The Ground Sailor

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I. Introduction

The need to exploit as much as possible natural resources is a priority of all modern technology. Nature offers various power sources and a wise use of these yields to high savings in the realization of any modern technological application. Wind turbine systems have proved to be an enormous power source that have not still been fully exploited. Another vital use of wind has been, in the history of mankind, in transportation and exploration.

The choice of the authors to assemble a vehicle, named the Ground Sailor (GR), capable of moving on ground propelled only by wind, is motivated by the importance that such instrument can have in numerous applications, i.e. autonomous exploration for scientific or military purposes. The main goal of the authors is to give this autonomous means of transportation a control system provided by the microcontroller Basic Stamp 2 (BS2) of Parallax. Auto navigation systems are widely used and the main aspect involved in the design of such devices is the need to elaborate simultaneous a great quantity of information. This challenging problem involves, the implementation of a plant capable of receiving the required reference information, the processing of such information and the actuation of the control effort in order to accomplish the route wanted.

The rest of the paper is organized as follows. In Section 2 there is a brief description of sailing and the issues of concern for the auto navigation system developed. The sensors and actuators used for the realization of the GR are described in Section 3. The circuitry and the PBasic code developed is present in the Section 4. Finally, the GR is described in all his most important parts in Section 5 and concluding remarks are present in Section 6.

II. Sailing

Operating and navigating a vessel has always been more an art than a skill. This art is more a science, and as usual a fine artist is the one that has a strong technical and cultural background. The physics of sailing has a long history and is not as trivial as one can imagine.

It must be mentioned a priori that the worry to float is absent since the GR is a land vehicle. In the design process there is no reason to study lateral stability since rolling is practically absent, as well as pitching and yawing. So the main concern is to catch the wind. The means to propel the vessel is in the wind acting on a single main sail.

Sails are flexible wings that use the wind to generate a force called lift. The flexibility is an important aspect of the sail since it must be able to work with the wind coming from either side in order to allow tacking.

In Figure 1 it is possible to observe how lift is generated. Along with this force there is obviously drag that opposes the motion. The magnitude of the lift generated by the sail depends on the relative position of the sail and the direction of the apparent wind.

It is easy to understand sailing downwind: the wind blows into the sail and pushes against it. The wind is faster than the boat so the air is decelerated by the sail. The sail pushes backwards against the wind, so the wind pushes forward on the sail. Basically the wind pushes you in the direction it is going. It is still easy to understand how it is impossible to sail directly upwind (Figure 2).

Now let us focus on the most important part of sail theory. From Figure 3 it is possible to examine a picture of the *points of sail*, that is the technical term used to give the relative position between a boat's course and the direction of the wind. There are three main regions that can be defined and they are: boat is on port tack (wind from left side), starboard tack (wind from right side) and head to wind (red zone of Figure 3, no-go-zone). The size of the no-go-zone differs based on the performance characteristics of the particular sailboat. Finally, chosen a size of 55° for the GR no-go-zone there are six possible configurations to take in account:

- *A.* In irons (into the wind);
- *B.* Close haul (27.5° to the apparent wind);
- *C.* Beam reach (90° to the apparent wind);
- *D.* Broad reach (27.5° away from directly downwind sailing);
- *E.* Running (directly downwind).

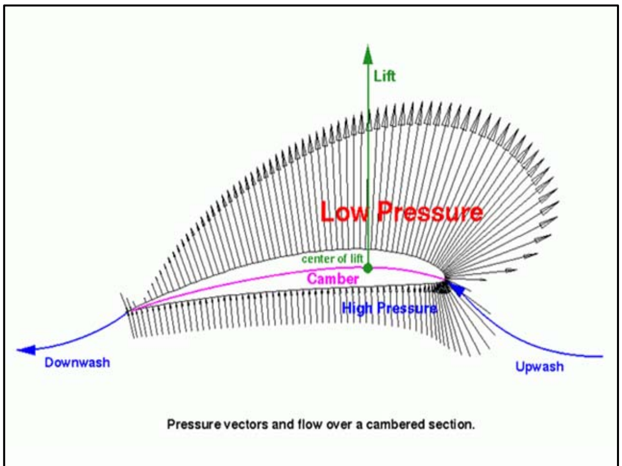

Figure 1

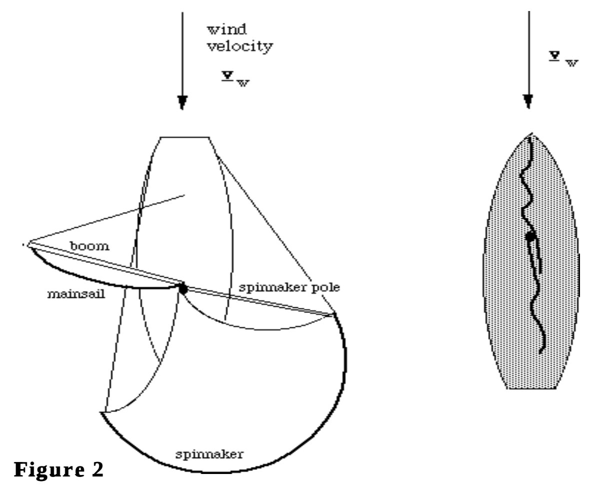

Figure 2

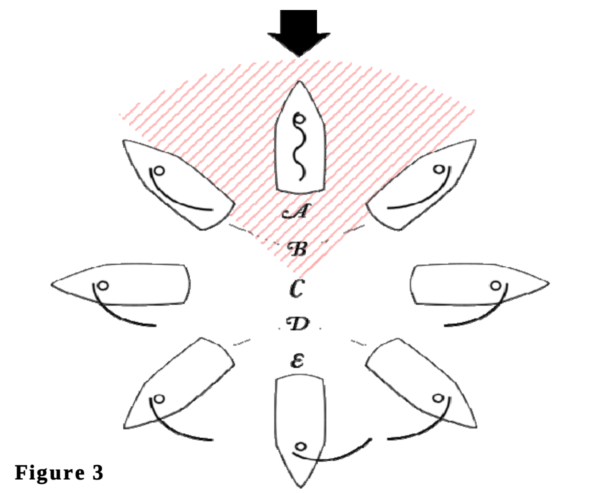

Figure 3

The essential information to sail the GR is to know where the boat is directed, where we want it to head and which is the relative position with the wind. The following Section 3 gives and overview of the sensors used to acquire the data needed.

III. Sensors & Actuators

Each subsection here individually deals with the arrangements done for the use of each sensor involved in the construction of the GR.

A. Compass

The analog compass (Figure 4) exploits the magnetic Hall-Effect in order to output the angle in which it stands respect to the magnetic North pole. The dimensions of the compass are shown in Figure 5 and the relative documentation provided by The Robson Company, Inc. is attached to the present paper.

Figure 4

Six leads are used to give respectively two signals, that resemble a sine and a cosine, that determine one angle. Figure 6 shows the two signals aforementioned and points A and B, that are the points in which the two signals intersect, individuate a certain ΔV (more or less 0.8V). This ΔV is the range in which the trend of the signals can be assumed to be linear. The choice made by the authors at this point is to pick the blue curve from point A to point C to read the first 90°. Following the dashed line from point C to point D, the region that defines from 90° to 180° is on the magenta curve from point D to point B. At point B there is another switch in the choice of the curves and the region that defines from 180° to 270° is on the blue curve from point B to point E. The final region from 270° to 360° is defined in the same fashion of the previous.

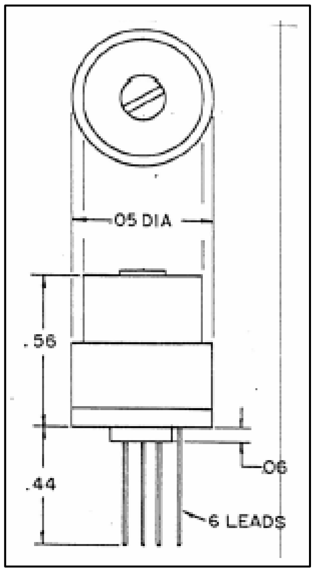

Figure 5

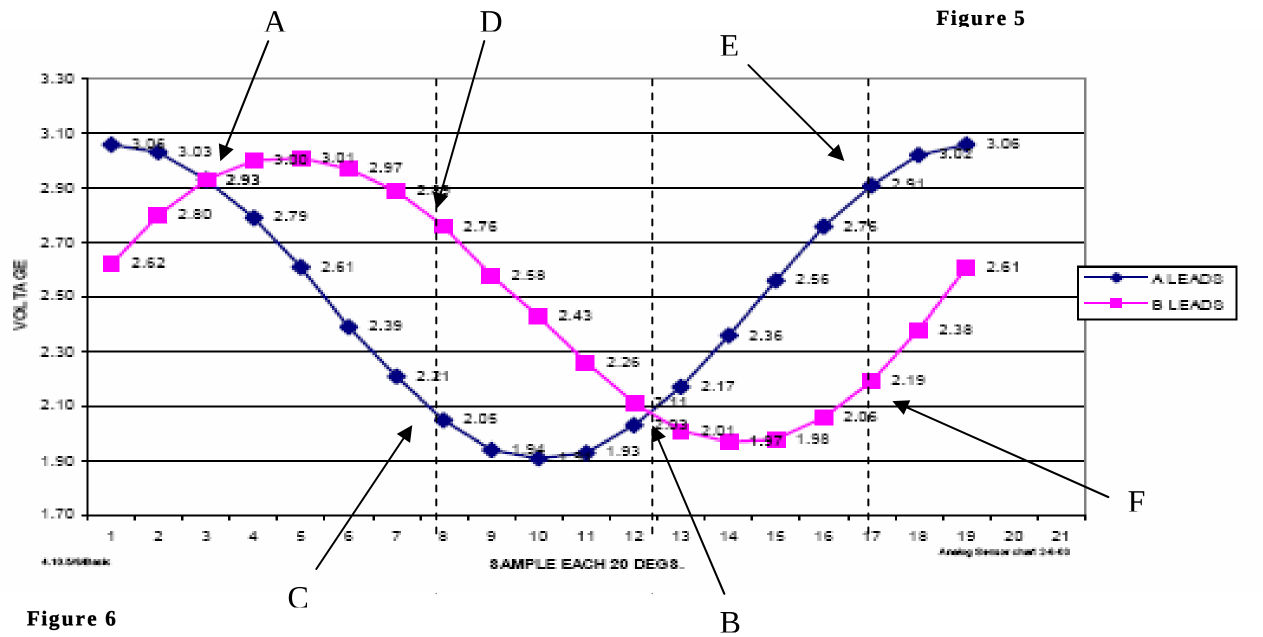

Figure 6

B. Wind Vane

The wind vane is made of two components: the pointer and a directional marker. The directional marker for the GR has been made using a non contacting Hall-Effect angle sensor.

The pointer is designed to be balanced but the momenta about the shaft's axis of the areas exposed to the wind are unequal. This unbalancing causes the vane to rotate to minimize the force of the wind on its surface. That causes the Metal End (Figure 7), with less momenta, to point the wind.

Beneath the pointer there is attached to the shaft a permanent magnet () that allows the sensor (Ametes 360ASMF) mounted under it to give the direction of the wind. The relative documentation provided by GMW Associates is attached to the present paper. The 360ASMF provides an analog output signal which is proportional to the mechanical angle of the magnet. The authors have chosen to use the full scale output range 360ASMF1-01 from 0° to 360° with output from 0.5V to 4.5V.

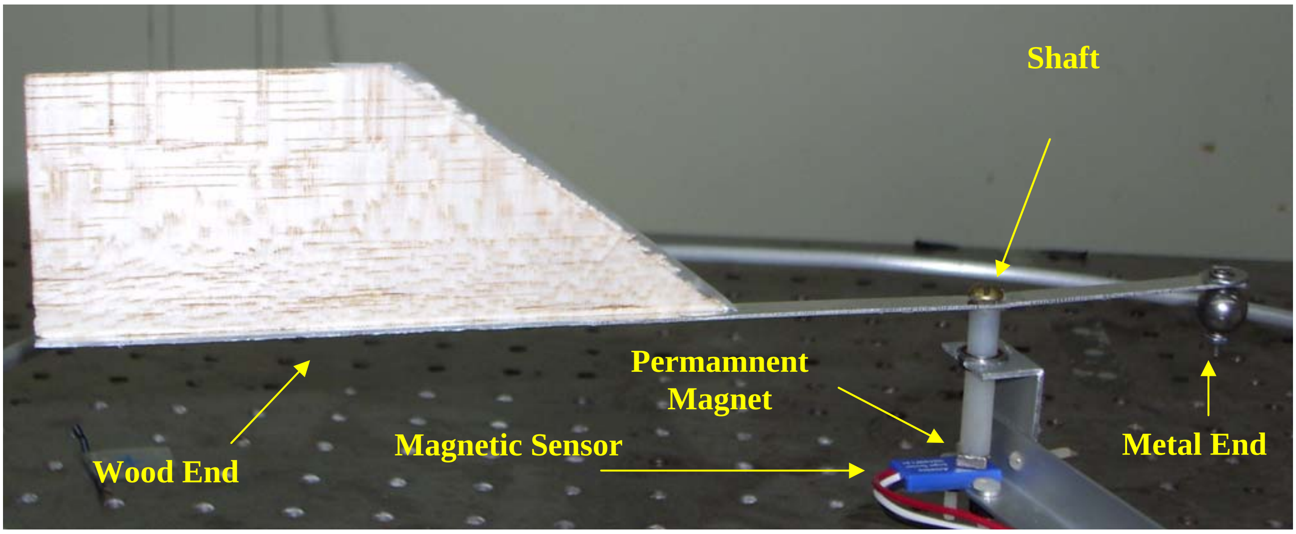

Figure 7

C. Encoder

The encoder has been constructed drilling a hole in the right front wheel and facing on the two sides a photo resistor and a red LED. Figure 8 shows how the encoder functions. Whenever the light is received by the photo resistor a BS2 receives a signal and stores the data in counter. A continuous count of how many revolutions the wheel does allows the GR to now how much distance has been covered.

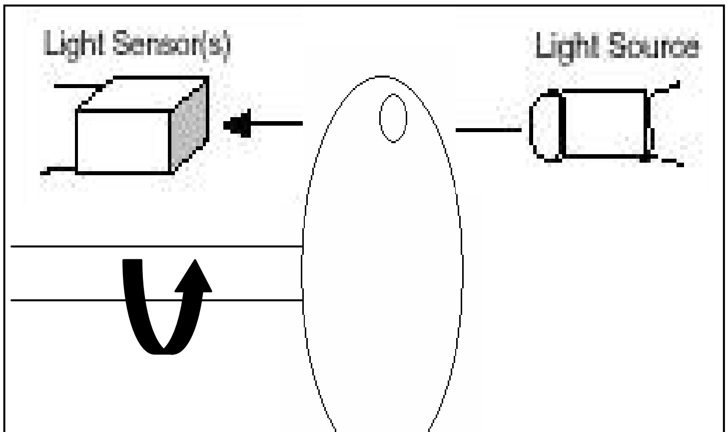

Figure 8

D. Servos

The two servos used as actuators are a Parallax (Futaba) Standard Servo (Figure 9), for the control of the back wheel that functions as the rudder, and a Hobbico Servo CS-72 (Figure 10), that controls the mast and hence the sail.

Figure 9

The Parallax (Futaba) Standard Servo has specifications attached to the present paper. This servo was mounted in order to rotate the rudder of the GR. The rudder is independently controlled by a BS2 that is commanded by a Master BS2 that runs the main program.

The Hobbico Servo CS-72 is an analog servo as well and has always specifications given at the following link. This servo is used in the GR to move the shaft commanding the sail.


Figure 10

IV. Circuitry & Code

A. PBasic Code

The code is attached to the present paper and a brief explanation of how it is structured is necessary to fully comprehend it, even if the code contains itself the comments necessary for so.

The first part of the defines the variable that amount to 3 words and 8 bytes, following there are 4 constants defined and then pin assignment.

The Main Program first calls the subroutine Compass and acquires the direction respect to the magnetic North Pole of the GR, then waits for the user to input the route desired and displays it in a Debug window. Now, the program reads the direction of the wind respect to the GR, once again the direction respect to the magnetic North Pole of the GR and computes the sum of these two angle in bitrads and stores it in the variable windcomp. At this point the subroutines Sail and Rudder are called and the variable wheelpic is debugged. After this the LCD is initialized, then displays the variables compdirb (from Compass) and routeb (from WinAngle).

The subroutines WindAngle acquire the direction of the wind respect to the GR by the commands of an ADC and the same does Compass, giving the direction respect to the magnetic North Pole of the GR, in the same fashion described in Section 3, using two ADC. The subroutine Sail tells the sail where to position itself relatively to the direction of the wind and calls the other subroutine Sailmove, that allows the master BS2 to tell the slave BS2 of the mast's servo to move accordingly. The last subroutine is Rudder that tells the tire, functioning as a rudder, to position itself accordingly to the compass's data and the route desired by communicating the variable wheelpic to the a third slave BS2 commanding the standard Parallax servo.

Finally, in the Main Program the command GOTO Main allows the whole process to be looped and permits the simultaneous control of the system. Attached to the paper there is another code similar to the previous that makes use of the encoder in order to give the distance covered and another as well that allows communication between master and slave Bs2.

B. Circuitry

Figure 11 shows the a comprehensive scheme of the circuitry involved in the construction and the control of the GR.

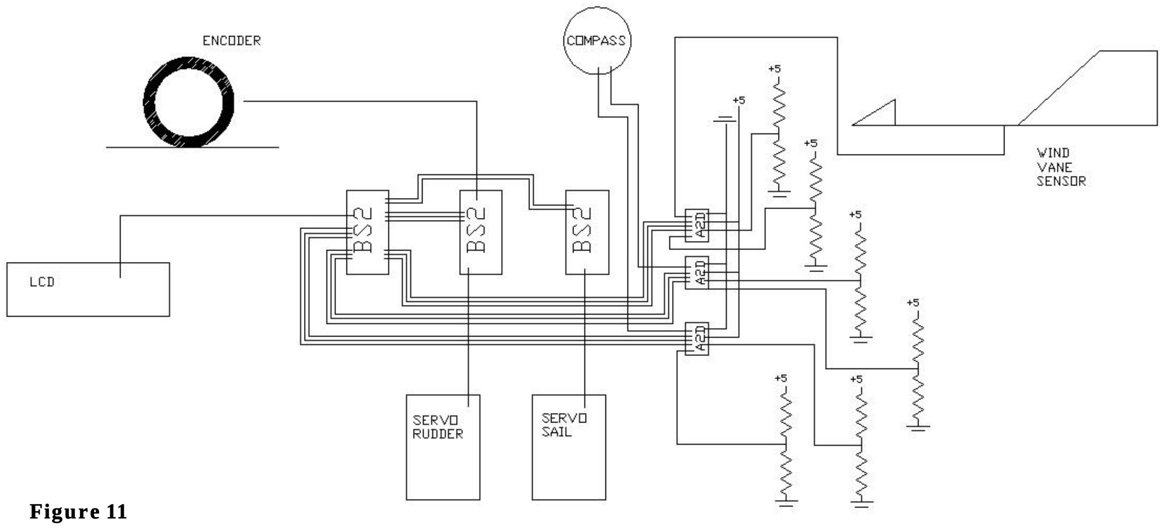

Figure 11

V. GR Components & Design

First main component of the GR is the sail that has been designed using an open source software called SailCad. This software requires the dimensions and the shape of the boat, so the authors had to decide a priori the geometry of the GR.

The dimensions of the GR have been chosen taking in account various issues. The first choice has been to enlarge the initial dimensions of the GR in order to render negligible the lateral forces of the wind and to give the necessary space to place all the hardware that would have been realized. This choice is perfectly inline with the basic design concept of Mechatronics, in which the interdisciplinary nature of the projects requires an a priori consideration of all the variables involved.

Figure 12

The haul of the GR and the bumper present in front of it, added in a second moment in order to avoid damaging the wind vane in case of a collision, is of Aluminium and the total weight is approximately 1.5kg, including the four pack

1.2V batteries and the 9V battery. The rudder has been chosen to be one single back wheel and a LCD display has been positioned along the front in order to allow a clear visibility of any information required by the user.

The centre of gravity of the GR is at 500 mm from the rudder and along the centre axis of the vehicle and at a height of 70 mm from the ground. It may seem that the appendix that mounts the wind vane could have shifted the centre of gravity but an accurate positioning of the BOE, the compass and the LCD display allowed this point to remain constantly fixed. The only slight alteration is given by the movement of the sail but this is even more negligible.

In Figure 11 and 12 it is possible to appreciate an upper view of the GR and a lateral view in which the main components have been highlighted:

- Sail
- Mast
- Boom
- Rudder
- BS2s
- Compass

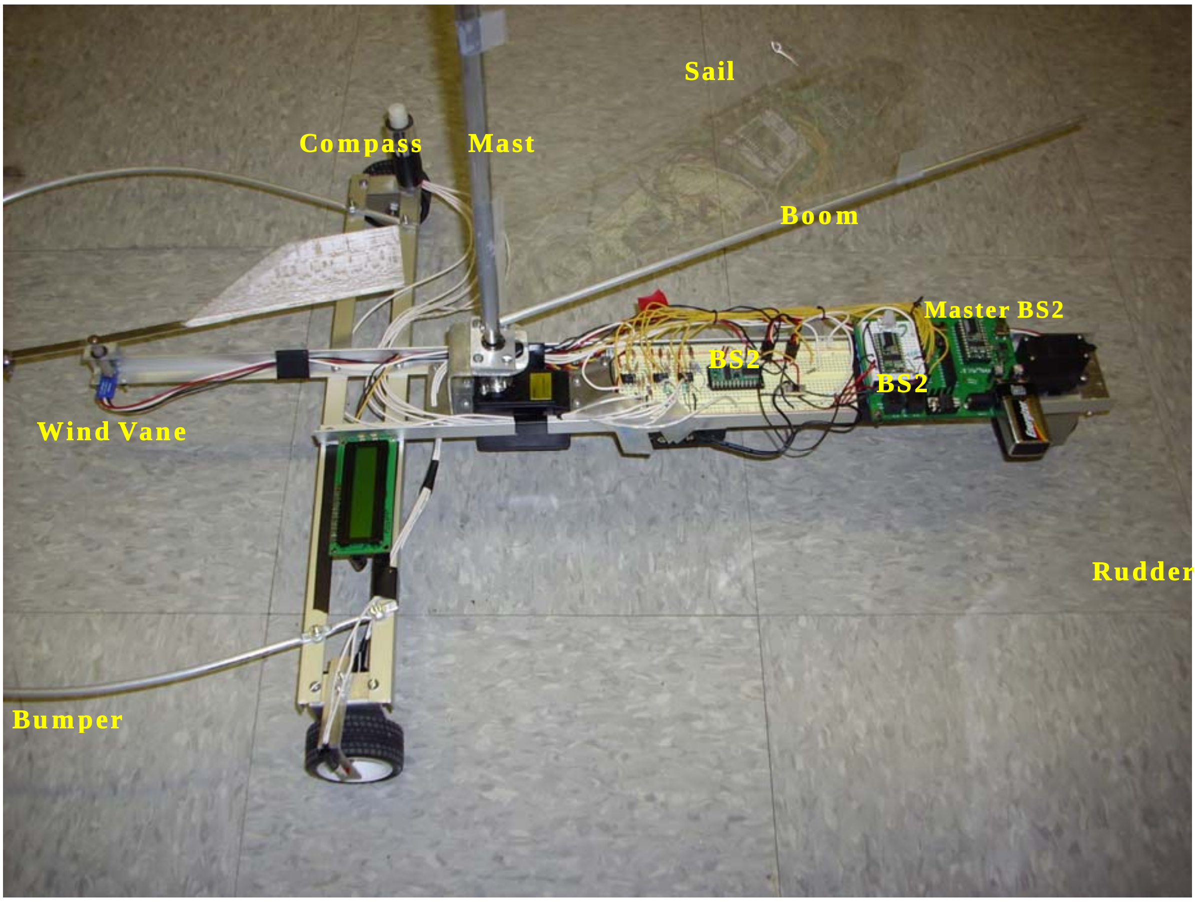

Figure 13

Finally, in Figure 13 and 14 there are the views from on top and the lateral view with the quotations of the GR.

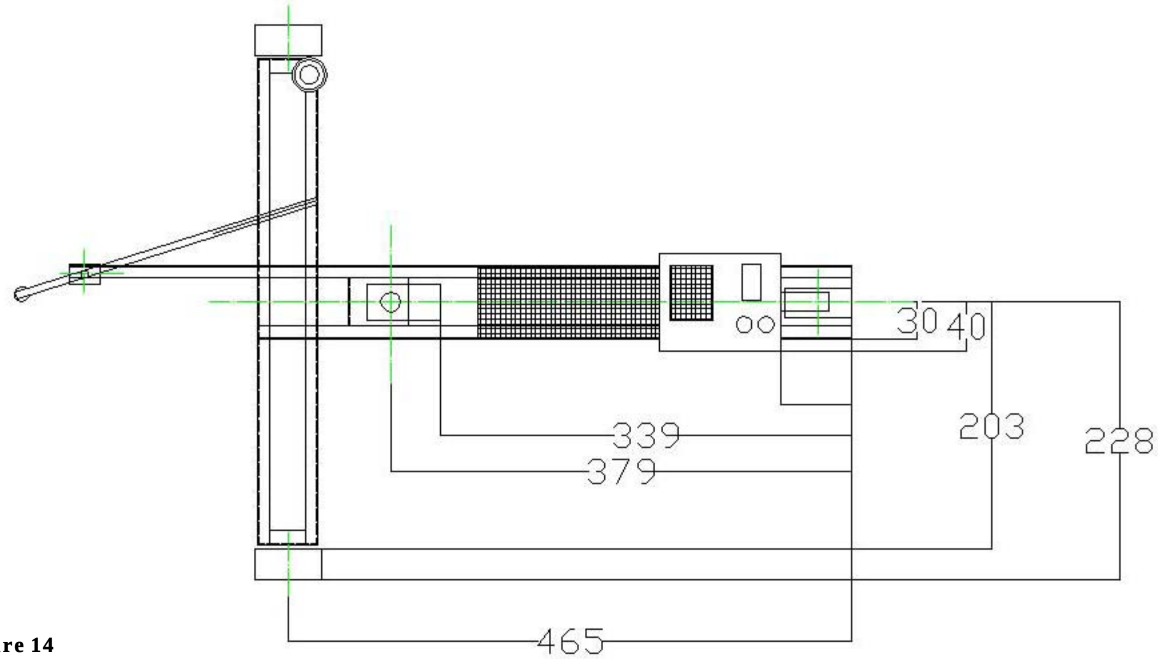

Figure 14

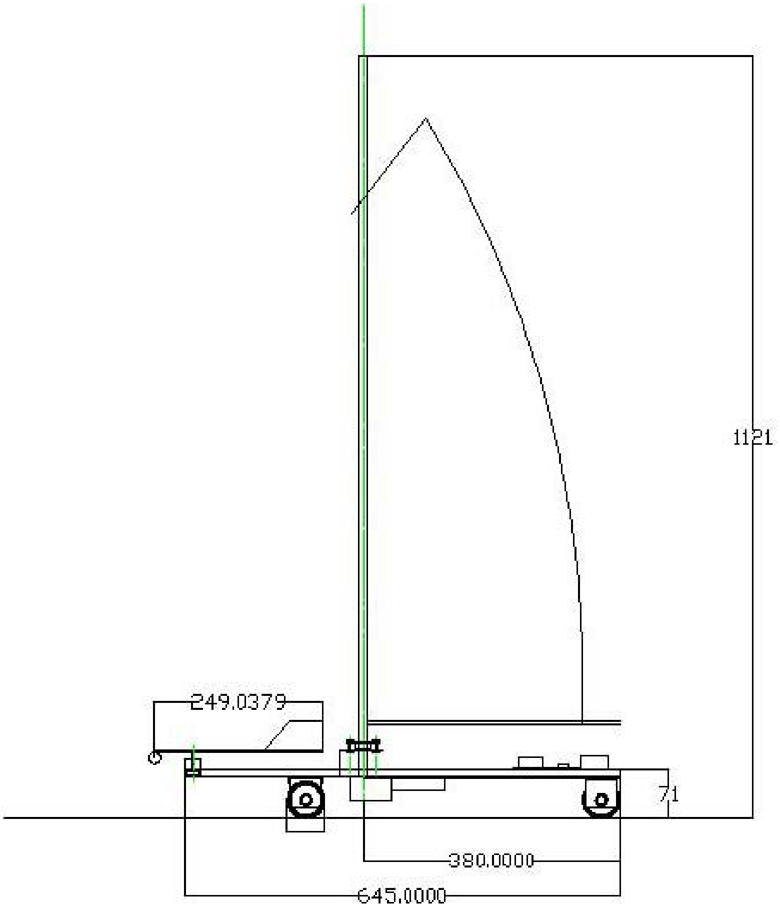

Figure 15

VI. Conclusions

In the present work the authors constructed a land vehicle propelled by the wind and capable to sail in the direction desired. Such kind of vehicle can be implemented with a variety of other sensors and actuators, giving it a multitask nature and expanding its capabilities beyond sailing.

The issues encountered during the realization of the GR and its navigation system have been extremely challenging. The complex nature of the system has continuously changed the decisions made during the design phase.

Future work on the GR is copious and an immediate improvement could be an obstacle avoiding sensory system along with the extension to a GPS integration to the navigational system and a remote control connection capable to make changes in the route avoiding to stop the vehicle and input it manually.