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Smart Sailing Robot for Oceanographic Research

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ABSTRACT: The development and deployment of autonomous robots for a number of applications has been successfully completed, most notably for planetary exploration. Whilst the use of unmanned (both tethered and drifting) buoys for ocean observation is well established, the use of unmanned systems capable of long term purposeful navigation is still in its infancy. A large number of autonomous underwater vehicles (AUVs) have been developed [1], [2], [3], but little experimentation with surface vehicles has been undertaken [5], [6], [7], [8]. Over the past decade there has been intense scientific work on autonomous sailing robots. As hardware gets smaller, cheaper and also better performing the possibilities increase for autonomous vessels. Recently there is a lot of research going on with the aim of reducing CO2 emissions. Smart sailing robot fit perfectly into these ambitions. A robotic sailboat is able to autonomously navigate towards any given target without human control or intervention. The optimal route is calculated dependent on strategic goals and weather parameters. Rudder and sails are autonomously controlled in order to keep course and to execute maneuvers like tack and jibe. As sailboats operate in a highly dynamic, environment an autonomous sailboat has to respond quickly to ever-changing environmental conditions. Incoming data from sensors (GPS, compass, etc.) have to be analyzed permanently by intelligent control mechanisms. The best routing decision, perfect handling of ever changing wind conditions and perfect timing during tack and jibe are some of the skills an autonomous sailing vessel has to master.

KEYWORDS: Aurdino, Zigbee, Bluetooth module, GPS, Ultrasonic sensor, IR Sensor, Accelerometer, Waterproof dc servomotors, Battery

I. INTRODUCTION

In this paper we will discuss the main developments of the past years in the field of sailing robot. In this paper the main applications for the use of sailing robot will be introduced with Hardware aspects. The most common boats, sails, microcontrollers and sensors that are used for sailing robot will be discussed. Also contains an overview about important software architectures for autonomous sailboats. Since the sailing robot needs a reliable connection for monitoring, debugging and remote control in case of emergency, the sailing robot needs a data link to the shore. To detect and avoid obstacles different mechanisms are used. Regarding to that, the collision avoidance chapter will discuss two approaches. The simulation and testing part of the paper will present common simulation methods and testing approaches. The conclusion will summarize the main aspects of this paper. This is an embedded hardware/software implementation for the computing system of a small scale unmanned autonomous sailing boat. The system is integrated with aurdino, Zigbee tx and rx, Bluetooth module, GPS, Ultrasonic sensor, Accelerometer, Waterproof DC servomotors,12 V battery supply build in a metallic prototype of boat.

Hardware challenges Equipping a robotic sailing boat with microcontroller, sensors, actuators and other special hardware needed is very difficult. Waterproofness is a major issue in this context. Sensors have to provide reliable data in an unstable environment. All components have to be small and lightweight enough to be carried by the boat.

Routing algorithms Routing of autonomous sailing boats is a challenging task since for a sailing boat not every course is directly sailable. There is also a huge difference in the maximum speed a sailboat can reach on a given course. It is also difficult to plan routes because sailboats are operating in an unstable and ever changing environment.

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Energy self sufficiency Autonomous sailing boats used in long term missions on the ocean have to carry all needed energy with them and/or gather energy from the environment.

Collision avoidance To eliminate the need to monitor robotic sailing boats all the time, they have to be able to avoid collisions with ships and other obstacles in the water.

SAILING MECHANISM

The sailing robot model is made of thin Alluminium Sheet Two brush-less DC motors are fixed to the boat model. Pedals made of MS (Mild Steel) are fixed to the shafts of the DC motors. To move the boat forward, both the motors are operated in clockwise direction by the microcontroller. To move the boat reverse, both the motors are operated in counterclockwise direction by the microcontroller. To turn left / right, one motor is rotated in clockwise and the other is rotated in counter-clockwise directions. The other key factor which must be considered in designing such a vessel is that of the sail type. Traditional fabric sails are typically controlled through a series of ropes known as sheets and halliards, these frequently break or jam (Particularly when swollen by salt water) and require regular attention from the crew. Performing such tasks autonomously would incur significant overheads resulting in excessive power usage, weight and financial cost. A potential alternative is that of a rigid wing shaped sail attached directly to the mast. The sail is manipulated through the rotation of the entire mast via an electric motor. This design eliminates common points of failure found in traditional Sailing and is therefore ideal for use in an autonomous sailing vessel.

II. RELATED WORK

The small-scale prototype is intended as a proof of concept for a robot with a number of key characteristics:
1) Station-holding capabilities under a wide range of wind and sea states
2) Useful payload capability
3) Low power consumption
4) Capability for long term autonomous operation

Points 1) and 2) both imply a larger rather than a smaller robot, however the nature of the resources available for construction and testing of the robot dictated some very real restrictions on the scale of robot to be built. It was essential that the initial prototype could be transported to allow access to the inland lake test-site, and that it could be handled.After consideration of a number of approaches to the design and construction of the hull a radio-control yacht hull form was chosen as a basis.The hull is of hard-chine construction which proved relatively cheap, easy and sufficiently efficient for the purpose of testing the concept. This also proved to be a reasonable selection in as much as it proved adequate for testing the concept.

Stelzer et al. also presented a research project where an autonomous sailing boat shall be used for marine mammal research [4]. They use the sailboat for passive acoustic monitoring of marine mammals while reducing the human impact on them. They state that the advantage of using a robot sailing boat is that the area of interest can be sampled with a very high spacial and temporal resolution for comparatively low cost. They also equipped their boat with additional sensors measuring chlorophyll and zooplankton. An acoustic streamer, three hydrophones, a depth sensor and a compass module are towed behind the sailing vessel. Cruz and Alves also published a paper on the possible applications of autonomous sailboats for ocean sampling and surveillance [10]. For ocean observation they name upper ocean dynamics, chlorophyll concentration, ocean acoustics, calibration of basin-wide ocean models and tracking of pollution plumes as fields of interest for scientists where robotic sailboats can collect required data for low costs. In the field of surveillance the authors state that autonomous sailing boats can be used for the detection and prevention of illegal trading, surveillance of immigration routes and assistance in the detection and disarming of minefields in the ocean.

III.SYSTEM BLOCK DIAGRAM

This we have the modules of Zigbee, GSM and Sensors which are interfaced with the microcontroller. The sensors used have different activity as per use. Aurdino Microcontroller is the brain of mechanical robot which receives the

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commands from PC through ZigBee wireless connection and processes these commands to perform pattern motion control. The main part in the robot main board is Aurdino microcontroller which generates two PWM signals for each wheel of DC motor. The two active wheels of the robot are actuated by two independent servo motors modified for continuous rotation. In particular, the robot is powered by 12 V battery. The hardware tools of the robotic system are: ZigBee, Aurdino Microcontroller, DC Motors, Bluetooth Module, Accelerometer, GPS, Ultrasonic Sensor, IR sensor. The hardware components of the robotic system are as shown as above in block diagram.

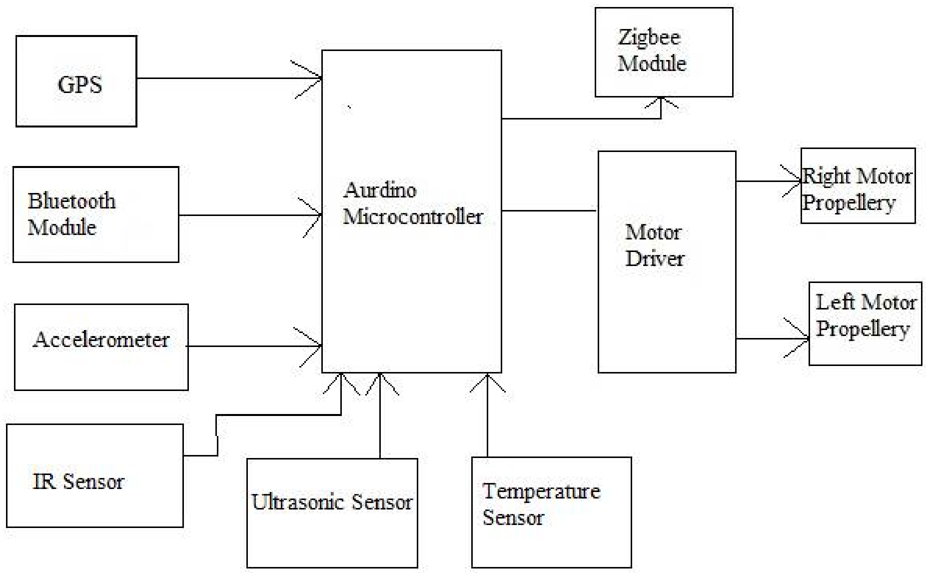

Fig. 1 Block Diagram

SAILING ROBOT HARDWARE TOOLS

DC Motors

DC motors are configured in many types and sizes, including brush less, servo, and gear motor types. A motor consists of a rotor and a permanent magnetic field stator. The magnetic field is maintained using either permanent magnets or electromagnetic windings. DC motors are most commonly used in variable speed and torque. Motion and controls cover a wide range of components that in some way are used to generate and/or control motion.

GPS

GPS has been used for navigating purpose. GPS is mainly used to track the location of robot in ocean and help to navigate in right direction.

Features: Environmental surveillance.

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IV.APPLICATIONS AND ADVANTAGES OF SAILING ROBOT

There are several possible fields of application for autonomous sailing boats.

- **Intelligend Sensor Buoys:**

Autonomous sailing boats can easily be equipped with several sensors measuring all kinds of data. As they are energy self sufficient their operation time is not limited. Therefore, it is very cost efficient to use them for surveys, mappings and ecological studies of oceans and lakes. Ocean sampling and marine mammal research are two applications where already projects exists to facilitate robotic sailboats.

- **CO2-neutral in Transportation of Goods:**

Conventional sailboats are unprofitable for the transportation of goods nowadays because they need a very big crew to be operated. Autonomous sailing boats do not suffer from that disadvantage and can therefore be used for the CO2-neutral transportation of goods.

- **Reconnaissance and Surveillance:**

Sailing robots can also be sent to operate in dangerous regions. For example, they could be used to measure the nuclear radiation in the ocean near Fukushima. Another application would be the surveillance of the borders in the Mediterranean sea.

- **Supply Vessel:**

Remote islands and regions that are sparsely populated could be supplied using robot sailing boats. For example, they could be used to supply scientists that work on small islands in the arctic ocean.
Obstacle detection:

Their algorithm uses a map of the coastline that could also be extended to work with other sensed obstacles. The sailboat determines its position on the map using a positioning system (e.g. GPS) and then casts rays from the robots position in every direction (every angle from 0-359 degrees) and senses the distance to the nearest obstacle in that direction. Once an obstacle is detected a new course is decided that avoids the obstacle. Collision avoidance is a challenging task for autonomous sailboats as they operate in an ever changing, unstable environment. Sailboats can change their route.

- **Communication:**

A permanent data link between boat and shore is necessary for monitoring, debugging, to control manually in case of emergency, for real-time monitoring. Real-time measurement data are needed for long-term observation tasks. Three communication partners are involved in the communication process. **1) Sailboat:** The sailboat transmits sensor values to the visualization. **2) Visualization software:** This computer program runs on a computer on the shore and represents the transmitted data. Furthermore, new target coordination, obstacle information or a new desired course can be sent from the visualization to the sailboat. **3) Remote controller:** This entity can be used in case of emergency to overrule the autonomous on-board control of the sailboat. It is especially needed during test runs. Desired actuator values like position of the rudder and sails are transmitted in real time to the sailboat.

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V. RESULTS

Control, communications and energy budget

Control of the larger robot should prove very similar to the small scale prototype, thus a similar level of low-level processing is likely to be used. PIC based computers are very flexible and low-cost and are more than adequate for these purposes. The full size robot will however have a number of other computational requirements. These will include the control of the reefing system which will also involve the monitoring of an additional wind strength monitor, as well as much higher level mission control tasks such as data transmission and reception and route planning. It is thus envisaged that a more capable computing platform will be installed in the robot in addition to the low-level PIC based systems. This is expected to be based around a low-power Aurdino controller. This should provide sufficient processor power and memory to enable effective use of the robot's resources and task performance. There will also be a requirement for long range communication of data, and the inclusion of satellite communication equipment seems to be the best choice with respect to power consumption,bandwidth, coverage and reliability. The impact of these additional systems on power consumption is significant, and overall projected energy budgets are summarized in table 1.Initial calculations indicate that 500mA should be sufficient for a balanced energy budget over long periods of time when combined with a large battery pack to act as a reserve for long periods of low intensity light.

TABLE 1.
PROJECTED ENERGY BUDGET STATISTICS

	Current Drawn By Battery Terminals			
Components	Standby(mA)	Average(mA)	Harsh(mA)	Maximum(mA)
Microcontroller System	50	100	150	500
Rudder Servo	10	100	150	1000
Compass	20	20	20	20
Communications	<1	50	50	50
Total	80	270	370	1570

Projected production cost and performance

Initial estimates made in conjunction with an established bespoke robot indicate that the detailed design and construction of an initial full scale prototype will cost in the region is more. This is assuming that large numbers of components will be used off-the-shelf, and that there are no major design changes from the small scale prototype. Assuming a welded hull construction table 2. presents an estimated breakdown of subsequent low volume production cost per unit.

TABLE 2.
PROJECTED COST BREAKDOWN

Component	Cost (*INR*)
Hull Assembly	5000
Batteries	1000
Communications	6000
Aurdino Controller	2000
Sensors	4000
Scientific Payload	Variable
Total Cost	18000

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Results

A series of test sailings were undertaken on a small inland lake in order to minimise the risk of losing the robot.The key aim of these tests was to test the ability of the control system to hold a pre-determined compass course and to test the ability of the motor design to cope with different navigational orders. Initial tests were performed with the aim of testing the performance and feasibility of the chosen hull design. Later tests focused on the development of a software control system and its ability to maintain a pre-determined compass heading.

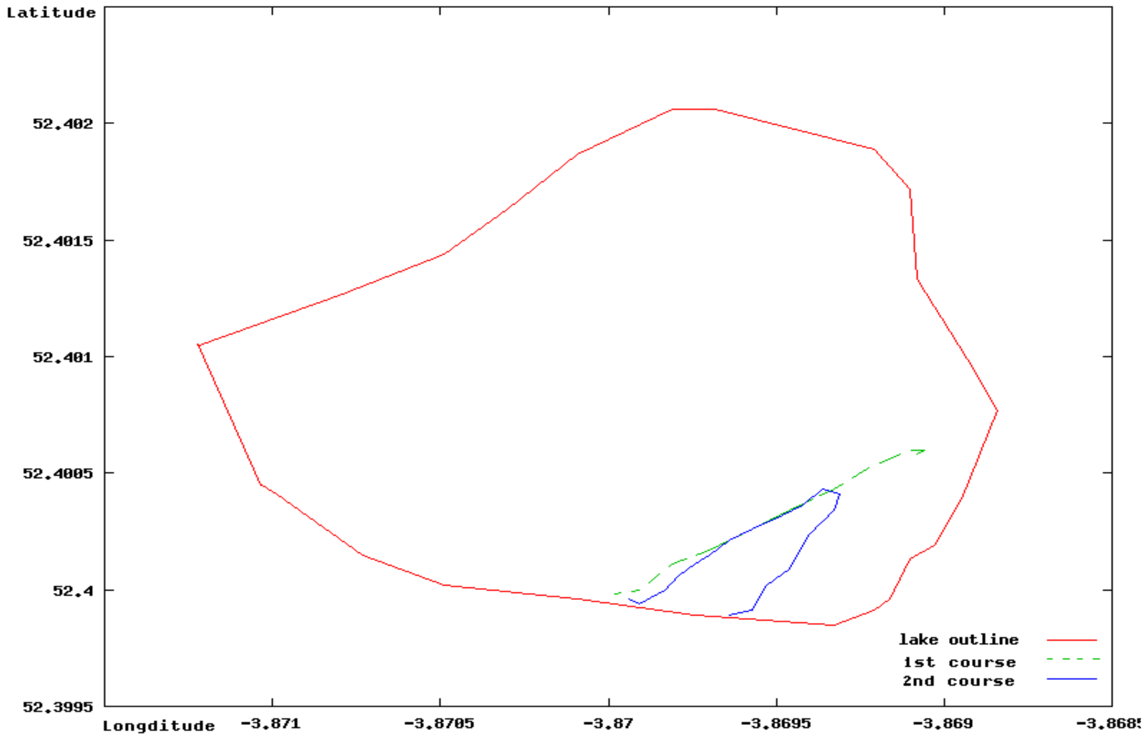

Figure2.: A GPS Plot showing the course taken by the first prototype boat in sailing across the lake and sailing halfway across and returning.

The sailing performance tests were primarily undertaken in the winter months when conditions at the test site were somewhat extreme with sustained wind speeds exceeding 15 km/h and wave heights exceeding 2cm in one case. Despite these conditions the hull remained stable and rarely heeled to an angle of more than 45 degrees. Although this is an encouraging start it remains to be seen if a boat of 4 times bigger size could survive wind speeds in excess of 100 km/h and wave heights in excess of 5m as would be expected upon the open sea.This (when moving at a reasonable speed) resulted in turns in excess of 90 degrees occurring within a single boat length, during these turns the hull would typically heel to approximately 45 degrees. This issue was later believed to be partially responsible for a constant oscillation of the boat with respect to its target heading when operating under software control.Due to issues in the sail movement the control system tests had to disable the automatic sailing positioning algorithm and operate using the course holding algorithm alone. With the problems caused a number of successful course holding tests took place. The boat was given a compass heading which was intended to take it across the lake over a distance of approximately 200cm. Several successful crossings were made with the boat managing to maintain a roughly straight line figure1. shows a plot from the onboard GPS receiver during one of these tests. It is worth noting that the system used by the GPS receiver to store its tracks compresses the data in a lossy manner removing the detail of many smaller movements which therefore are not visible in figure1.The boat's rapid turning ability combined with a high proportional gain resulted in wild oscillations with respect to the heading during early tests. It is believed (although virtually impossible

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to accurately determine from the results gained) that these were in part due to the compass misreading headings as the boat heeled due to the action of the wind and due to the extreme turns it was taking. A reduction of the proportional gain reduced, but did not eliminate these oscillations. A later experiment sailed the boat for 2 minutes on the compass course used in the first experiment, then moved the sail onto its opposite position and gave the course holding program the reverse heading to follow for an indefinite time period. The end result was that the boat returned to near the point it had departed from.Figure1.shows a GPS plot of this test. Note the amount of space it takes for the turn is not the time the boat actually spent turning, but is mostly the time it spent rotating the sail which also had the action of causing a turn in the correct direction to begin, during this time the boat was not attempting to perform any other control as there was no attempt at parallelism in the software being used.

From the lake trials are summarized in Fig.3. Wind conditions during experiment 1 were extremely variable due to the nature of the surrounding terrain. Shifts in direction of more than 90 degree occurred and in general the wind was very light.The tracks achieved by the robot in the lake trials are shown in figure 3. It is clear from the track plots that in all the experiments the robot achieved a steady rate of progress to windward. The starboard tack was less prone to accidental tacking and gybing than the port tack. The gross disparities in averages for port and starboard tack are possibly also caused by the difficulty of measuring the wind direction on the lake.

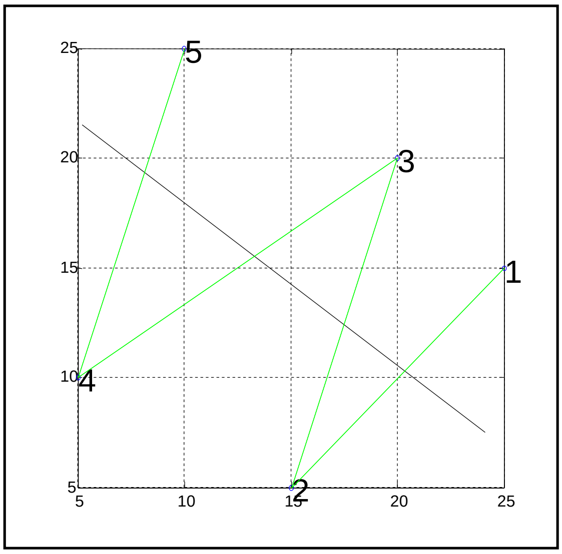

Fig. 2
Fig.3. Tracks followed by the robot in experiments on the lake. Blue line show wind directions.

VI. Conclusion and Future Work

The work presented here proves that production and control of autonomous sailing robots is possible, and that reasonable performance can be obtained from low-complexity and lowcost components. The possibilities for long-term autonomous operation have been discussed and presented as a real possibility for the near future. The construction of a small fleet of autonomous sailing robots would add an extra string to the bow of oceanographers and climate scientists for obtaining in-situ measurements and samples at sea. Whilst the ocean surface is clearly an extremely hostile environment for engineered systems the initial indications from this work are promising mainly due to the mechanically simple nature of the robot.

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