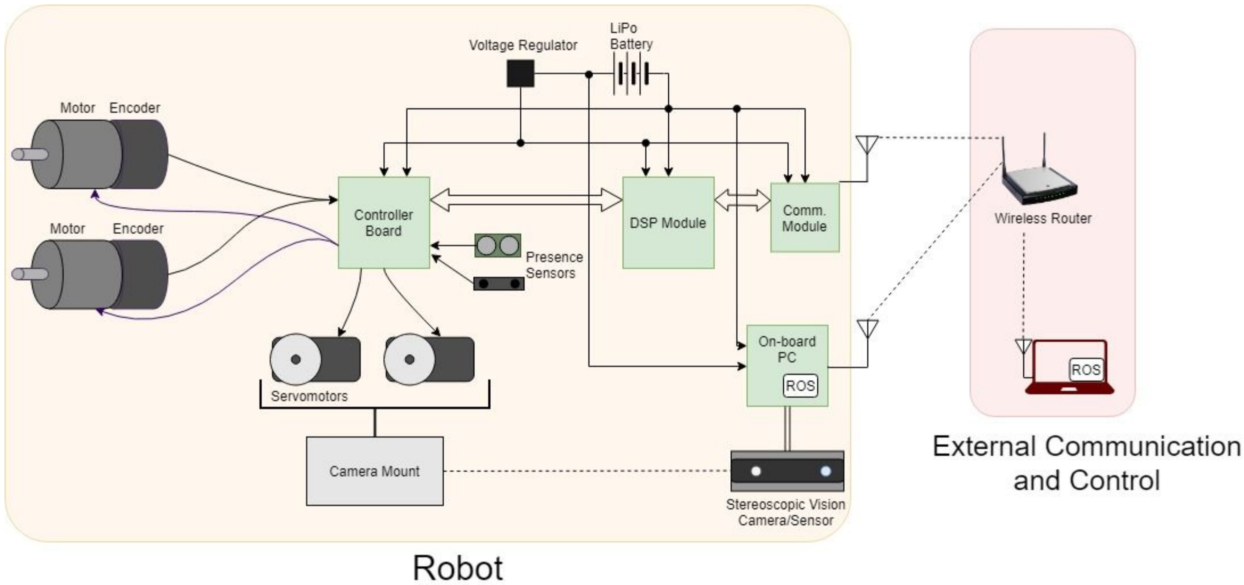

Fig. 3 Component interfaces

The robot will have external communication through a wireless network which will also be accessed by a computer to give general commands and receive any useful generated data. Internally, the robot's subsystems will have wired interfaces. The boards communicate with each other through data buses, so that a command received through the communications module can be processed and turned into actuator outputs. The main controller board can control the motors that move the wheels, the servomotors that position the vision system and receive feedback from the encoders and sensors. The signal from the camera will most probably be processed by an individual embedded computer fed with a suitable power source and the data or command obtained from this signal be transmitted through the network. In this particular case, even though the data flow reaches an external interface and returns through another one, the implemented ROS infrastructure can make it appear as a purely internal movement of information.

Risk assessment

The project has inherent uncertainties that could affect one or more of the established objectives and requirements. With the goal of being conscious of the risks and having the capability to avoid, reduce or mitigate their effects on the project's development, the following risk probability matrix. Each risk is assigned a probability of occurring and a measure of its impact on aspects of the project such as completion time, cost, quality and safety. The obtained risk rating guides the team's response to each risk [3].

Probability						
	Very High	Low Risk (I)	Medium Risk (II)	High Risk (III)	High Risk (III)	High Risk (III)
	High	Low Risk (I)	Medium Risk (II)	Medium Risk (II)	High Risk (III)	High Risk (III)
	Medium	Low Risk (I)	Low Risk (I)	Medium Risk (II)	High Risk (III)	High Risk (III)
	Low	Low Risk (I)	Low Risk (I)	Medium Risk (II)	Medium Risk (II)	High Risk (III)
	Very Low	Low Risk (I)	Low Risk (I)	Low Risk (I)	Low Risk (I)	High Risk (III)
		Negligible	Minor	Moderate	Significant	Severe
		Impact				

Fig. 4 Risk probability matrix

Most identified risks are technical risks, since the financial and organizational aspects are greatly aided by Tecnológico de Monterrey staff and infrastructure. Technical risks can also be important underlying causes of temporal delays. Nonetheless, team management and external factors have also been considered. Table II lists risks associated to the project, their estimated probability and impact and avoidance or mitigation strategies that must be followed if the risk rating is high enough.

Table II. Risk assessment for the project

Risk	Probability	Impact	Risk Rating	Avoidance/mitigation
The robot is dropped while being handled or resting on top of an elevated surface	Low	Significant	II	Keep the robot at floor level when in use and ensure it is off when leaving it on a table
The robot navigates into a hazardous space (e.g. staircase, driveway, water puddle)	Medium	Significant	III	Make the tests in closed, controlled spaces and closely monitor the robot if used outside the lab
Short circuit or incorrect electric/electronic connection	Low	Significant	II	Double check diagrams, polarities and voltages before connecting. In case of damage, inspect the equipment before

				trying to connect the power again. Assess which components are still in good shape
Loss or lack of access to the laboratory access key	Medium	Severe	III	Always keep the team members informed of the location of the key and tell everyone if the key is transferred between members. Unfortunately, due to established policies, copies of the key cannot be made
The robot bumps at a high speed against walls or objects, causing damage	Low	Minor	I	
Overcharged / undercharged battery	Medium	Significant	III	Always observe the charger LED when charging the battery. If the robot has been used for long periods, charge the battery to at least half its charge before suspending activities
Worn components cause malfunction	Very Low	Moderate	I	
The developed code is lost	Low	Significant	II	Keep an updated repository in Github and have the local repositories synchronized as much as possible
The embedded PC locks up or fails due to conflicts in software caused by a team member	Low	Significant	II	Record any software changes/updates and ensure that any installation is actually needed for the project
Unauthorized access to	Very Low	Moderate	I	

the wireless control of the robot				
An external contingency prevents work from being done for some days or weeks (e.g. earthquake)	Low	Minor	I	
The communication protocols/interfaces do not work as originally expected so another means of remote control must be developed	High	Minor	II	Make communication one of the earliest tasks to do for the project
Work teams who have previously worked with the robot have made unfavorable configuration or equipment modifications	Medium	Minor	I	

References

[1] Riisgaard, S. & Rufus, M. (2005). A *Tutorial Approach to Simultaneous Localization and Mapping*. September 3rd 2019, Massachusetts Institute of Technology. Retrieved from: https://dspace.mit.edu/bitstream/handle/1721.1/119149/16-412j-spring-2005/contents/projects/1aslam_blas_repo.pdf

[2] Dr Robot, Inc. (2019). X80: *WiFi Mobile Robot Development Platform with extreme mobility and Video/Audio Capability*. Retrieved from: http://www.drrobot.com/products_item.asp?itemNumber=x80

[3] PMI. (2008). A *guide to the project management body of knowledge* (PMBOK *guide*). Newton Square, Pa: Project Management Institute, p. 292.