MARIUS: A Sailbot for Sea-Sailing

Cédric Anthierens, Elodie Pauly, and François Jeay

Abstract. This paper deals with the design process of a specific sailing robot designed for sea sailing. So we will present the aims and the context of the project and thus the specifications that guided the sailboat design. Next, a part will be devoted to the methods and tools chosen to define and create such a complex mechatronic system. The third part will describe the role and the influence of the embedded intelligence to safely carry out a given mission. Finally we will conclude this paper with up-coming works.

1 Goals and Specifications

Nowadays many investigations are led on AUV to explore underwater environment but the surface of the oceans as well [1]. All these systems have to adapt to an unknown and varying environment to usually carry out some long missions. The energy management is a key issue for mobile robots such as AUV, this is the reason why there is a great interest in exploiting green and free energy to increase the AUV autonomy. Gliders are based on very

Cedric Anthierens
SUPMECA TOULON LSIS UMR 7296, Maison des Technologies,
Place Georges Pompidou, 83000 Toulon, France
e-mail: cedric.anthierens@supmeca.fr

Elodie Pauly
ISEN, Maison des Technologies, Place Georges Pompidou, 83000 Toulon, France
e-mail: elodie.pauly@isen.fr

François Jeay
SUPMECA TOULON, Maison des Technologies, Place Georges Pompidou,
83000 Toulon, France
e-mail: francois.jeay@laposte.net

F. Le Bars and L. Jaulin (eds.), *Robotic Sailing 2013*,
DOI: 10.1007/978-3-319-02276-5_1,

known marine principles since they intelligently use electric energy from a battery and the ballast principle to carry out long range missions. Such a way to move in water involves dealing with water streams, this makes the system's states very dependent on the environmental parameters. This is the case also for sailing robots that rely only on the wind to move and reach a desired location. Numerous sailing robots work as autonomous surface vehicles to demonstrate the capabilities of an autnomous system to move within an unknown and harsh environment, to make do with and manage its own energy production and also to move within a varying environmment by relying only on a natural energy source, i.e. the wind. All these challenges are very ambitious but also very exciting.

The interest of such drones is to sail unlimitedly by remaining the most environment friendly as possible. So some natural phenomena related to marine wildlife can be monitored provided there is no disturbance generated by the instruments carrier. In this context, the authors decided to create a new sailboat that performs such kind of long missions. To do so and go further than the other sailboats did, the design of the robot was guided to make it robust and resistant against harsh environments in order to keep on properly working in any conditions. For safety reasons, a sailboat cannot be as big as classical sailboats to reduce the risk of dammage to others in case of troubles. Indeed we cannot claim that an embedded controller is always as safe as a skipper for sailing in any cases. Therefore it was decided to design a sailboat shorter than 2 meters and lighter than 100 kg as total weight. In addition, such a size is enough to embed several instruments for oceanographic inspection.

In order to control the sailboat, two modes are required, i.e. manual and automatic modes. This means the manual mode allows a user from a follower boat to remotely pilot the sailbot through to a GUI that runs on a laptop. This mode is necessary to edit the route, to have a look at the logged and current data of the sailbot and to possibly keep hand on the actuators to order the sailbot to stop for instance (it means to heave to). The automatic mode controls the sailboat in order to follow a desired route defined by GPS waypoints for example or to track a specific phenomenon or to stay on the spot to monitor what happens within to desired position. These both modes have implied some specifications for the embedded control unit of the sailbot and its software architecture.

Finally because of the location of our lab (south of France), we have designed a sailboat primarily to sail in Mediterranean Sea that represents a great interest in terms of marine observations. With no comparisons with Atlantic ocean, Mediterranean Sea is however often very windy this may generate big waves. Avalon badly experimented this environment because its rig got broken in last September off Saint Tropez [8]. Our sailbot is thus named MARIUS for Mediterranean Autonomous Robot ISEN Union SUPMECA with a nod to our both institutes ISEN and SUPMECA TOULON.

2 Process of Design

Such a complex mechatronic system cannot reasonably be tackled linear way. Indeed an iterative process is necessary to meet the issues like energy management, navigation skills and so on. An organic description is given below for needs of writing but we keep in mind that many interactions happened during the design process between the mechanics, electronics and control processing.

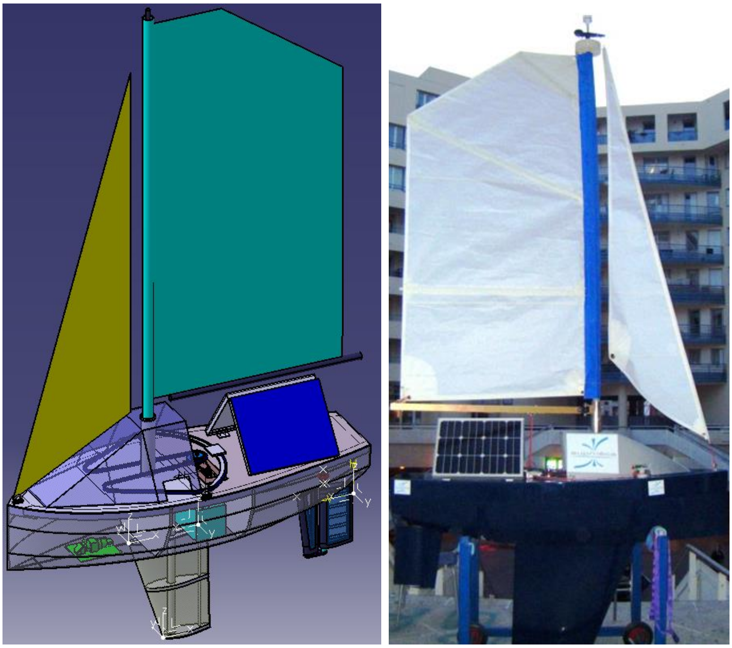
2.1 Mechanical Part

In opposition to other sailbots (ASAROME, VAIMOS, Erwan I), the whole design of Marius started from scratch instead of starting from an existing hull (MiniJi for instance) [1, 6, 7] . The hull was designed with Delftship software, which allows creating chines hulls that are easy to manufacture and cost efficient [4]. So the hull has a shape that favors a good stability and balance of the sailboat rather than a potential high speed (beam: 80 cm). A long keel was chosen instead of a bulb shaped keel to prevent the sailboat from dragging objects that might remain stuck on the keel (Table. 1). So the fin shape of the keel helps potential braced objects such as plastic bags, nets, fishlines... to glide away.

The skeg placed just forward of the rudder has also a fin shape to protect the rudder from the same hazards. The skeg contributes to guide the rudder in rotation as well. The whole hull works in water displacement mode and uses its whole length to raise its maximal speed. The water line passes just at the bottom level of the buttocks provided the total floatting weight nears 100 kg as planned. Obviously such an assumption takes into account the weight of all the components of Marius (including the battery, the instruments, wires and computer unit), the wind force depending on the dragging force (thus the hull shape and the waterline) that lead consequently to size the balance torque generated by the keel (thus the draft and the keel mass). We notice here that we are facing a complex design issue that implies an iterative process to design and to size all these interactive parts. In addition, we mention that a 30 kg payload can get aboard Marius without significantly changing its behaviour for sailing (provided this additional load is well placed within the hull).

A doghouse is fixed upon the deck to help the sailboat to turn back in case it rolled over. The entire hull was made from wood, fiberglass and epoxy whereas the doghouse is in foam and epoxy, the keel, the rudder and the skeg are made from steel, foam and epoxy. The entirely equipped hull weight is 70 kg (including 35 kg of the keel) and the draft is 80 cm long. These features provide the sailboat with a very good balancing torque, which highly contributes to the robustness of the mechanical part.

Table 1 Marius as CAD drawing and in reality on stand



The rig is composed of an carbon-epoxy mast that is 2.4 m long (upward from the deck), a 2.2 m^2 main sail, and a 0.7 m^2 jib sail. The mast is fitted in a 80 cm long stainless tube fixed to the bottom of the hull and the deck, whereas the mast top is braced to the deck by 3 dyneema ropes to give more rigidity to the rig (each rope withstands static loads higher than 1000 kg). The boom and thus the main sail are driven by a slider that moves along a circular rail from 60° at port side to 60° at starboard (Fig. 1). This dof is controlled by a DC gearmotor fixed on the inner side of the deck. The belt follows a W shaped path and is composed for a part of a chain and for another part of a dyneema rope. The chain is driven by a sprocket fixed on the motorized shaft whereas the rope is guided by the cheek blocks (pulleys) and the circular rail. A short rope is tied to the moving slider and to the sail boom to make them move together.The rudder shaft is also driven by the same type of actuator fixed under the deck, that transmits its torque through a chain and a cog system. Each dof is equipped with a rotative potientiometer, which provides an absolute angle measurement for the rudder and the main sail. The DC motor driver boards are placed into an electric box, which includes and gathers the supply sockets for all the instruments and also the control unit.

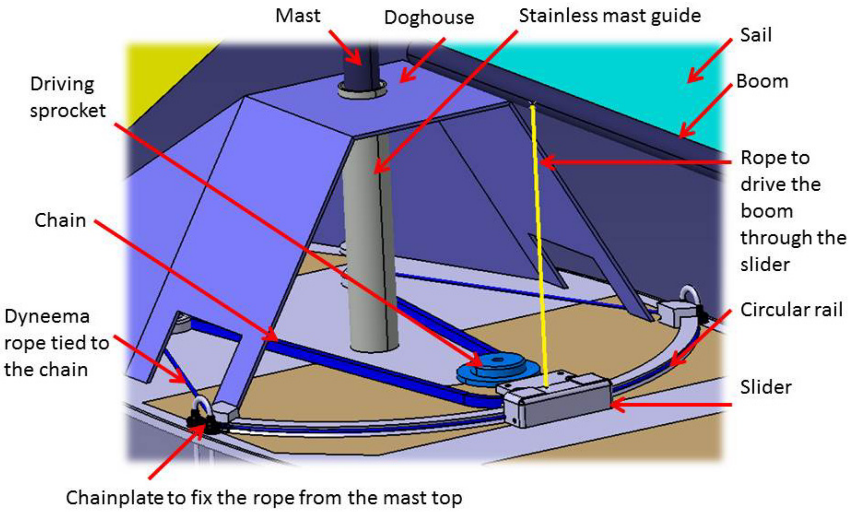


Fig. 1 Main sail actuation principle

2.2 Instruments and Energy

The skipper mode chosen to control MARIUS aims at reproducing the best as possible what skippers usually do. This means relying on several measured data, i.e. heading, GPS position, wind speed and direction, in order to properly control both actuators, i.e. the rudder and the main sail. Many other data related to the states of the sailbot could be monitored as well in order to improve to sailing skills but this might make the skippering algorithm much more complex without assuring noticeable improvements. Such improvements might be studied as future works after upcoming sailing tests are done.

So MARIUS is equipped with a magnetometer compass, a GPS and a wind sensor that are NMEA standard instruments. The wind sensor is an ultrasonic sensor that is placed on the mast top. The GPS is fixed on the deck close to the buttocks whereas the compass is fixed in the hull below the deck to the front of the boat far from any magnetic disturbances. These three instruments are plugged to the control unit through serial ports. Moreover a 3 axis accelerometer has been added not in order to directly control actuators but to monitor MARIUS' behaviors in relation with the wind and waves conditions. This sensor works as inclinometer and primarily helps the programmers to determine the best settings for the main sail angle (depending on the wind speed/direction and on MARIUS' velocity) and also to know whether MARIUS has rolled down.

A 90 Ah gel battery supplies energy for all electronic stuff. The free space inside the keel was initially supposed to be filled with NIMH batteries, but for economic reasons, such a solution was given up. Therefore a much bulkier (23 kg) and classical battery was chosen to be fixed on the bottom of the hull. Two 35 W photovoltaic pannels placed like a tent on the deck provide the battery with energy through a MPPT charger. This charger can simultaneously work with solar pannels or a wind generator. The design of this latter device is presently in progress. A dedicated vertical Savonius wind generator with helicoidal blades should equip Marius soon in order to contribute to the energy production (30 W targetted).

2.3 Control Unit

The control unit has been concurrently specified with the rest of the robot. Because of the short duration of the design phase of this project, a high level of programming language was required. The potential evolution of Marius missions and of its features have pushed the authors to select a modular control unit compatible with many types of signal (digital, analog...). For safety reasons, Marius must be remotely controlled if requested from 100 m around. This feature is necessary to request Marius to stay on the spot (sailing facing the wind), this allows the staff to catch it in order to drag it into the harbor for example. To do so the control unit must be compatible with a wireless communication type to create a private link to a host PC, which runs a GUI program aboard the follower boat. Finally the control unit must be able to be embedded aboard the sailboat and be compatible with the energy requirements (low consumption, low supply voltage if possible). For all this reasons, a Real Time target from National Instrument was chosen. The Compact-RIO 9076 provides four slots for C modules. It can be power supplied from 9 to 30 volts and its consumption cannot exceed 15 W. Presently, three connected C modules feature four RS232 serial ports where the GPS, the compass and the wind sensor are plugged, eight analog inputs for the 3 axis accelerometer and the both potentiometers (main sail and rudder), and four analog outputs to drive the both DC motors. About the half of the whole ressources remain avalaible therefore the actual energy consumption of the control unit is about 6 W. This control unit offers a USB port and a RS232 ports to connect peripherals and an internal storage memory of 512 MB. A bluetooth dongle (1,2 W) plugged on the control unit provides it with a long range wireless communication way (up to 300 m according to the provider and tested up to 100 m).

The control unit, a supply board, the two motor driver boards are placed in a watertight box, that protects the electronic stuff from water but allows evacuating the heat thanks to a large alloy wall. This electronic box is fixed on the bottom of the hull in the front. The inside frame of the hull includes drilled walls to help the convection thanks to a natural air flow. A thermal sensor has been added to monitor the temperature inside the hull in summer time especially during very sunny days. The overheat ought to be avoided even during sunny days thanks to the shade of the solar pannels and the shade of the doghouse and also to the average temperature of the bottom of the hull (the water temperature rarely exceeds 30 degrees Celcius in Mediterranean Sea in summer).

3 Embedded Intelligence

The programs implemented on the control unit meet two main requirements, i.e. to remotely control Marius and to let Marius manage autonomously its behaviour in relation to its current mission. For this reason, the authors decided to split the embedded intelligence in two modes, i.e. the manual control mode and the automatic mode. All the programs are coded in LabVIEW language, which is a graphical language. It is especially interesting because the programs are hierarchically sorted and can easily interact with the hardware inputs/outputs. Many functions dedicated to signals like acquirement, measurement, treatement and analysis are already preprogrammed. The control unit Compact-RIO 9076 includes FPGA chips that give the opportunity to speed up the code execution and also to reduce to power consumption. In the first step, all the programs are implemented in scan mode, this means that inputs/outputs are scanned and the FPGA functions are not used. In this mode, the execution frequency reaches 500 kHz, this is very confortable for our application (the classical sample time for sensors and instrument does not exceed 20 Hz).

3.1 Manual Control Mode

In the manual mode, the pilot remotely controls Marius. It means to collect and to display all the data about Marius' states provided by the embedded sensors/instruments, to edit the path to follow as a GPS waypoint file and to directly drive the both actuators of the main sail and the rudder. The GUI that runs on the host laptop has been programmed in QT language. The main window gives the possibility to edit the path by clicking on the static or dynamic (if Internet is available) Google Map. All the waypoints are stored in a list that can be easily modified before uploading it to Marius. The map displays the desired and the actual paths. From the main tab, the pilot can check if all the instruments work properly. A big double-arrow button allows refreshing the data including the battery level. A permanent led shows the user if Marius is connected or not. There is a command window that is used to send requests to Marius. The sailbot does not transmit its data unless requested and connected. This helps to save energy by using the bluetooth module only when necessary. A second tab is dedicated to the manual control of each actuator. The heading, the wind direction and the wind speed are continuously refreshed to help the pilot to easily control Marius (Fig. 7).

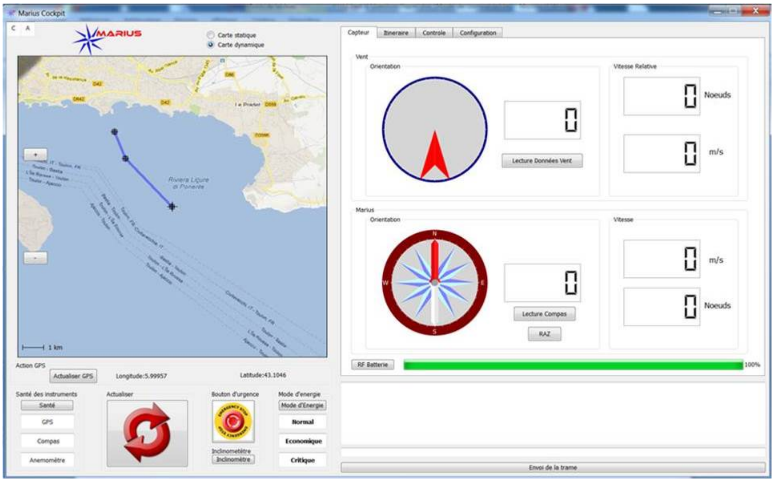


Fig. 2 Snapshot of Marius Cockpit - GUI for the remote control mode

The manual mode includes also an emergency button that launches an automatic function, which drives both actuators so that Marius turns until facing the wind. During this maneuver Marius goes upwind to heave to (i.e. keeping the rudder 10 $^\circ$ on one side and the sail 10 $^\circ$ on the other side). Of course the pilot can switch whenever he wants to the automatic mode. In this case, Marius will target the next waypoint it has not passed through.

3.2 Automatic Mode

The automatic mode was first designed to make Marius follow a path defined as a list of GPS waypoints. To do so, it was decided to get inspired from the algorithms that control Vaimos [3]. Despite the experience we gained from Avalon's challenge in last September in Toulon, we could not adopt the same control method because Marius' rig is not based on a balestron, thus it cannot jibe by turning its sail futher than the 120 $^\circ$ range given by the circular rail and limited by the position of both lateral shrouds. The chosen algorithms take the wind conditions into account but do not consider potential obstacles. Indeed no device of obstacles detection was implemented aboard Marius yet. The implemented automatic control mode has to follow a path where each waypoint owns a value of dangerosity. This value illustrates the proximity of dangerous areas or shore. Therefore Marius is allowed to pass more or less close to the considered waypoints.

Marius manages its energy through three levels of energy. We distinguish two main modes (normal and economy modes) where the sampling frequency switches from 5 Hz to 0.1 Hz for the instruments and the control of actuators. A third mode is a critical mode that prevents the battery from the deep discharge by turning Marius in idle mode (Marius gets to heave to). Afterwards it lets itself drift until the battery be charged again above 50%. The energy management has to be experimented during a long mission to validate its relevance, but this has not been done so far.

Fig. 3 Marius in test

4 Conclusion and Future Works

Marius project is a very young project (6 months) that led to an operational sailbot designed to be robust against harsh environments and climatic conditions. For a beginning, its control modes are basic but are supposed to be improved after several missions in forthcoming months (Fig. 3). Moreover, as it was mentionned before, some important features related to security and navigation skills are still missing on Marius. This is the reason why the obstacles detection and obstacles avoidance are included in future works to do. A long range transmitter for GPS position will also equip Marius in a short future. Finally, some other evolutions will certainly stem from the requirements of various oceanographic missions.

References

1. Romero-Ramirez, M.A.: PhD thesis: Contribution à la commande de voiliers robotisés., Universite Pierre et Marie CURIE, Paris, France, p. 206 (January, 23, 2012)
2. Erckens, H., Busser, G.-A., Pradalier, C., Siegwart, R.Y.: Navigation Strategy and Trajectory Following Controller for an Autonomous Sailing Vessel 17(1), 45–54 (2010)
3. Jaulin, L., Le Bars, F.: A simple controller for line following of sailboats. In: IRSC 2012, Cardiff, UK (2012)
4. Naveau, M., Anthierens, C., Pauly, E., Courmontagne, P.: MARIUS: Design of a sailbot for oceanographic missions. In: Oceans 2013, MTS/IEEE, San Diego, September 23-26 (submitted, 2013)
5. Guo, Y., Romero Ramirez, M.A., Leng, S.H., Plumet, F., Benosman, R., et Gas, B.: Reactive Path Planning for Autonomous Sailboat using an Omni-Directional Camera for Obstacle Detection. In: IEEE International Conference on Mechatronics (ICM), Istanbul, Turkey, pp. 445–450 (2011)
6. L'Ifremer en videos, http://wwz.ifremer.fr/webtv/Liste/Nouveautes/VAIMOS (May 5th, 2013)
7. Erwan, I.: le MiniJI de l'Ecole Navale, https://sites.google.com/site/minijiecolenavale/project-definition (May 5th, 2013)
8. Grundmann, S.: Avalon Toulon 2 HD, http://youtu.be/H7PBQG_crzY (May 5th, 2013)