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Design of a Twin Hull Based USV with Enhanced Maneuverability

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Abstract: This paper provides an overview of the development of a catamaran-like autonomous surface vessel. The vessel is intended to serve as an experimental platform to study algorithms for control, sensor data fusion as well as path planning and collision avoidance. The mechanical design, the electronics and software architecture is described together with the sensor and actuator setup. The propulsion system comprises of two azimuth thrusters with limited azimuth angles. This concept provides additional degrees of freedom resulting in an overactuated control system. A mathematical model of the vessel has been adapted and implemented for model based control strategies, simulation and hardware in the loop testing. In this paper some results of the parameter identification process are presented. For the overactuated system a control allocation algorithm has been developed.

Keywords: USV conception, control allocation, parameter identification

1. INTRODUCTION

The development of autonomous vehicles has been a popular research topic for the last decades. Still, one major goal is to increase autonomy in such a way that the vehicle could operate safely in populated, man made or natural environments. In this regard the most popular project currently is the Google driverless car. Google has been the first receiving a license for driverless cars for the streets of Nevada (Marks, 2012). For the maritime environment there are many projects related to the development of autonomous vehicles as well. In 1993 the MIT Sea Grant College started to develop the first Unmanned Surface Vehicle (USV) ARTEMIS (Manley, 1997). ARTEMIS is a 1/17 replica of a fishing trawler. The main research topic of this project was to develop a navigation and control system. Additionally, some high level tasks like automated bathymetry have been considered. However, ARTEMIS was not able to operate at open sea because of its small dimensions. Therefore, the MIT developed a second USV called ACES. Building upon the experience of ARTEMIS they decided to use a twin hull structure because of better roll stability.

After the MIT started the development of USVs many other projects for military, civil and academic research have been carried out. A lot of different USV approaches e.g. high speed vehicles for military tasks or slow speed vehicles for measurement tasks have been presented in (Motwani and Analysis, 2012; Bertram, 2008). An overview focused on civil USV projects was provided by Manley (2008). Caccia (2006) presents the design trends and technological developments for USVs of the last decades and additionally identifies some research topics e.g. "Modeling and Identification", "Guidance and Control" and "Mission Control".

In the following the most important twin hull approaches are shortly recalled. Most of these approaches have been developed to reduce the cost of measurement tasks in oceanographic research. The MIT developed two twin hull USVs for collecting bathymetry and hydrographic data, ACES presented by Manley (1997) and AutoCat presented by Manley et al. (2000). The University of Rostock developed the measuring dolphin MESSIN for water monitoring (Majohr and Buch, 2006). The catamaran Charlie has been developed in the SESAMO project by CNR-ISSIA for sampling the surface microlayer of the Antartica (Caccia et al., 2005). Caccia et al. (2006) also present some work for modeling and identification of twin hull USVs with differential drives. Later they enhanced the vehicle with a rudder based steering system (Caccia et al., 2008). The Springer vehicle was developed by the University of Plymouth (Plymouth, U.K.) for sensing, monitoring and tracking of water pollution (Naeem et al., 2006, 2008). The Autonomous Systems Laboratory at the Instituto Superior de Engenharia do Porto (Porto, Portugal) has developed several autonomous catamarans for rivers and estuarine environments. ROAZ, ROAZ II and SWORDFISH. ROAZ and ROAZ II were set up for environmental monitoring like bathymetry of riverbeds, estuaries, dam basins and harbours (Ferreira et al., 2006a, 2009). The SWORDFISH is developed as a relay for air-to-underwater communication (Ferreira et al., 2006b, 2007). The Instituto Superios Tecnico-Instituto de Sistemas e Robotica (IST-ISR, Lisabon, Portugal) developed an autonomous catamaran DELFIM for marine data acquisition and as an acoustic relay for a communication between a support vessel and an autonomous underwater vehicle (Pascoal et al., 2000). They also carried out some work for a controlling and navigation system for trajectory tracking and path following (Alves et al., 2006).

CaRoLIME [1], currently under development at HTWG Konstanz is a twin hull USV for rivers and inland waters. In Fig. 1 it is shown operating on Lake Constance. It has been developed specifically for measuring and surveillance tasks. Therefore, it can be equipped with several sensors e.g. sidescan sonars, echolot or water samplers. In a first step the vehicle itself has been designed and a navigation and control system has been developed and integrated. In this article we present the mechanical and electronic design in section 2. The software design is presented is section 3. The mathematical model and the parameters identification process are described in section 4. A description of the control allocation is provided in section 5. The paper finishes with a brief summary with conclusion and suggestions for future work.

Fig. 1. CaRoLIME: USV of the HTWG Konstanz

2. VEHICLE DESIGN

The vehicle design is divided in five parts: hull design, propulsion design, electronic devices, sensors selection and communication link. The main design goal was to get a prototype to develop navigation and control algorithms. The size, weight and robustness of the vehicle is optimized to test navigation and control algorithms efficiently. For this purpose the vehicle should be manageable by just one or two persons. The weight of the current setup is about $224kg$. Using a launching trolley makes it possible for a single person to handle the prototype. The vessel is capable to carry $120kg$ of payload, providing ample headroom to attach more sensors for future applications. Detailed information about the vehicle parameters is listed in Table 1. The most impact to the vehicle's weight is caused by the rechargeable batteries. These batteries provide the power for all the electrically-driven thrusters and for all electronics. Currently, rechargeable lead-gel batteries with a capacity of 80Ah are used. These batteries provide an operation time of about three hours in full speed mode. For future projects these batteries should be replaced by lithium-ion batteries to enhance the operating time. In the current configuration the vehicle is equipped with ultrasonic sensors for close range distance measurements. With these sensors only a collision avoidance with static obstacles is possible. For future projects it will be possible to extend the configuration with additional sensors like automotive radar sensors for enhanced obstacle detection or sonar sensors for bathymetry. For localization and vehicle state estimation a GPS receiver, a compass and IMU sensors are used.

Table 1. Technical data

Length:	$2.5m$
Width:	$1.2m$
Weight:	$224kg$
Additional Payload:	$120kg$
Electric Motor Power (each):	$600W$
Supply Voltage Level:	$12V$
Power capacity:	$80Ah$

2.1 Hull Design

For USVs a catamaran-like twin hull design is selected quite often because of the increased roll stability in contrary to single hull designs. In this project the focus is put on a robust, simple and low-cost hull. Thus, a polymer hull is preferred over a fiberglass one because of the increased robustness. To match the low-cost requirement the hulls of a single paddleboat MOB.Y SPLASH [2] are used. These hulls are not optimized subject to hydrodynamics but to robustness. If for future projects a hydrodynamic optimization is required this could be easily done by adding some extensions to the stern and the bow of the hulls.

2.2 Propulsion Design

For the propulsion unit externally stern mounted thrusters with panning units like azimuth thrusters are used. The panning unit includes a lock mechanism to fix the thrusters parallel to the longitudinal axis for a differential drive mode. This makes it possible to analyze the potential of a simple differential drive model as a starting point. For more complex tasks like docking, dynamic positioning or trajectory tracking with heading control it is beneficial to make use of the additional degrees of freedom that are provided by panning the thrusters. Thus, a comparison between control algorithms using underactuated and overactuated control can be done. Because of the possibility to invert the rotating direction of the propeller the operating range of the panning unit is limited to 180°.

2.3 Electronic Devices

The electronic devices are required to run the software components and to connect sensors and the motors of the propulsion unit. An overview of the electronic system including motors and sensors is shown in Fig. 2. To run the main software for communication and mission handling an embedded platform with an arm processor (Pandaboard) is used. For the control algorithms a rapid control prototyping unit MicroAutoBox (MABX) is deployed. This platform is directly connected to the motor-driver for the thrusters and the panning units. Because control algorithms require data with a high update rate the IMU sensors and the rotary encoder are also connected directly to the MABX. For the motor-drivers commercial products with PWM and analog input are used. A Sabertooth 2x60 from Dimension Engineering is used for the thrusters and

[1] Catamaran Robot for Locomotion In Maritime Environments

[2] http://www.mob-y.de/splash.html