Design Report 2005
Intelligent Ground Vehicle Competition

Presented by Capra
Dynamic and Autonomous Robotic Club
École de technologie supérieure
Montréal, Canada

I certify that the engineering design in the vehicle (original or changes) by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

_____
Tony Wong B.Ing., M.Ing. (ÉTS), Ph.D.
Director of Automated Production Engineering Department
École de technologie supérieure

Université du Québec
École de technologie supérieure

1.   Introduction

Have you ever thought about a robot capable of thinking? Like a lot of people on this planet, the Capra student club from the École de technologie supérieure started to dream about it a few years ago. *Mentis*, from the Latin word "consciousness", was born in the minds of a group of students and was soon realized. Time has passed since the first version of Mentis came to life and now, Mentis II is offering a solid base upon which to develop and test the results of the mobile autonomous research done by the Capra's team; the promotion of autonomous ground vehicles being the main objective.

Mentis II is being presented at the 2005 IGVC for the last time since a completely new robot is planned for the year 2006. The main changes from last year up to now include the addition of the CANBus for various sensory devices on the robot, a better integration of those sensors on the multimodal map, the use of Matrox Imaging Library (MIL) for the line detection as well as the enhancement of the multimodal map by implementing an object cleaner, a timestamp generator and a log book. This report presents the characteristics of Mentis II by focusing on these improvements.

2.   Organization

The student club Capra integrates many disciplines for its benefit and for the benefit of its members. Although the main design challenge is software, Mentis II also requires a crew capable of handling electrical and mechanical design. Obviously, a strong administration team is present to coordinate the developments. All the members of Capra are students voluntarily giving their time to the project. Since the project is not related to any course in the university program, a good organization is mandatory to achieving a certain level of performance. The team evolves continuously as members arrive and leave throughout the year, making the integration of new members even more difficult. The team also excelled at human resources management by organizing weekly meetings for all sections in addition to a general meeting each month.

Capra is the only student club at the ÉTS developing an autonomous ground vehicle. In that respect, the club represents the university at many events, the IGVC being the culminating point of all the research carried out throughout the entire year. Here is a list of all the members currently learning through and participating in the development of Mentis II.
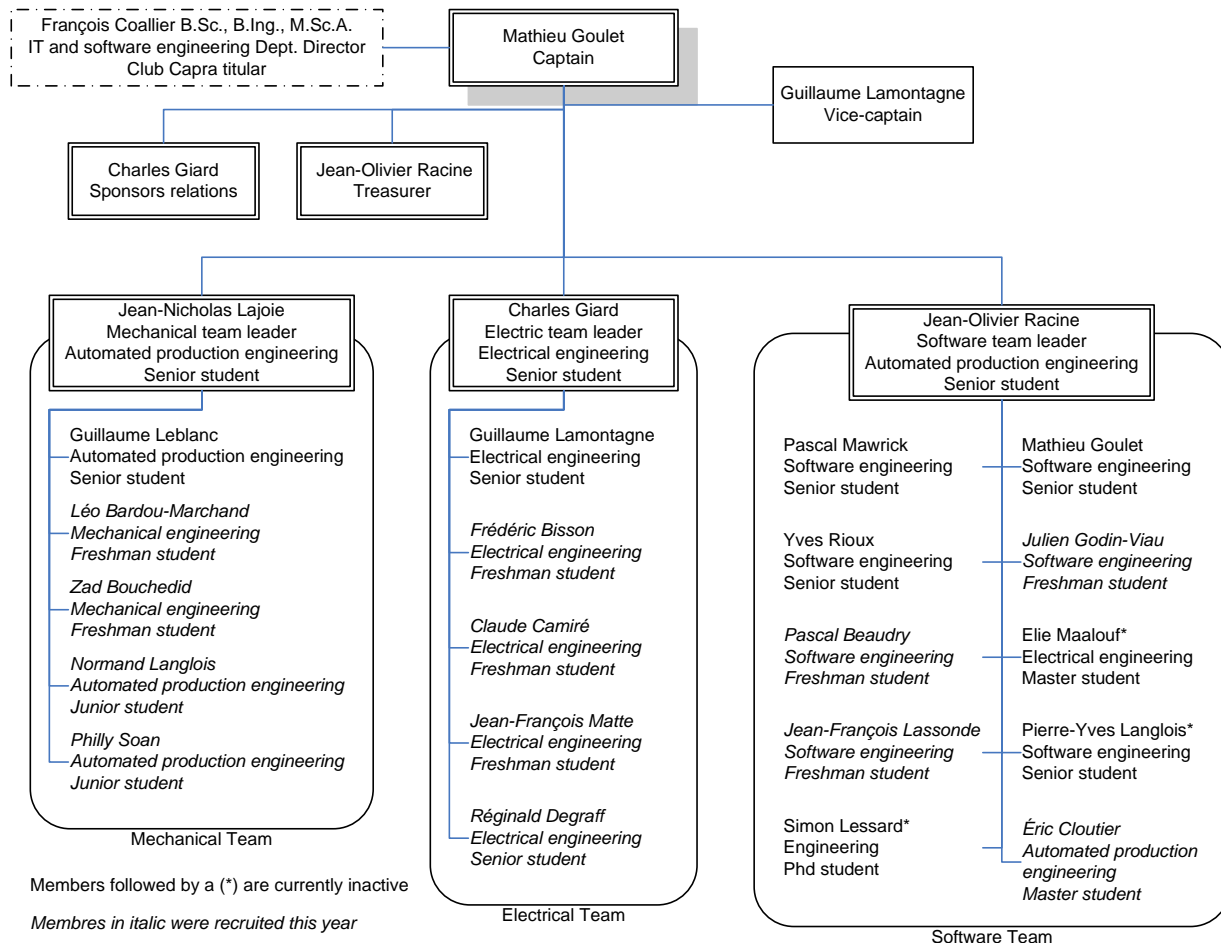

Figure 2-1 - Team organization

3.   Design Process

The design process of Capra is simple and relies on the usual scientific approach of engineering. Since the members are all engineering students, acquiring a strong design process adds good value to their course. The student club conducts most of its work through meetings and written discussions on an online forum. Questioning newly discovered problems, new ideas and reviewing designs is common. Also, good basic documentation is maintained by adhering to the club's documented objectives, project requirements and the actual user manual for the robot.

The first step of the design process is to identify the need. This need may consist of the rework of an existing module, or the development of a new functionality. Once the need is identified, a quick study of the feasibility and the resources cost is made in order to help establish priorities. It is also important to study the actual schedule to decide whether or not to start the new project.

A new iteration commences once a project is well defined and if the schedule allows it. The use of UML modelling for the software team or schematics for the electrical and the mechanical teams is strongly encouraged, as it offers a powerful tool to help understand and review the designed architecture. The development can start once a detailed design is completed. Aware of its constantly changing member base, Capra has made the modifiability of Mentis a priority, allowing for the quick and easy integration of new modules.

Before and after a project is integrated into the overall system, extensive unit and system testing are performed in order to evaluate its functionality and to detect failures of any malfunctioning parts. The already existing components are also tested to detect possible integration errors. This year, Capra completely retested Mentis almost every two months.

4.   Design Innovations

Although Mentis II has been operational for a significant period of time, Capra spent the whole year enhancing its performance and functionalities. Mechanically, the front has been modified to

reduce the time required for changing batteries and accessing the engines. A new range finder support has been designed to allow vertical tweaking. The back wheels were exchanged to improve performance on grass. Capra also decided to completely integrate the CANBus technology to enhance communication between Mentis' devices by making it more efficient and reliable. From now onwards, CANBus will replace parallel and serial communication between computers and input devices.

From the software point of view, Capra is really proud of Archie, a powerful library consisting of a modular design which is easy to use, quick to understand and specialized in robotics. Archie can be used within different contexts and on independent platforms. Moreover, Capra is about to share Archie with other student clubs that are getting involved in autonomous robotics, and will be used by future generations of Mentis. Finally, Capra acquired a new embedded Matrox 4 Sight II system. This computer is specialized in video acquisition and real time rendering. The 4 Sight is optimized to work with MIL.

5. Functionalities

Since Capra is an unmanned robotic club, its main objective is the continuous development of systems capable of achieving an autonomous navigation. Thus, as a guideline, this robot was designed for three specific functionalities: IGVC's Autonomous Challenge, its Navigation Challenge and also the development of public relationships for the university.

5.1 Autonomous Challenge

The autonomous challenge consists of following lanes and avoiding obstacles. For this purpose, the required input devices are the camera, the range finder and the encoders. While the range finder scans the area for obstacles, the camera scans the land to detect lines and the encoder reports the distance covered by the wheels. A software module processes the input data provided by the camera in order to detect lines and subsequently reports it on the virtual map. Because other patterns can interfere with the line detection algorithms, the vision modules also detect

speed bumps and sand traps to support navigation and line reports. On the other side, the range finder module reports barrels and other physical obstacles on the virtual map. Since some fences are beyond the range finder's capacity, the vision system also helps to detect them by reading different shape and color patterns. The encoder module reports the progress made by the robot on the virtual map. With all this data, the navigation system is equipped with an expert system to establish a trajectory, as explained in the software section of this design report.

Expert	Task
Line Expert	Forbid line crossing and follow lines
Barrel Expert	Forbid physical obstacles crossing
Orientation Expert	Enforce going straight forward
Sooth Turn Expert	Enforce smooth turns, avoid rough movements

Table 5-1 - Experts used for the Autonomous Challenge

5.2 Navigation Challenge

For the Navigation Challenge, the robot has to reach several navigation points on the map while avoiding obstacles. The working base system for Mentis II is a bit different. In this challenge, the range finder, the GPS and the encoders are important input devices. While the range finder detects physical obstacles such as barrels or pot holes, the encoders report the progression of the wheels and the GPS tries to detect any trajectory errors made by Mentis II. The vision system attempts to detect physical obstacles such as high fences by recognizing recorded patterns. All of the detected data is shown on the virtual map, and the navigation expert system constructs a trajectory according to the implemented rules.

Expert	Task
Navigation Expert	Enforce reaching waypoints coordinates
Barrel Expert	Forbid physical obstacles crossing
Sooth Turn Expert	Enforce smooth turns, avoid rough movements
Boundary Expert	Forbid going out of bounds

Table 5-2 - Experts used for the Navigation Challenge

5.3 Public relationship

This year, a special effort has been put on public relationships as the sharing of knowledge is very important in Capra. Throughout the year, Mentis II participated in several events to promote the club as well as autonomous robotics in general. To arouse interest for robotics within children, it is safe for them to individually take short rides on Mentis II while the remote control is used to determine its movement. This remote control is also very useful for presentations and transportation as it is safe and efficient.

6. Non-functional requirements

6.1 Safety

Safety is a critical issue for any autonomous vehicle like Mentis II, especially since it is presented relatively close to people. For this purpose, the remote control stop (E-Stop) is a critical part of the robot that is implemented as a hardware shut down of the engines. Mentis II is equipped with powerful motors to propel it on a variety of surfaces. However, the maximum power is limited by the controller determining the maximum speed it can reach.

6.2 Reliability

Extensive testing was conducted on Mentis II for it to be more reliable. Some components have been added to the motor drives as to protect them from high power surges. The software architecture is a very reliable base upon which it is possible to implement new algorithms without any worries of breakdown.

6.3 Durability

The materials used to build the mechanical structure of Mentis II are very solid materials such as aluminium and carbon fiber. The cab and the structure underneath are strong enough to support an individual's weight without incurring any damage. The wires used to interconnect the different devices within Mentis II are mostly clipped or soldered to prevent disconnection despite the robot's rapid movement.

6.4 Other requirements

In addition to the previous requirements, the club has to consider unstable human resources with very different specialities and knowledge bases. Thus, modifiability, usability and testability are three important aspects to consider throughout the entire project.

7. Mechanical Design

Physically, Mentis II is almost an exact replica of the robot used for last year's competition. In order to improve its mechanical capacities and steadiness, certain components were replaced and adjusted. Mentis II is powered by two 12 volts electric wheel chair engines connected to their original gearbox. During the past year, Capra

Characteristics	Value
Length	120 cm
Width	64 cm
Maximum height	91 cm
Weight	115 kg
Maximum inclination	21°
Maximum speed	12.8 km/h (3.58 m/s)
Positioning precision	± 6.5 cm
Maximum capacity	200 kg

Tableau 7-1 - Mentis II Technical Sheet

experienced some difficulties with the prototype when it was following a straight line trajectory. To correct the problem, the original retention spring was replaced by a softer one more adapted to the robot's needs. Also, to ensure the functionality of the positioning system, the two drive wheels' optical encoders were exchanged for more efficient ones. These new devices allowed the rotation speed of our motors to go up to 1500 RPM as opposed to 300 RPM. An aluminium structure was installed on the platform to hold the cab in place and to assure the precise position and stability of the camera stand. The use of an aluminium chassis allows for easier manipulation of the fibreglass shell and simplifies the batteries maintenance operations. The frame was created and assembled by members of the team using a TIG welding machine. Fixed to the aluminum structure, the new camera stand is stable and minimizes vibrations produced upon movement of the robot on the ground. To the stability of the camera stand, a simple installation system and a specially designed head were added to allow adjustment of the camera position with four degrees of freedom. On the robot's front, the range finder was positioned on a rigid steel support

designed exclusively for a single position. The mechanical team is currently working on replacing it with a multiple axis adjustable stand especially made for this range finder model. This change will allow for the adjustment of this essential equipment to its best possible position.

8. Electrical Design

8.1 Power Supply

The propulsion's power supply comes from two serial batteries with a nominal voltage of 13 volts and can sustain the required 12 volts while supplying up to 36 amperes. This power is processed via a motor drive based on a high speed, low ON resistance MOSFET bridge. With four bridges placed in parallel, power consumption is considerably reduced. The MOSFET control system uses a PIC microcontroller which supplies two precise PWM signals to drive the bridge via a MOSFET driver. This control method makes Mentis II very power efficient. In fact, most of the power is directly sent to the motors. Only a negligible part is absorbed by the MOSFET at switching.

The electronic system power supply can come from two different sources: two serial batteries or directly from a power outlet (120V AC). Two power supplies, one DC/DC and one AC/DC, is then selected at will, dependent upon the active source and the current needs. This system provides the ability to reduce battery usage when tests are performed on the electronic systems.

8.2 Control System

The control system is on a 486 DX2-66 DOS platform, which offers real time processing at very low cost. The analog to digital and digital to analog conversion are done through a Sensoray IO card on the ISA bus. Encoders, PWM control, motor speed, joystick inputs and drive current feedback are all interfaces through this card. Laptop components are used to improve power efficiency and resistance to shocks.

The intelligence system, the Matrox 4Sight, is an embedded computer with specialized hardware that accelerates all computer vision tasks and offers high performance. Combined with the

Matrox Imaging Library (MIL), this Pentium Celeron 850MHz with 256 Mbytes of RAM and a Meteor II Digital frame grabber is an excellent platform for our vision and artificial intelligence needs.

8.3 Communication

The actual communication system is a mix of CANBus and standard serial communication (RS232). Currently, only the compass and GPS are connected on the CANBus. A protocol was designed to allow proper communication between the AI computer and the different modules. This improvement offers provides the robot with a scalable, modular device architecture.
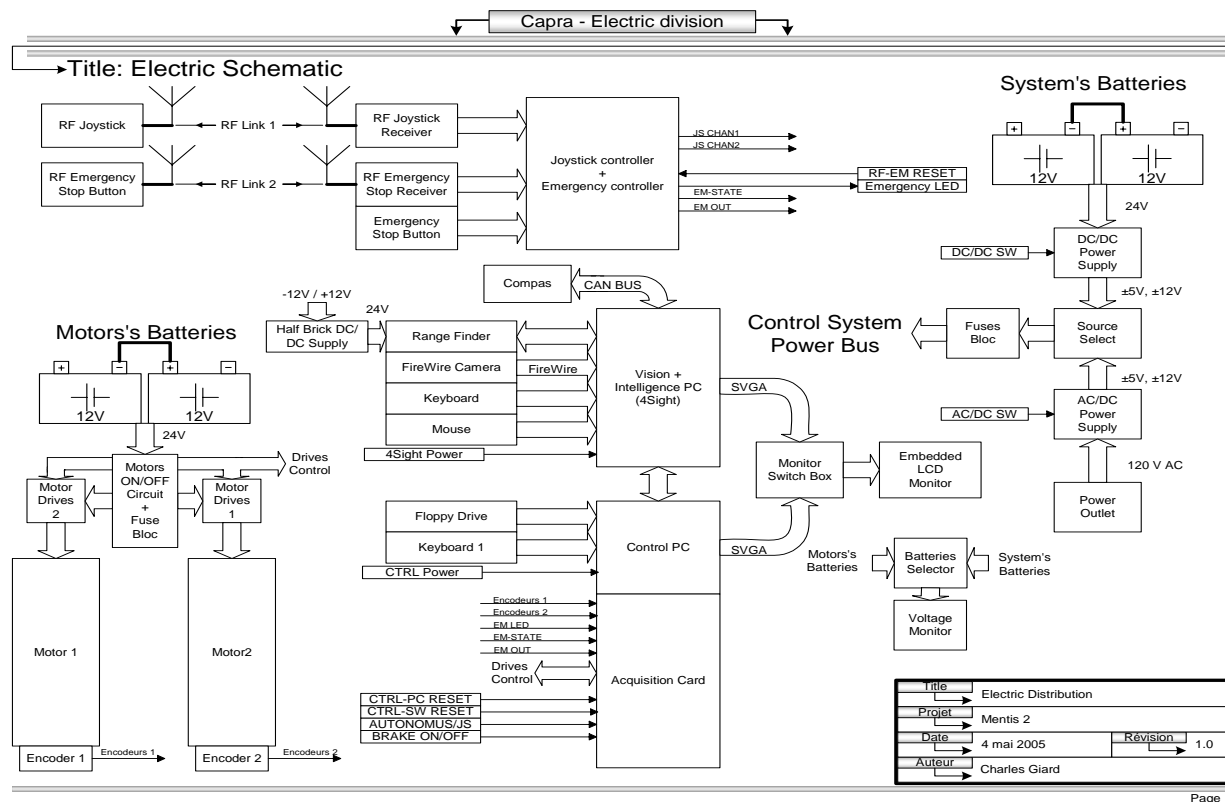

Figure 8-1 Mentis II Electrical Schema

9.   Software Design

The software section of Mentis II was designed with platform independence in mind. Of course, certain aspects such as the controller cannot be disassociated from the drives or the motors, but by building a flexible layered design, most of the developed software can be integrated into other robots. The software design of Mentis II is divided into three logical parts, as explained below.

9.1   Archie

Archie is a software environment based on the implicit invocation architecture. Archie has the responsibility to spawn, activate and connect independent modules. A XML file indicates which module to spawn and activate, and allows data exchange between those modules. A text user interface allows dynamic module activation as well. Archie also uses encapsulated data to enforce coherence between modules in an ever-changing context.

A module is essentially a class or a set of classes that fulfill a limited set of requirements. This high level of cohesion helps developers to understand the high level performance of the software, which provides an excellent solution to a student club realm with rapidly changing human resources. Each module implements an interface to ensure that they work in the current environment. They consist of an activation control, a mechanism to read encapsulated data and process it, in addition to an output method to send new encapsulated data to other connected modules. Archie transmits encapsulated data between the corresponding modules.

This year, a logging feature has been added to Archie to help retrace and identify issues in the software by indicating how the modules are reacting and communicating with their environment. This feature is also used by the system to identify a malfunction and to react in a convenient manner by avoiding errors, breakdowns or accidents.

As you can see, Archie does not implement functional requirements, but satisfies non-functional requirements through its solidly implemented architecture.

9.2 Caasi

Caasi is the software implementing the functionalities of the prototype. It contains modules for sensor management as well as the vision, navigation and cognitive mapping. It also provides a graphic user interface along with a testing environment. In fact, Caasi is only a set of modules developed especially for Mentis II functionalities with Archie in the backstage making it work. Caasi is also the part of the software with the most changes from last year.

Sensor management is a very important task for Caasi. Mentis II's sensors are composed of a front camera, a range finder, a GPS, a compass and the encoders. All these physical devices are sending data to the software in order to make the navigation system adjust to its environment. For each device, a module links the external communication data with the inner message bus. Some devices such as the camera and the range finder have their own set of devices to extract the significant object from raw data, as explained later on in this section.

A brand new vision system was implemented this year. This vision uses the Matrox Image Library which offers a wide variety of functionalities specialised in vision recognition systems, camera recording and live image treatment. This year, the artificial vision has been improved based on previous experience. Some team members worked for Matrox and were able to create a partnership with the company in order to use MIL for our image treatment. The following diagram explains the line detection process.
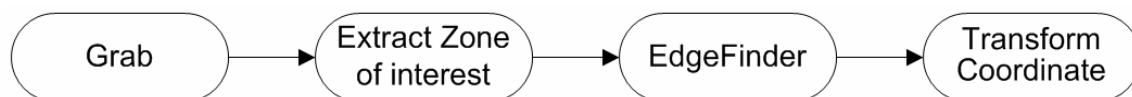

Figure 9-1 - Vision Detection Process

In addition to MIL, the team added some algorithms to improve resistance to environmental changes such as brightness.

A navigation system was also implemented in Caasi. Its responsibility is to create a path vector based on information kept in the virtual map, according to the rules implemented in the expert system. First of all, a trajectory holder module keeps and monitors the trajectory length and determines the good moment to add a new point in the vector. Then, the expert manager constructs a set of potential points on a blackboard and sends it to the experts. Each expert uses its rules with the knowledge found on the virtual map to vote on each candidate point. At this point, an expert can vote against a candidate or vote in a scaled preference. Once every expert has voted on the candidates, the expert manager compiles the vote, eliminates points that were voted against and sums up the preferences on the other points. The winning candidate is then added to the trajectory vector. The navigation system has been implemented with a full set of configurations in the main XML file. Each expert and the trajectory holder can be adjusted with a lot of details.

Another development of this year is a brand new virtual map which was implemented during a major iteration of Caasi. This version divides the map into small zones. When a module needs a list of object in a particular area, the virtual map only works with the relevant zones in order to boost its efficiency. However, the insertion of new data is more complex because the map has to run an algorithm to determine which zones may contains detected objects. This solution was implemented because some performance issues were noted last year when the map contained too many data. To improve performance, a map cleaner was also added this year. This module continuously scans the map to detect redundant or bad data. To accomplish its task, the module tries to regroup objects with similar coordinates and sizes and removes duplicate objects. Because the line and barrel detection modules are constantly adding data even when it is

Figure 9-2 - Caasi's GUI

detecting the same objects over and over, adding a cleaner module became a priority.
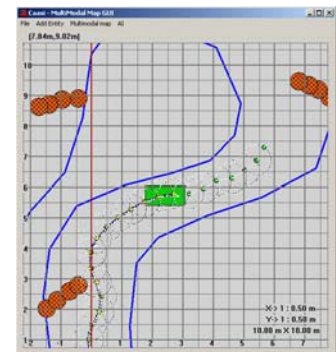
Caasi also adds a graphic user interface, which greatly helps to understand the functioning of the sensors and navigation system. From this interface, the developers can directly add objects into Mentis' virtual map, otherwise interact with the navigation system or just monitor the robot's thought process. In addition to the interface, Caasi possesses a complete testing environment to help develop and understand the navigation system and the robot's adherence to the desired trajectory. The testing environment replicates the controller and imitates the reaction to the trajectory usually sent by the navigation system.

9.3   The Controller

The controller is contained within the lower embedded system level of Mentis II and controls the robot's movements. It directly sends commands to the drives and receives raw data from the acquisition card of the encoders on the wheel motors. The Controller is running on a DOS environment and functions in two modes. The "joystick" mode takes data received from the antennae and interprets it for movement. The "autonomous" mode receives the vector sent by Caasi, smoothes it and transforms it in commands for the robot. It is the lowest level of implementation for the robot.

10.   Predicted performance and testing

Metric	Performance
Speed	8 km/h
Ramp climbing ability	21 degrees
Reaction time	500 ms to 2 s.
Battery life	3 to 5 hours
Distance at which obstacles are detected	10 m to 3 m
Dead ends, traps, potholes	Detection of potholes and traps with Caasi. Will take alternative paths if encountering a dead end.
Accuracy of arrival at navigation waypoints	30 cm

Table 10-1 – Performances for Mentis II

11. Vehicle Costs

Items	Value	Paid cost
Frame	660,00 $	510,00 $
Electrical components	950,00 $	300,00 $
Communication devices	985,00 $	506,00 $
Motors, drives, encoders and wheels	415,00 $	415,00 $
Control embedded PC and IO card	550,00 $	- $
Matrox 4Sight	5.000,00 $	- $
SICK range finder	6.000,00 $	5.000,00 $
Camera Point Grey Research	150,00 $	- $
GPS CMC Electronic	400,00 $	- $
MIL	5.000,00 $	- $
Total:	20.110,00 $	6.731,00 $

Table 11-1 - Overall vehicle costs

12. Conclusion

In conclusion, Mentis II is Capra's project to assist students developing autonomous robotics. Although this prototype has been active for several years, the team is about to launch the development of a new robot for IGVC 2006. The design will be quite different, based on our experience with our current robot. More time will be dedicated to the design process, as it is the most crucial part to success. The functionalities of the next generation are intended to be the same as the current one, while its level of efficiency will hopefully rise dramatically.