Autonomous Robotic Boat of ENSIETA

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(WRSC/IRSC-2009 Paper)

***Abstract*— This year, we launched MicroTransat Project in our school to prepare the next year transatlantic race. In this article we will talk about the solutions in mechanics, electronics, sailing strategies and simulation that we developed for our autonomous robotic boat. As for the mechanics, the hull is home-made using mainly glass fiber mat bound together with a resin binder. As for the electronics, we tried to use off-the-shelf components as much as possible to ensure the maintainability of the system. In order to test the sailing algorithm we are using a simulator made with SCILAB.**

***Index Terms*— Autonomous, Sailing boat, WRSC/IRSC 2009.**

Fig. 1. Our robotic boat

I. About our participation in the WRSC

This year, our school ENSIETA (French Graduate Engineering School) has launched the project of participating in the MicroTransat challenge. Many factors helped in the project creation. First, ENSIETA is located in Brest, a city on the North-West of France on the Atlantic ocean shore. Moreover, our school is multidisciplinary since there are departments of informatics, electronics and mechanics and particularly the sub-department of naval architecture. Because ENSIETA take part of the challenge for the first time, we will not participate this year in the real challenge. However, we will be participating next year for sure (if nobody had crossed the Atlantic of course).

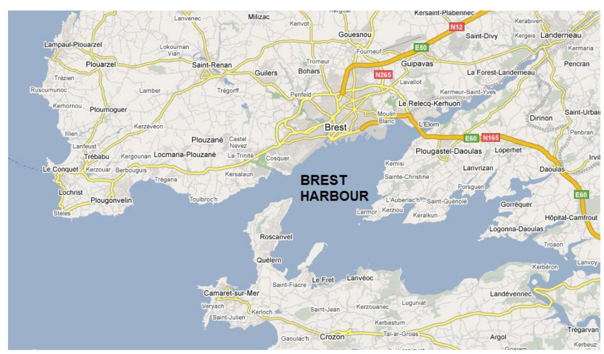

Fig. 2. Brest harbour

In order to gain some experience and find sponsors for the real challenge, we decided to make a smaller intermediate private challenge of autonomously crossing the Brest harbour (see figure

2). For that purpose we are building a small boat 1m20 long that will only be able to do short distances. As for an official challenge, instead of MicroTransat , the WRSC will be the first official challenge for our small boat.

II. Our first robot

A. Mechanical design and construction

Fig. 3. IMOCA Class

Our sailing robot design is based on the IMOCA class design (race boats see figure 3). We only made the mast smaller in order to enhance its stability.

The next sub-parts will talk about the mechanical architecture.

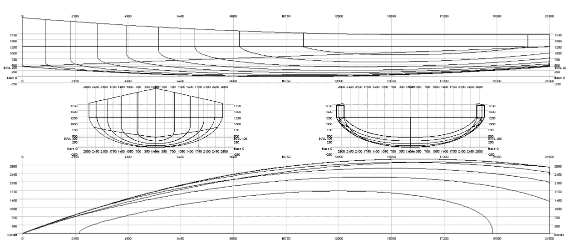

Fig. 4. Created using Delftship (free version)

1) Hull construction: In order to build the hull we used the following steps.

- Create a mould with a form corresponding to the hull using plaster.
- Cover the inside of the mould with a special resin in order to be able to remove the hull from it
- Put some Gel Coat and obtain the result in figure 5-(a).
- Put 2 layers of glass fiber mat bound together with a resin binder (figure 5-(b)).
- Extract the hull (figure 5-(c)) and add the internal structure elements using wood and glass fiber mat bound together with a resin binder (figure 5-(d)).

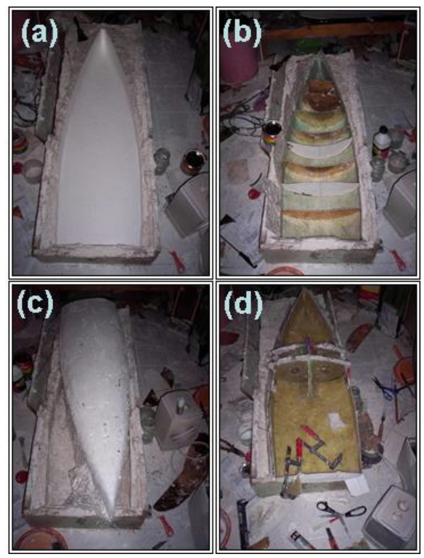

Fig. 5. Hull construction

2) Waterproofness: The deck normally seals well enough the inside of the boat. However, we would like to be able to remove the electronics from the inside of the boat for maintenance and debug purposes. This creates waterproofness problems. We solved this problem using a waterproof box and Switchcraft waterproof connectors (see the figure 6). In fact, we cut a rectangular hole in the deck in which we put the box. Then we cut the box's bottom and glued the borders of the box to the deck with special glue. The communication between the external sensors and the inside electronics is made through waterproof connectors.

Fig. 6. Waterproofness

3) Mast: As for the mast, we used an aluminum mast ordered in Germany. It is a profiled mast with a groove for the sail.

4) Sail: The sail is not triangular but has the form as in the figure 7 in order to lower the wind force application point keeping the same efficiency but at the same time rising the stability of the boat.

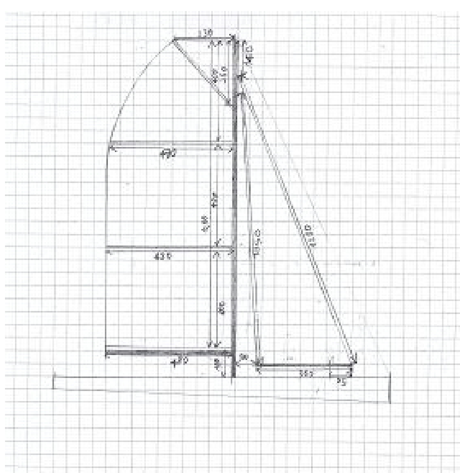

Fig. 7. Sail

5) Rudder blade: Like in the IMOCA class boats, there will be two rudder blades to allow steering even when the boat is leaning sideways.

6) Servos: Because the boat is designed for short distances, we do not need resistant servomotors. We used rc-model servos.

7) Keel: The keel's lead bulb was cast using a mould as you see the figure 8.

Fig. 8. Bulb mould

B. Autonomous boat electronics

1) Solutions:

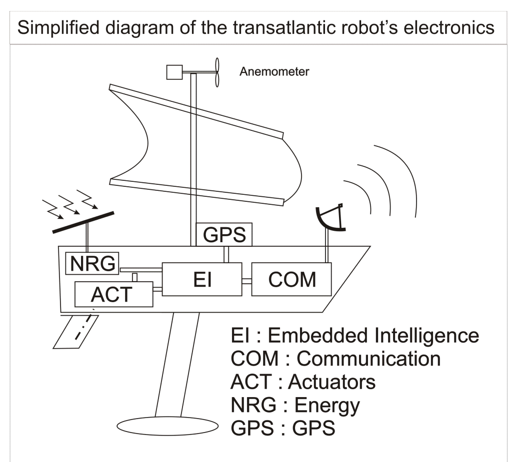

Fig. 9. Electronic architecture

While designing our electronics (figure 9), we have first thought of the solution shown in the figure 10.

Even if we didn't chose this approach, it is an interesting one. In fact, the solution is based on two principles:

- Use of COTS (Commercial off-the-shelf) elements
- Use most integrated elements (that do most of the tasks as the Neo and the Labjack)

In fact, the Neo Freerunner is a mobile phone with an LCD touch screen. Besides a GSM communication module, the Neo has WIFI and Bluetooth, useful for debugging and configuration, a GPS, 2 Accelerometers and an embedded Linux Debian allowing an easy programming (In C/C++ language using standard libraries).

Fig. 10. Old solution

The other "universal" component is the Labjack that makes the interface between the Neo and the Sensors/Actuators. This component has several digital I/O, ADC (Analog to Digital Converter) and DAC (Digital to Analog Converter). It can also connect to an I2C bus.

We were able to make this solution work properly with a robotic car. But the problem is the complexity of the Neo. In fact, because there is an embedded Linux, the system has to boot when powered. This causes problems since sometimes the system were not working properly after rebooting. However, this approach is promising since it provides with high quality integrated systems at a good price. Besides, the development of electronics becomes very simple since we can add a new sensor just by connecting it to the Labjack and writing the program that manages the data acquisition.

As for our current architecture, we used more components that have exactly the same behavior when rebooted and have lesser power consumption. In fact, we are preparing the electronics for the transatlantic race where rebooting might be frequent due to frequent power shortage.

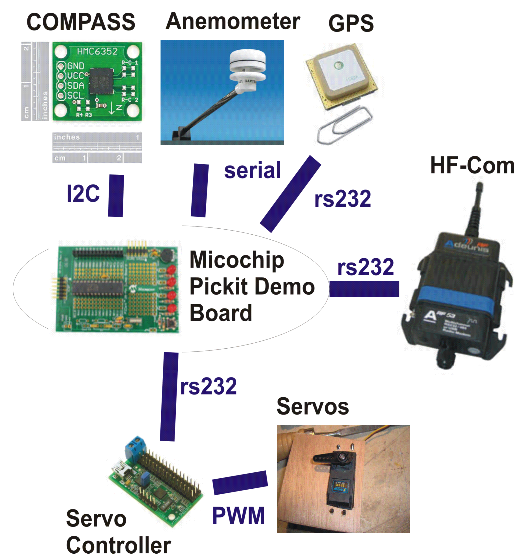

Fig. 11. New solution

2) GPS: As for the GPS we used the EB-85A (FV-M8). In fact, this GPS is small and has good precision.

3) Compass: We used the HMC6352 Compass module since it has one degree resolution.

4) Intelligence: We used a PIC18F2550 from Microchip mounted on the 28-pin Pickit demo board [8]. We have chosen the PIC since it is more robust to power shortage (no booting) and use less energy than the Neo Freerunner.

5) Energy source: As for now, the energy source are lithium polymer batteries (figure 12) from RC-Systems that will be sufficient for crossing the Brest harbour and might even be sufficient to do the 48h WRSC race. Regarding the progress of the project, we will start the development of the solar energy module.

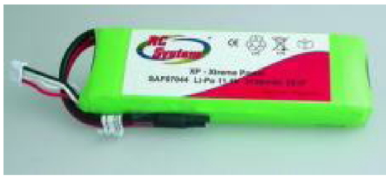

Fig. 12. Lithium Polymere battery

6) Communication: Even if the boat is supposed to be autonomous, we need a way to communicate with it for debug and configuration purposes. We use two Adeunis ARF53 HF modems (one on each side). This modem is long-range and can be controlled by the PIC and the base PC through RS232. At first, we wanted to use the GSM/GPRS (figure 13-(b)) but we would have to pay for the subscription fee for the GPRS data line both for the boat phone and the PC modem so we gave up on this solution.

As for the MicroTransat challenge we might use IRIDIUM modem (figure 13-(c)) or the SPOT messenger(figure 13-(a), found at the MicroTransat mailing list!). In fact, the SPOT messenger is a lot cheaper and gives the possibility to track the position of the robotic boat using E-mail or GSM phone.

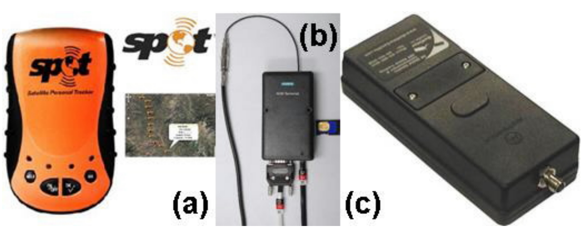

Fig. 13. Communication modules

7) Servo control: At first, we wanted to control the servos directly from the PIC but it used too much of its resources so we decided to add a separate servo controller. As for now, we will use a homemade servo controller. In order to increase the reliability, we might use COTS IC as the POLOLU or PARALLAX (figure 14-(a) and 14-(b) resp.).

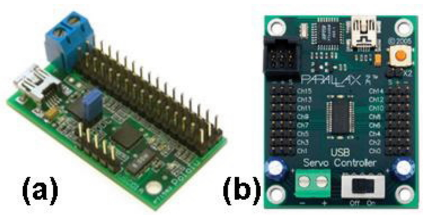

Fig. 14. Servocontrollers

8) Anemometer: We will use the CV7 ultrasonic anemometer from LCJ Capteurs. We avoid using mechanical anemometers since there are more likely to break.

9) Reliability: We are trying to make the boat able to move forward using only the GPS. The other sensors would only increase the accuracy of the actions. As an example, if the anemometer stops working, we will have to infer the wind orientation from the GPS position/speed and the COMPASS. The trick is to stop the boat. A immobile boat will automatically take a specific orientation from which we can infer the wind orientation.

We are still working on that kind of aspects so we do not have any results yet.

C. Sailing algorithm

In order to test our algorithms, we are using a simulator written in SCILAB language. The sailing boat represented is described by the following state equations

$$
\left\{
\begin{array}{lcll}
\dot{x} & = & v\cos\theta, & \text{(i)} \\
\dot{y} & = & v\sin\theta - \beta V, & \text{(ii)} \\
\dot{\theta} & = & \omega, & \text{(iii)} \\
\dot{\delta}_s & = & u_1, & \text{(iv)} \\
\dot{\delta}_r & = & u_2, & \text{(v)} \\
\dot{v} & = & \frac{f_s\sin\delta_s - f_r\sin\delta_r - \alpha_f v}{m}, & \text{(vi)} \\
\dot{\omega} & = & \frac{(\ell - r_s\cos\delta_s)f_s - r_r\cos\delta_r f_r - \alpha_\theta\omega}{J}, & \text{(vii)} \\
f_s & = & \alpha_s\left(V\cos\left(\theta+\delta_s\right) - v\sin\delta_s\right), & \text{(viii)} \\
f_r & = & \alpha_r v\sin\delta_r. & \text{(ix)}
\end{array}
\right.
$$

The inputs u_1 and u_2 of the systems are the derivatives of the angles δ_s and δ_r. The state vector $\mathbf{x} = (x, y, \theta, \delta_s, \delta_r, v, \omega)^{\mathrm{T}} \in \mathbb{R}^7$ is composed with

- the coordinates x, y of the inertial center G of the boat
- the orientation θ,
- the sail angle δ_s
- the rudder angle δ_r
- the tangential speed of G
- the angular velocity ω of the boat around G.

The intermediate variables are

- the thrust force f_s of the wind on the sail,
- the force f_r of the water on the rudder.

The parameters (that are assumed to be known) are

- the speed V of the wind,
- the distance r_r between the rudder and G,
- the distance r_s between the mast and G,
- the rudder lift α_r,
- the sail lift α_s,
- the tangential friction α_f of the boat with respect to the water,
- the angular friction α_θ of the boat with respect to the water,
- the angular inertia J of the boat,
- the distance ℓ between the mast and the thrust center of the sail,
- and the drift coefficient β.

These parameters will be chosen as

$$\begin{aligned} \beta &= 0.05, r_s = 1, r_r = 2, V = 10, \\ m &= 1000, J = 2000, \alpha_f \in 60, \\ \alpha_\theta &\in 500, \alpha_s = 500, \alpha_r = 300. \end{aligned}$$

We simulate the behaviour of the boat using Euler approximation.

$$\mathbf{x}(t + dt) = dt * \mathbf{f}(\mathbf{x}) + \mathbf{x}(t)$$

$\mathbf{f}$ represents the state equations.

In order to be able to develop strategies, we first need a regulator that regulates the boat's sail angle δ_s and orientation θ to a specific target $(\hat{\delta}_s, \hat{\theta})$. (see article [1] for more details)

$$\mathbf{u} = \mathbf{r}(\mathbf{x}, \mathbf{w}) = \mathbf{r}(\mathbf{x}, \hat{\delta}_s, \hat{\theta})$$

As for the strategies, in order to sail to a specific waypoint, we can use a hybrid second stage regulator. In figure 15, we can see the four different directions θ_i to follow that will be chosen by the regulator with regards to the position of the boat with regards to the target. Denote by θ_{hr} the current direction to be followed by the hybrid regulator. For example, if the boat is in zone $q = 3$ then $\theta_{hr} = \theta_3$. The target orientation $\hat{\theta}$ will the filtered response of θ_{hr} with a first order filter in order to avoid brutal transitions of $\hat{\theta}$. The sail angle depends directly of the orientation $\hat{\delta}_s = h(\hat{\theta})$.

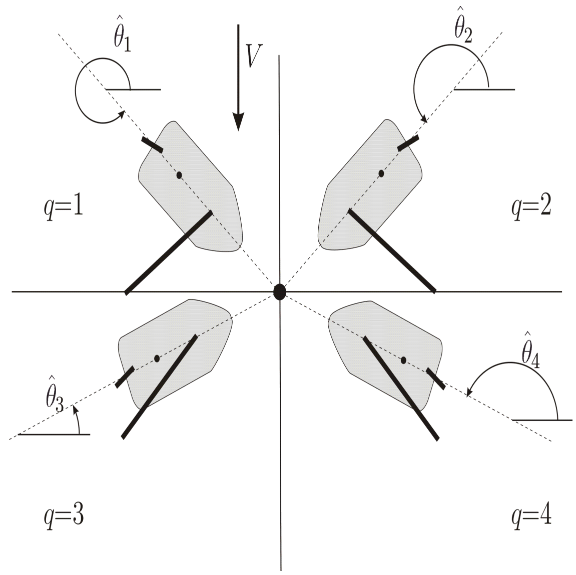

Fig. 15. Four possible target orientations

Some results of the SCILAB simulator are displayed on figure 16. The scilab file can be found on the following address `http://www.ensieta.fr/sliwka` in the MicroTransat section.

D. Real tests and debugging

In order to be able to develop the electronics at the same time as boat construction, we decided to test the electronics and the different algorithms using a robotic car as shown in figure 17.

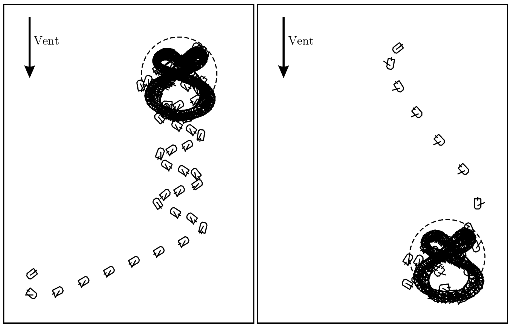

Fig. 16. Simulation

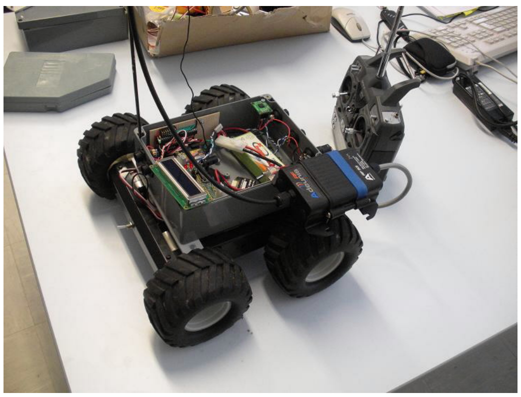

Fig. 17. Robot for electronics debuging

III. Conclusion

The boat is already working but we will still have to do many tests and improvements and refine the winning strategy ;).

References

[1]L. Jaulin (2004) Modélisation et commande d'un bateau à voile, CIFA2004 (Conférence Internationale Francophone d'Automatique), Douz (Tunisie)