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### Introduction

At the École de technologie supérieure (ÉTS) of Montréal, Québec, the Capra team has been working on the development of mobile robotics for the past two years. The ultimate goal of this team is to create a robot that will replace men in life threatening situations. The Capra robot (Figure 1) will display the following features: quadruped, ability to move with agility, possibility to modulate its fluid gait as it moves, autonomous behavior in terms of power supply as well as of its capacity to make decisions on its course of action.



Figure 1: Capra Robot



Figure 2: Building of Motus

This prototype complies with all the

To facilitate its implementation, this project was divided in several modules: mechanics, control of the gait and reflexes, environment perception and road planning. The Motus prototype that will be described in this presentation is dedicated to the development of Capra's autonomy. It is a four-wheel vehicle that is



requirements of the Intelligent Ground Vehicle Competition (IGVC) and it will be the main topic of our presentation (Figure 2).

Through this document, we will first identify the different designed parts of Motus. We will elaborate on his mechanical making, its components and its electrical network. Then, we will explain the new methods and technologies that had to be developed through the different steps of our project implementation as well as the different actions that had to be made to comply with the IGVC requirements. Finally, we will present our system integration methods.

## 1. The Motus Robot

### a. *The Motus Mechanics*

As mentioned earlier, Motus is a four-wheel vehicle that will help us develop the

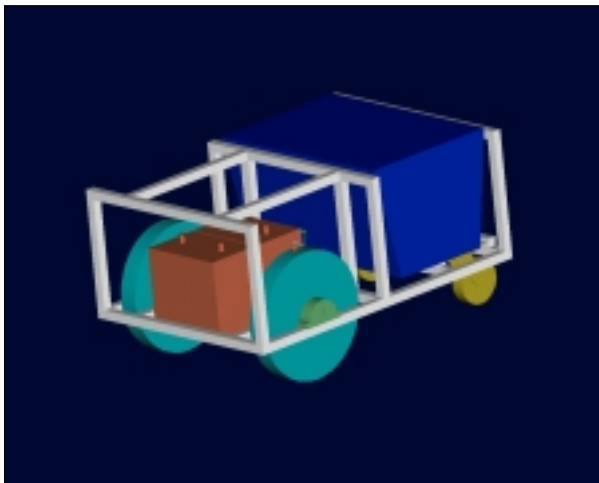
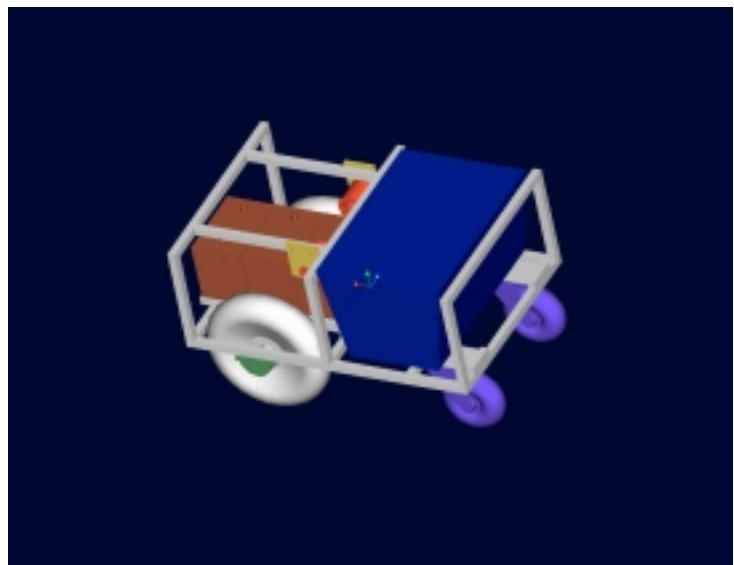


Figure 3 : First CAD Version of Motus

autonomy of Capra. A first mechanical design had been suggested (Figure 3), however we rapidly saw that it presented flaws. As a matter of fact, its driving wheels were far too narrow and would not allow our vehicle to pass another one in a sand bunker. For the specific needs of the competition, we had to proceed with some modifications. Its new mechanical

design (Figure 4) is very simple, yet very sturdy. It is composed of a parallelepipedic steel frame, two front wheels mounted on a 36V DC engine with a 1/10 gear ratio, and two swiveling wheels in the back. As they are installed inside the frame, the wheels are protected. They are also a



lot larger than those used on the original . Figure 4 : Final CAD Version of Motus

Between the two driving wheels, the frame is designed to support three 12-volt batteries,



balanced on the rotation center of the propulsion assembly in order to facilitate the respect of defined trajectories. In fact, the batteries are the heaviest element in the total mass of the robot.

Moreover, the protection against water and any external projection is guaranteed by a box of sturdy plastic as well as a fiberglass frame. Also, with security in mind and to comply with the requirements of this competition, Motus is equipped with an emergency stop button that controls both the mechanical and dynamic breaks. The breaking will systematically shut the engines down, which will stop the wheels.

### ***b. The Motus Electrical Data***

The global power supply of this robot comes from 12-volt batteries. One of them is plugged to an inverter which allows to get 120 V AC to supply the different computer systems. The drives connected to the engines are supplied by two batteries plugged in-line. The autonomy offered by these batteries allows us to work with the robot for several hours without interruption. Our choice was dictated by two important factors: first, as our development was oriented towards the trajectory to follow, we did not want to experience power supply difficulties and, second, the weight of the batteries permits to place the robot's inertia center very low between the driving wheels. Turning the drawbacks of our batteries into useful qualities, we did not hesitate to use as many of them as possible.

The engine performances are controlled by power regulating drives that are supplied with 36 V DC. These drives allow us to limit the speed of our robot as a limit is imposed on the power

received by each engine. All this pertinent data as well as the description of the computer hardware will allow us to establish a global electrical network of our robot (Figure 5).

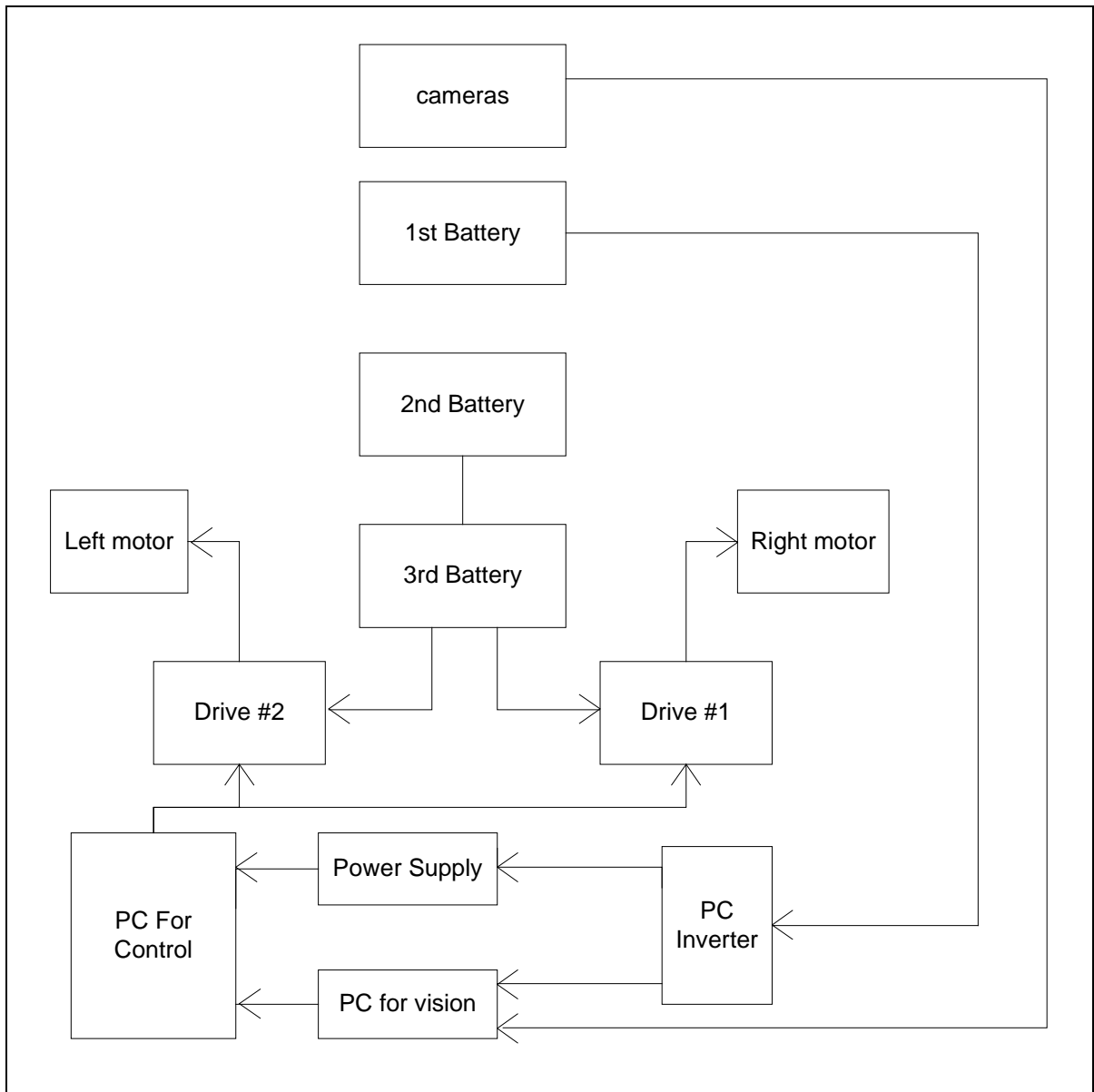


Figure 5 : electrical network

### ***c. The Computer Hardware***



In order to identify its environment, analyze the images taken, process the gathered data and apply the information to a selection solution, we have chosen to use high-tech hardware.

Chart 1: Technical specs of used material

Material	Use	Cost (Can \$)
Single Board Computer Teknor Viper 809 486, 66MHz	Control	1000
I/O board Sensoray 425	PC	125
Power Supply	PC alimentation	50
Motor Electro-Craft Corporation Mode 642/R8023	Actuators	1000
2 Encoders	Actuators	400
2 Drives	Motor Regulation	716
3 Batteries 12V	Alimentation	320
2 cameras	Vision	2200
PC 4sight II	Vision	4700
Inverter 800 W	Inverter	150
Total in CAN \$		10661
Total in US \$		6862,80

## 2. Systems Developed to Comply with the Competition's Requirements

In order to comply with the different requirements of the competition, we have developed our approach of robot autonomy in function of only one mean of detection: visual sensors. As a matter of fact, the challenge that we are hoping to achieve starts with the concept that humans work with only one distance sensor: its vision. So, we would like to produce a robot featuring the same type of reactions as a human. The autonomy is divided in three parts: the robotic vision, the definition of a trajectory, and the respect of this trajectory.



### ***a. The Robot's Vision***

As the course is extremely complex to analyze, we tried to identify all the possible factors to take into consideration such as yellow or white lines, solid or broken lines, barrels, etc. With this in mind, we defined a series of vision algorithms based on all the necessary basic actions such as grabbing of data, pre-processing, image processing, identification of obstacles, and finally environment reconstitution.

The camera that are used are oriented in order to create a wide angle vision. This allows to create two half images that will be joined to create a global corrected image. The robot's vision will cover some 6 meters, which should be sufficient to plan the trajectory to be followed within this segment.

The vision system is designed in order to supply the trajectory planning system with simple and clear information. It can transform the raw data sent by the camera into a synthetic image that will only identify the obstacles and the course restrictions such as lines. All obstacles, whether they are traps, potholes or dead ends will be considered as obstacles to be avoided and will be integrated in a list of all existing obstacles.

Also, it is very important to take into consideration the quantity of data processing made by the vision system. The use of the vision algorithms considerably slows down the robot

processing. Even after optimizing all the algorithms, they remain the main factor influencing the speed of data processing.

The different steps of the vision system are presented in the images of figure 6.

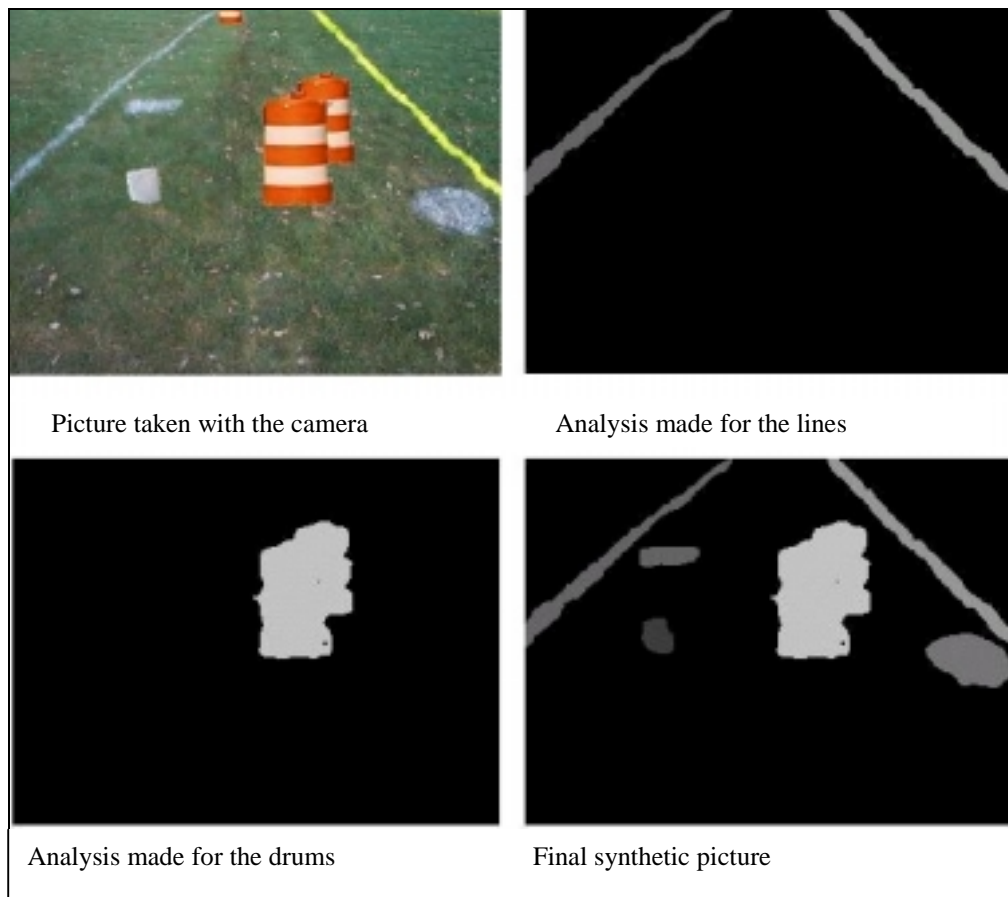


Figure 6: The Different Steps of Vision Processing

### ***b. The motion Planning***

To define the itinerary to be followed, we process the synthetic images supplied by the vision system. First of all, a calibration of the vision system is made in order to define the existing relationship between the distances shown by the image and the real distances identified



on the y-axis of the image. This calibration is made in accordance with the rules of linear perspective. This distance will be used to measure the free zones between two obstacles allowing in the same time to select a trajectory. This image will be analyzed by n horizontal layers corresponding to the course scanning distance in relation with the camera.

For each of these layers, we take in consideration every possible cases suggested by the vision system (barrels, broken lines, full lines, etc.) while attempting to remain in the center of the path. After processing the image, we identify a trajectory divided in n points starting from the robot and going towards the limits of the camera's vision range. This trajectory is sent by parallel port to the controlling computer, which will then be able to modulate the direction of the robot accordingly with the different points to be followed. Figure 7 gives a brief explanation of these processing methods.

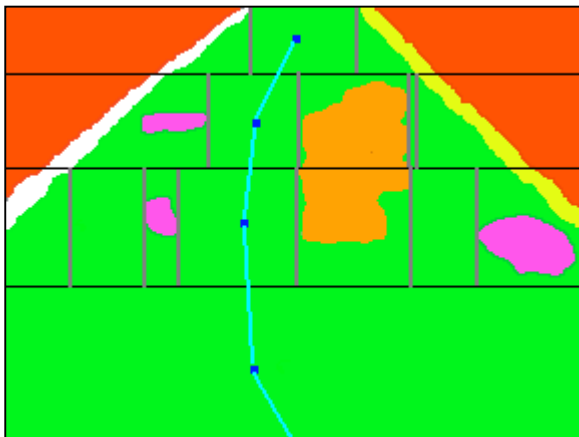


Figure 7: Definition of Trajectory to be Followed

### ***c. Respecting the Trajectory***

Once the trajectory is defined, it is crucial to have an excellent system that will allow the robot to respect this proposed itinerary. On order to do so, we use two servo-controlled engines.

To control these engines, a series of calculation is made to adapt the robot's specific data (speed, angle, position) to those received from the trajectory planning system. The processing sequence is presented in figure 8.

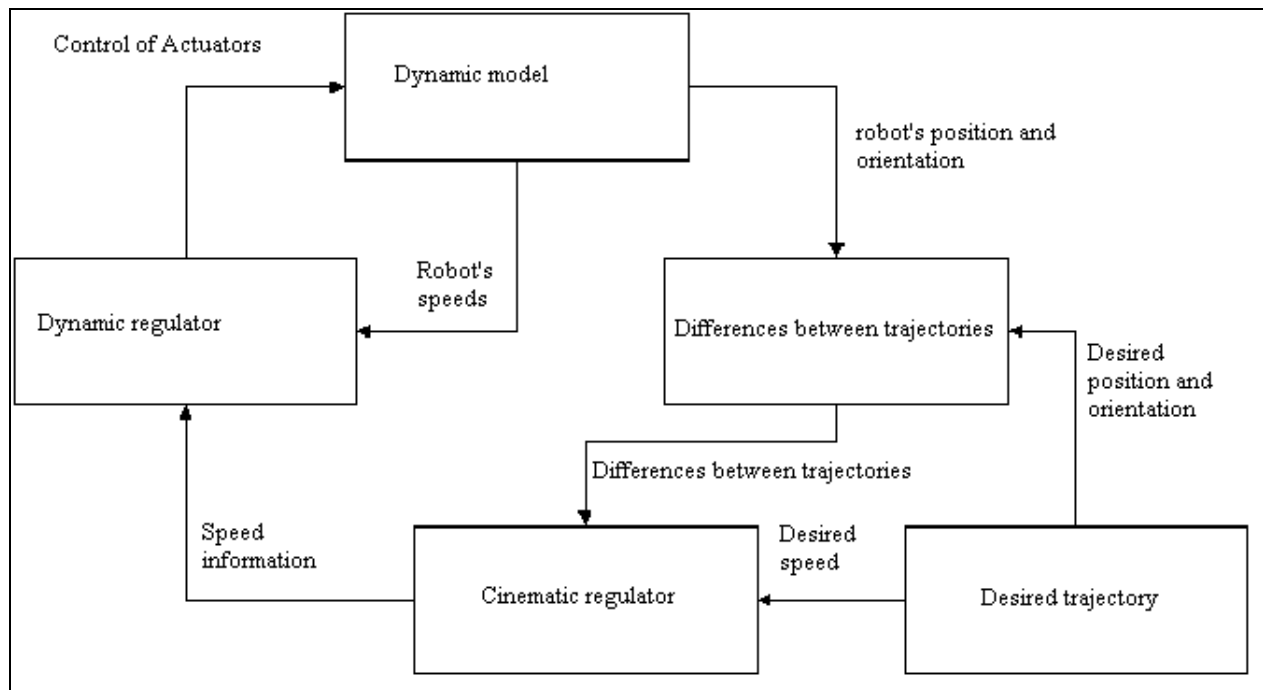


Figure 8 : The model developed for the control of Motus

This figure explains briefly how the different data are processed to get a direct control on the engines. The trajectory planning module identifies the goals, the dynamic model contains the real data concerning the robot, and the different loops compare all the data in order to calculate how to control the engines.

The system in charge of respecting the trajectory in Motus is quite extensive as it calculates separately the lateral and longitudinal discrepancies of the robot's dynamics, before reintegrating them together in the information sent to the engine.



#### ***d. Follow the Leader: a Specific Case of Image Processing***

The competition, “Follow the leader”, requires a different image processing. Instead of analyzing the global image, we are looking for the orange rectangle and, following a second processing of this image, we have to identify the white squares that are within the rectangle. The height separating the center markers of each white squares allows to identify, after calibration, the distance separating the robot and its leader, while the horizontal change of position of those markers permits to find the desired angle of our robot’s movement.

### **3. The Project Implementation**

#### ***a. The Main Phases of Motus Development***

The development of Motus actually started in December 2000. Prior to that date, the mounting of our robot was not ready yet. In order to start giving shape to all the components, we had to define their specific tasks and actions. Also, we established some deadlines and the list of tests to be ran. This allowed us to concentrate our team efforts towards precise goals in specific timeframes and, in the same time, to implement the project step by step.

The module in charge of respecting a trajectory was completed for our first presentation at the end of March 2001. The structure of our vehicle was modified and finalized in April. The vision system tests started indoor in the month of March and, later on, were continued outdoor in the month of May.



**b. The team**

Our team is divided in several groups targeting their efforts on specific robotic functions: vision, trajectory definition, respect of the trajectory, mechanics, electrical supply, and organization. Here is a organization chart of the team indicating the competence of every team member. (Figure 9).

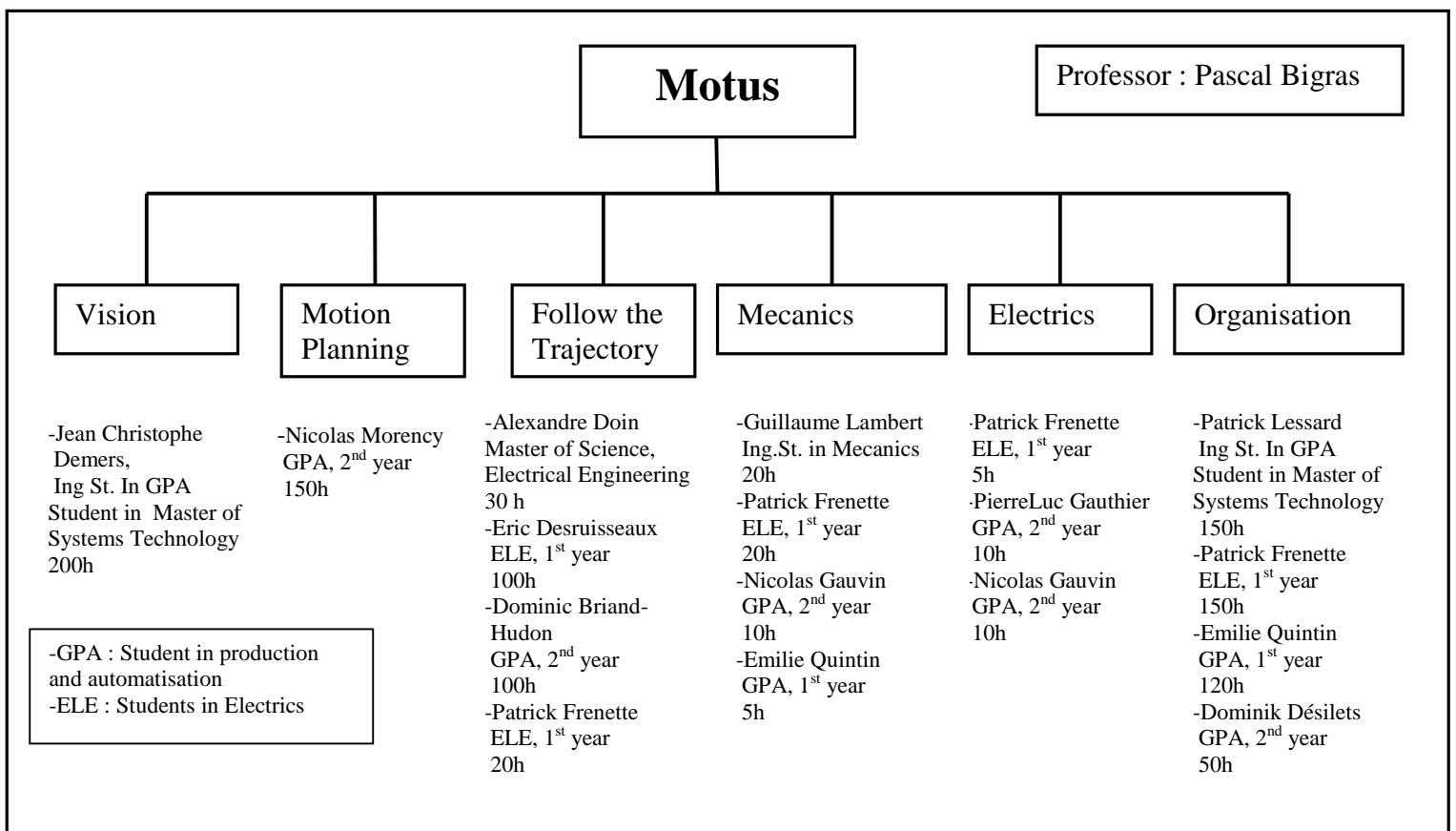


Figure 9 : Organisation chart of the team



### ***c. Systems Integration***

For the development of the different components involved in the autonomous movement of our robot, the tasks of each team member were clearly established. Before integrating all the modules together, we made sure to optimize each actions and to debug them carefully. Later on, the integration of all modules was a lot easier to do, the required modifications were only little adjustments and a few unpredictable factors. As the robot is composed of two computers, the communication between them is made through a standard parallel port.



### Conclusion

In the past six months, we built a sturdy and stable robot that allowed us to implement a top quality vision system. During this period, our team had to manage its time efficiently by adopting a group dynamic based on the respect of a precise schedule. Besides some important technical achievements, which brought us great pride, we have the privilege to develop strong bounds and to experience great teamwork.

In the beginning, Motus was simply built to test the different environment recognition techniques of Capra. Still, we are now proud to present it in the IGVC. We are convinced that it features all the required competencies to take part in such a competition, and we truly hope to win! Such a victory would be a tremendous springboard towards success for Capra, the walking robot, which is the ultimate goal of our research.