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Robotic Boat Setup for Control Research and Education ⋆

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Abstract: In this paper a robotic boat setup for research and education in control is presented. It was designed for students to develop their practical experience and validate theoretical results at the course "Control Methods for Robotic Applications", which is being taught at the Department of Control Systems and Informatics of ITMO University. Four use cases of this setup are suggested in the paper. They are aimed to design controllers of various structures.

Keywords: Control education, Control applications, Robotics, Ship control, Control system design.

1. INTRODUCTION

It is significantly important to develop both theoretical and practical experience in any applied science including control theory. Understanding of lecture material will be much easier for students if they have opportunity to carry out experimental studies testing various book-learning results. Thus, robotic setups are extremely useful for educational and research control purposes. Recently mobile robots and quadcopters (Pyrkin et al. (2014a,b)) have become popular in conducting various experimental studies. They can be constructed by students or purchased ready-made. For example, Lego Mindstorm NXT can be used to construct simple mobile robots equipped with actuators, sensors and encoders (see Bobtsov et al. (2011a); Kolyubin et al. (2012); Pyrkin et al. (2013a)). In Bobtsov et al. (2009) Lego is used to construct a movable platform for the Mechatronic Control Kit to stabilize the inverted pendulum under condition of its linear movement.

In Zhang and Liu (2012) the expected-time optimal path planning problem for mobile robots is addressed and feasibility of the proposed approach was confirmed by its application to the mobile robot PowerBot. In Botao et al. (2013) the same PowerBot is used for experimental study of optimal path planning for multiple target search.

Another example is robotized boats. Constructing such plants is more sophisticated since they are supposed to move in water. So, the requirements for hardware design are higher than for other types of robots. Marine robots should have a watertight body and lightweight facilities.

There are laboratories focused on design and investigating control and modeling approaches for vessels. In Bo et al. (2015); Bø et al. (2015) the simulator of marine vessels and power plant is presented. The paper Bo et al. (2015) provides detailed description of all subsystems of the vessel and their interconnections. Especially the integration of power and positioning systems is studied. Some case studies of the simulator (dynamic positioning with disturbances, power bus reconfiguration, energy supply) are shown in this work.

In this work a robotic boat setup for research and educational purposes is presented. The rest of the paper is organized as follows. Section 2 is devoted to the overview of the robotic boat setup. The detailed description of the setup and its components is presented in Subsection 2.1. Interconnections between the subsystems, the scheme of the closed-loop system and operation strategy are shown in Subsection 2.2. The capabilities of the setup are illustrated in Section 3 by the following use cases: robust controller design (Subsection 3.1), anti-windup compensation (Subsection 3.2), adaptive tuning of the control parameters (Subsection 3.3), and identification of the plant parameters (Subsection 3.4). The conclusion of the paper and direction of further work are presented in Section 5.

2. SETUP OVERVIEW

The robotic boat setup (RBS) depicted in Fig. 1 was designed to develop practical experience of students at the course "Control Methods for Robotic Applications", which is being taught in the Department of Control Systems and Informatics of ITMO University.

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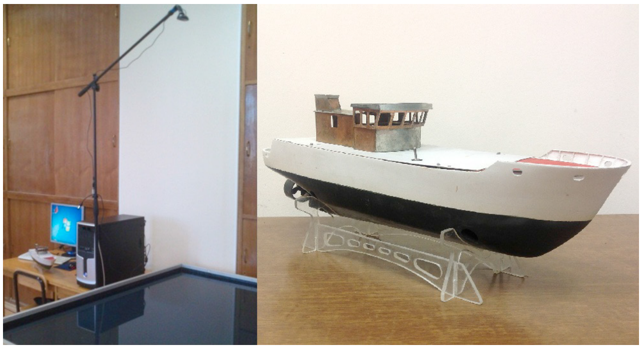

Fig. 1. Robotic Boat Setup

2.1 Structure of RBS

The main parts of the setup are the robotic boat, experimental basin, digital camera with the tripod, computer, a gamepad used for remote control.

The robotic boat is a copy of a real trawler ship represented at a scale of 1 : 32. Its dimensions are $(0.432 \times 0.096 \times 0.052)\, m$. It contains the main engine, two tunnel thrusters on the bow and stern and servo drive for heading control. The hardware also includes the battery and three printed-circuit boards. The first one contains the following elements:

- input ports;
- main microcontroller ATmega32;
- voltage stabilizers $5\,V$ for the microcontroller and $3.3\,V$ for Bluetooth module;
- protection rectifier.

The second board includes:

- Bluetooth module BTM-112 (U1) for wireless communication;
- signal conversion unit UART.

The third board is comprised of three drivers for the actuators. The PWM signal received by these drivers is processed by the auxiliary microcontroller ATmega8 and then through the field-effect transistors block is applied to the motors.

The experimental basin represents the workspace of the boat. It is made of plywood sheets with dimensions are $(1.50 \times 1.10 \times 0.1)\, m$. It holds about $150\, L$ of water. The internal surface is covered by sealant and painted with dark color for simplification of the computer vision.

On real surface vessels the task of coordinate determination may be carried out by satellite navigation systems. At the scale of this educational setup it is suitable to use the computer vision instead of the latter. The digital camera is attached to the tripod above the basin. The captured image is transmitted as a RGB signal to the computer,

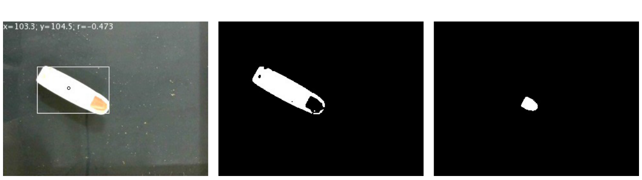

Fig. 2. Visualization of the computer vision system

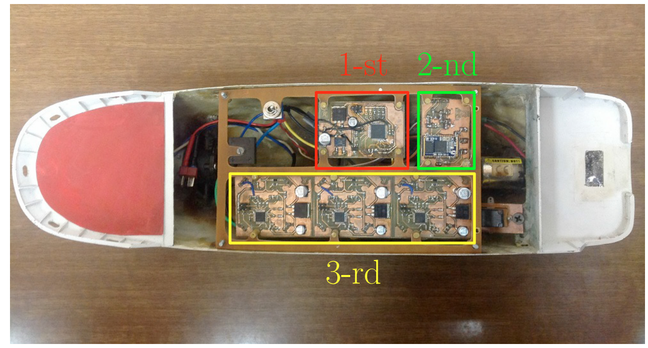

Fig. 3. The printed-circuit boards placed inside the boat

where it is processed in order to get the coordinates of the boat. The camera was chosen without automatic focusing to reduce noise in the measurement channel.

2.2 Operation Principle

The position and orientation of the boat as any rigid body on a plane can be specified by three independent variables: the linear coordinates x, y and angle ψ, which is usually called heading in marine navigation and control systems. Since the boat has the three controlled actuators (the main engine and two thrusters) and three output variables ($x(t)$, $y(t)$, $\psi(t)$), it should be mathematically described by the MIMO model of the form

$$x(t) = F(P_e, P_b, P_s, \alpha_e), \tag{1}$$

$$y(t) = G(P_e, P_b, P_s, \alpha_e), \tag{2}$$

$$\psi(t) = H(P_e, P_b, P_s, \alpha_e), \tag{3}$$

where P_e, P_b and P_s are the inputs of the main engine, bow thruster and stern thruster, respectively, and α_e is the value of steering.

To simplify the control strategy, the decomposition of the model (1) is performed as follows

$$P_x(t) = P_e(t), \tag{4}$$

$$P_y(t) = P_b(t) + P_s(t), \tag{5}$$

$$M_\psi(t) = -\alpha_e(t)P_e(t)L_e + P_bL_b + P_sL_s, \tag{6}$$

where $P_x(t)$, $P_y(t)$ and $M_\psi(t)$ are the generalized forces and moment (see Fig. 5), L_e, L_b and L_s are distances

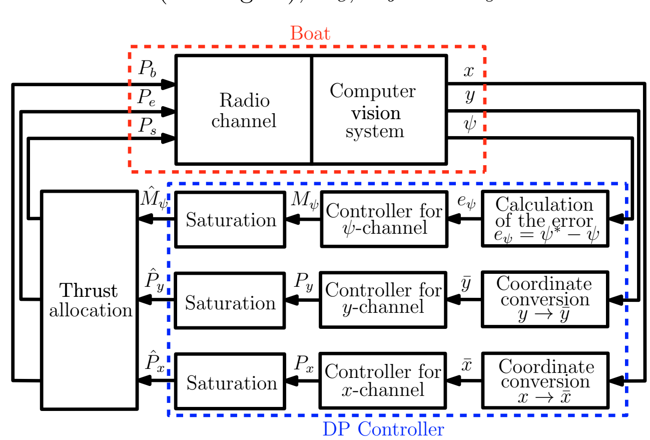

Fig. 4. Interconnections between the subsystems