A study on potential energy savings by the use of a balanced rig on a robotic sailing boat

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Abstract The drive for the sail trim has been identified as one of the largest consumers on the autonomous sailing boat ASV Roboat. The presented work analyses the potential energy savings of a balanced rig compared to the conventional sloop rig, which is currently in use on this boat. Results of a computer simulation show that a balanced rig can save about two-thirds of the power needed for the sail trim.

1 Introduction

Recent events, such as the devastating tsunamis in Asia, the Deepwater Horizon oil spill in Gulf of Mexico, accidents involving refugee boats off the coast of Lampedusa in Italy, and pirate activities in the Gulf of Aden have clearly and impressively emphasized the importance of a fully integrated ocean observation system [11]. Robotic sailing boats represent a rapidly emerging technology for various tasks on lakes and oceans. They offer the possibility of sampling an area of interest with high temporal and spatial resolution at low cost [7].

The effect of a balanced rig on the power consumption of a robotic sailing boat has been investigated using the example of ASV Roboat [13], the current world champion in robotic sailing. The basis for the ASV Roboat is the commercially available boat type Laerling [8]. It has a length of 3.72 m and consists of a 60 kg keel-ballast, which will bring the boat upright even from the most severe heeling. Including batteries the overall weight of the boat is about 300 kg. It currently features a conventional sloop rig. The sail area of mainsail and foresail together is 5.4 m^2. The average power consumption of the ASV Roboat is approximately 35 W. This measurement was taken during a test sailing on the Baltic Sea at an average wind speed of 6.5 m/s.

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The main power source of the ASV Roboat is a set of solar panels providing up to 285 W_p of power during conditions of full sun. 285 W_p corresponds to approximately 30 W of average output over a whole year under central European weather conditions [5, 12]. To cover the night period, electricity is stored in two deep-cycle batteries of 1.92 kWh together (80 Ah at 12 V each).

In order to be able to operate the boat at least for a limited period in conditions of reduced sunlight (night, bad weather) or if the solar power system breaks down, the boat is also equipped with a direct methanol fuel cell (EFOY Pro 1600). It delivers 65 W and features as a backup energy supply. The fuel tank contains 28 l of methanol. With a methanol consumption of 1.11 l/kWh as stated in the data sheet, the boat can operate about a month with the fuel cell as its only source of electricity.

The boat is currently showing a slightly negative energy balance. The drive for the sail trim has been identified to be one of the largest consumers in the entire system. Therefore, a balanced rig design as a replacement for the current sloop rig on ASV Roboat has been analysed with regard to potential energy savings. Table 1 gives an overview of the power consumption of the current version of ASV Roboat. It can be seen that the sail gear is the biggest consumer beside the main computer on board.

Component	Model	Power	Pct.
Embedded PC	VIA EPIA-MIII	15.20 W	44.0 %
Power supply	ATX	0.31 W	0.9 %
GPS receiver	Maretron GPS100	1.80 W	5.2 %
Compass	Maretron SSC200	1.62 W	4.7 %
Depth, speed, water temperature sensor	Maretron DST100	0.58 W	1.7 %
NMEA2000 protocol converter	Maretron USB100	1.82 W	5.3 %
Weather station	Airmar PB200	2.64 W	7.6 %
WiFi access point	Buffalo WHR-HP-G54	3.4 W	9.8 %
3G modem	HUAWEI E220	2.5 W	7.2 %
Satellite modem	Iridium SBD 9601 (switched on 2 min/h)	0.06 W	0.2 %
Sail gear	self-construction (non-balanced sloop rig)	4.58 W	13.3 %
Rudder gear	self-construction (balanced rudder)	0.02 W	0.1 %
Overall sum	**34.53 W**		

Table 1 Power consumption of ASV Roboat (September 2011)

2 Research hypothesis

The general aim of the presented work is to evaluate the effect of a balanced rig on power consumption and sailing performance. The aim of the simulations described below is to validate the following hypotheses:

1. A balanced rig provides great potential to save power. Based on our own experience with the balanced rudder system of the ASV Roboat, we anticipate a potential saving of at least 50 % from a balanced rig design.
2. The sailing performance is not negatively affected by the use of a balanced rig instead of a sloop rig.

3 Methodology

On a conventional sloop rig, which is the most common rig type on sailing vessels, relatively high power is needed to tighten the sails against wind force. As being self-sufficient in terms of energy is one of the major goals in robotic sailing, the rig design has become the focus of attention. A balanced rig design (also known as Balestron rig, Aerorig^{TM}, swing rig, and EasyRig^{TM}) offers great potential for saving power [1, 9]. A balanced rig consists of an unstayed mast carrying a main and jib (see Fig. 1(b)). The main boom extends forward of the mast (the mast passes through the boom) to the tack of the jib. The main and jib are sized in such a way that the force from the mainsail is slightly stronger than that from the jib. That is, the combined centre of effort is just behind the mast.

Balanced rigs have been used on the autonomous sailing boats *Avalon* [6], *VAIMOS* [4] and *IBoat* [2]. Furthermore, most of the rigid wing sails used on robotic sailing boats can be considered to be balanced rigs [3, 10].

We have simulated several points of sail with the corresponding sail positions for a wind speed of 6 m/s. Figs. 1(a) and 1(b) show the two models which have been compared. Mast height, sail area and sail shape have not been modified.

For this study we used the software Star CCM+ for the simulation process, Icem Ansys for the preprocessor and Rhinoceros for the design. Firstly, the existing geometry (which includes many extraneous details) has been modified in Rhinoceros to leave only the elements which affect the simulation - mainly the upper side of the sailboat.

Both sails have been divided in ten vertical stripes parallel to the axis of rotation. The forces on each of the stripes are used to calculate the overall torque for each of the two sails. Table 2 shows the parameters used in the simulation process.

(a)

(b)

Fig. 1 Analysed rig designs: (a) original sloop rig and (b) modified balanced rig

Space	three dimensions
Movement	stationary
Motion	stationary
Material	gas
Flow	segregated flow
Equation of state	ideal gas
Time	steady
Viscous regime	turbulent
Reynolds average turbulence	k-epsilon turbulenc

Table 2 Simulation parameters

4 Results and conclusions

Simulations have been carried out for several true wind angles from 30 deg to 180 deg. The torques caused by the wind forces acting on the sails have been analysed and have shown a mean energy saving of 68 %. Fig. 2 shows the energy savings for the simulated points of sail.

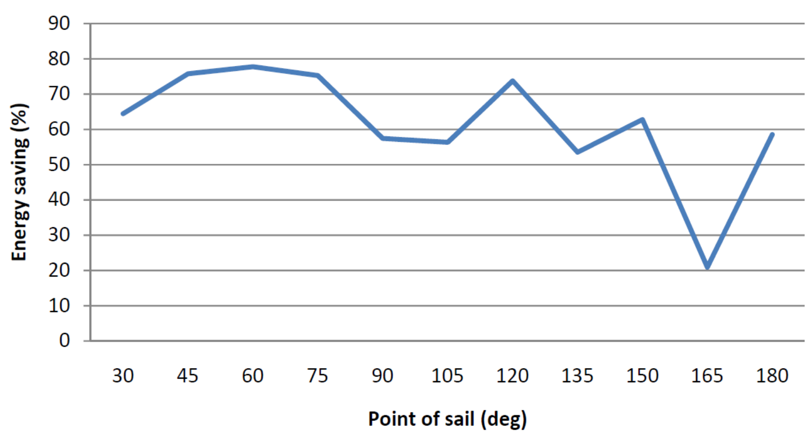
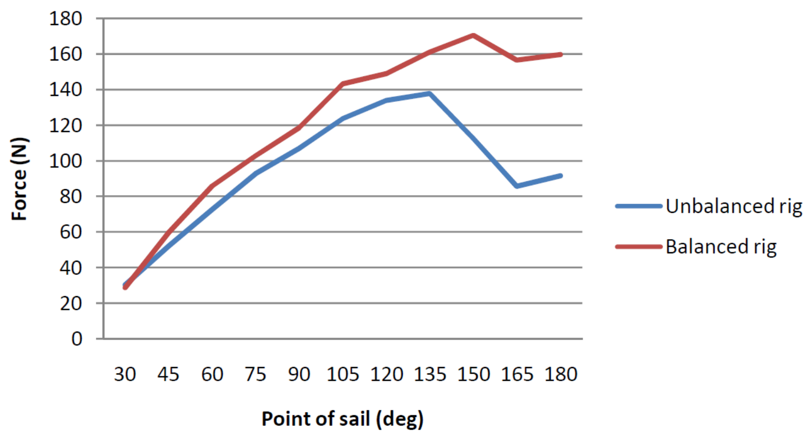


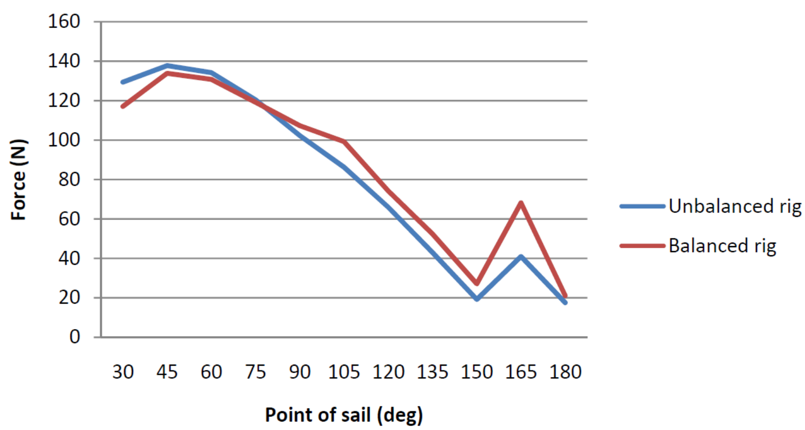
Fig. 2 Energy savings (reduction of the sail torque) for the simulated points of sail: 0 in irons, 180 running downwind

Furthermore, the forward and lateral forces on the boat have been simulated (see Fig. 3). The results show that the forward force is similar on close hauled courses, but is significantly higher for the balanced rig when running downwind. The lateral force, which leads to lateral drift, is not significantly affected by the change of the rig.

According to the simulation a balanced rig provides the theoretical potential of saving approximately 68 % of power on the sail drive without negative implications on the sailing performance. This value reflects only the expected reduction of the



(a)



(b)

Fig. 3 Results of performance analysis: (a) forward force and (b) lateral force

sail torque and therefore assumes a degree of efficiency in the sail drive of 100 %. Therefore, the percentage of power saving in practice might be slightly smaller as there is a certain fixed amount of power consumption for the sail gear, regardless of the torque on the sails. However, the simulation results are promising and useful as a first approximation. It is planned to validate and further investigate the influence of a balanced rig design on power consumption in real world experiments on the ASV Roboat.

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