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IFAC-PapersOnLine 49-23 (2016) 524–531

Construction and Control of an Autonomous Sail Boat

Henning Seeberg Stenersen *

* *Department of Engineering Cybernetics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway (e-mail: henning.stenersen@gmail.com)*

Abstract: A small scale autonomous sail boat has successfully been designed, built and tested. It is capable of sailing a feasible predefined track with no further input from the user, using only the sails as propulsion.
The physics of sailing are tamed by the means of navigation, control and guidance. The boat has been equipped with flexible and powerful hardware for computerized control. This hardware gathers measurements, runs actuators and execute both high and low level control algorithms. A control allocation scheme for the sail boat has been proposed. The scheme ensurers progress in all feasible points of sail and has proved efficient in tests. A controller uses the scheme to close the heading loop and in turn the position loop is closed by a waypoint tracker.

Keywords: Autonomous sailing, autonomous control, embedded systems, path planning, sensors, autonomous mobile robots, autonomous vehicles.

1. INTRODUCTION

Compared to field robots, like UAVs, ROVs or AUVs, little research have been done in the field of robotic sailing. According to the *World Robotic Sailing Championship* (World Robotic Sailing Championship 2014) nobody yet has managed to cross the Atlantic ocean with a sailing robot. In 2011 it was stated that automated sail trim was not well covered by scientific publications (Stelzer and Jafarmadar. (2011)).

However, in resent years there has been some research on several aspects within the field, like: hardware design, system development, collision avoidance, path planning, rig design, controllers, modelling, stability and power management (Alexander Schlaefer (2011), Finnis (2012) , Fabrice Le Bars (2013)). Many prototypes of autonomous sail boats exists out there. These prototypes use a broad variety of boat designs, sail rigs used and control system designs.

The idea of transferring rules and common sayings from sailors into a controller is not a new idea. The use of *fuzzy controllers* to implement these rules has been tried by Abril J. (1997), Stelzer R. (2007) and Y. Briere (2009). These have all made real experiments that have showed working results. The control allocation scheme in the proceeding is also based on experience from practice in sailing, but the approach is different from fuzzy controllers.

The work presented in this paper is above all, personally, viewed as an interesting, challenging and relevant problem to solve. Previous work has already been conducted in (Stenersen (2015)). However, the autonomous sail boat may have some interesting applications. An autonomous sail boat can be constructed, not only to use the wind as propulsion, but to harvest energy for its internal systems. Hence, it can be completely self-sufficient and it has no crew cost. It can even carry other autonomous vehicles and supply them with energy, such as a flying drone. In the future we may see autonomous sail boats used for offshore inspection, surveillance and coast guard tasks, ice berg detection, scientific data gathering and more.

Main contributions are:

- Design and building of a small scale sail boat with necessary hardware to test and achieve autonomous sailing in relevant conditions.
- Design, make and enable a computer framework in order to:
  - · Gather, log and make available a variety of measurements required for the application.
  - · Execute high level control algorithms and provide a readable and modular implementation environment for such algorithms.
  - · Interact with a smart phone user interface which enables efficient testing and running of the system.
- Suggestion of a control allocation scheme that ensures progress and controllability in all feasible points of sail, using only the sails as propulsion.

10.1016/j.ifacol.2016.10.489

- Suggestion of simple control algorithms for autonomous sailing.
- Execution of several field tests where basic autonomous sailing was achieved successfully.

2. EMBEDDED COMPUTERIZED CONTROL

During the development, a computerized hardware framework was realized. The computerized hardware was developed with the following criteria in mind:

- Enable running a variety of high level control algorithms for sailing/navigation/etc. that require a higher amount of computational power.
- Enable running a variety of low level control laws prone to real-time requirements.
- Manage a variety of sensors and actuators in a modular, flexible and expandable manner.
- Allow for runtime user input.
- Provide performance results to the user, both in real-time and post operation.
- Remain operational and operate safely.

2.1 Realization

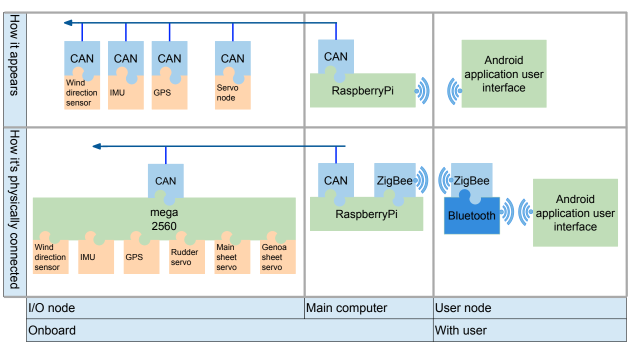

Fig. 1. Final system overview

In order to meet the system requirements, it was decided to use a high level computer running a common operating system. Hence, high level software are available to speed up the implementation of control algorithms. To achieve a modular, maintainable and expandable system, actuators and sensors were connected as nodes on an internal bus. The main computer would act as a master controlling the other nodes. Figure 2 shows the design overview of this design. The user interacts with the system through a wireless user interface.

The system was realized using a *Raspberry-Pi* computer with a common *Linux* distribution called *Rasbian* (Raspberrypi). The Raspberry-Pi computer was expanded with CAN bus (CAN bus). This was done by milling out a circuit board containing a *MCP2515* CAN-driver chip (Microchip), connecting it to the Raspberry-Pi and writing drivers for CAN-bus functionality. The drivers were installed as a module within the interpreted programming language*Python*.

It became somewhat cumbersome to implement one physical node for each sensor or actuator. Hence, it was thought better combine the basic sensors and actuators into a single physical node based on a powerful micro-controller with

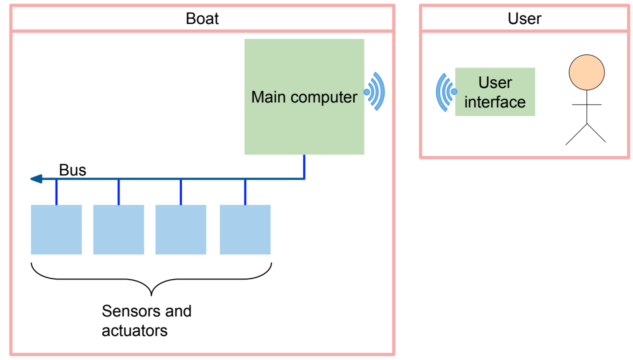

Fig. 2. Design overview

sufficient input/output/external peripherals. This would become the *ATmega2560* micro controller (Atmel). Each sensor and actuator would still appear as different nodes on the CAN-bus. Hence the system remained expandable as further physical nodes still could be connected.

In order to obtain a modular implementation of the shared resources on the ATmega2560, basic scheduling was achieved by modifying a port of *freeRTOS* onto it (FreeRTOS). This required more data memory and external RAM was fitted.

Figure 1 shows the final system overview, physically and how it appears.

3. NAVIGATION

The boat is equipped with an accelerometer, a magnetometer, a GPS and a wind direction sensor. Together, these instruments provide roll, pitch, heading, position, speed, course and wind direction for use in the control algorithms.

3.1 Roll and pitch

The accelerometer provides estimates for roll and pitch by assuming that the measured force vector equals the gravitational vector. This assumption holds well for this application as the sail boat is not subject to rapid acceleration.

3.2 Heading

Heading is obtained by calibrated magnetometer readings. A calibration routine is implemented to eliminate static hard and soft iron interference and scale factor errors. The resulting calibrated field vector is then rotated into the NED-frame and heading is obtained as follows:

$$\psi = 2\pi - atan2(X_{calRot}, Y_{calRot}), \tag{1}$$

where ψ is the heading and X_{calRot}, Y_{calRot} are the magnetic field components in north and east directions, respectively.

Filtering the heading measurement In order to filter out a noise component of $\pm$ 2-3 °, a low pass filter was considered. However, the phase lag became too large and an adaptive filter was designed in the following way: