Università degli Studi di Padova

Dipartimento di Ingegneria dell'Informazione

DEPARTMENT OF INFORMATION ENGINEERING

BACHELOR'S DEGREE IN COMPUTER ENGINEERING

Fusing vision and inertial measurements for autonomous navigation in narrow channels

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Abstract

This thesis addresses the design, development, and validation of an automatic system for detecting roll, pitch, and yaw of an autonomous boat. The main objective is to create a low-cost, low-power, and easily transportable solution capable of accurately determining the boat's attitude. To achieve this, both computer vision and an onboard inertial sensor will be used. By fusing data from these two sources, a precise estimate of the boat's attitude will be made available to the entire system. For the computer vision part, two cameras will be used to exploit stereo vision. The attitude estimation will be processed on a Raspberry Pi 5, chosen for its low cost. For this purpose, ArUco Tags—two-dimensional fiducial markers commonly used in robotics and augmented reality for pose estimation—will be employed. Regarding the inertial sensor, the onboard device will provide velocities and accelerations along the three axes. Finally, an extended Kalman filter, which will utilize both inertial and computer vision data, will be applied to reduce drift and improve the accuracy of roll, pitch, and yaw estimation.

Introduzione

In recent years, the field of **autonomous systems** has played an increasingly central role in robotics. All this has also been made possible thanks to solutions such as **Robot Operating System 2 (ROS2)**, which is one of the platforms for the development of robotic applications. This has been achieved thanks to its *modular architecture*, support for *real-time communication*, and its *open-source* nature, which has made it an excellent choice even for advanced robotic systems.

This thesis is part of the **Autodocking project**, focused on the ability of a boat to navigate and dock autonomously. Although the structure and the basic control systems were already in place, a **computer vision–based system** for autonomous navigation was missing. My contribution was related to the creation of a **ROS2 node**; more specifically, I dealt with the entire **pipeline** ranging from **image acquisition**, **attitude estimation**, and subsequent **sensor fusion** with the inertial sensor data. To achieve this, I needed a **ROS2 node** that handled the acquisition of images from the various cameras installed on the boat and their publication on a *topic*, so that my algorithm could access them.

Chapter 1

Introduzione

1.1 Autonomous Surface Vehicles: challenges and applications

Unmanned Surface Vehicles (**USVs**) are particular surface vessels capable of navigating without the presence of a human crew to maneuver them. They can be *remotely operated* through radio or satellite communication, or be completely *autonomous* and controlled by a computer or artificial intelligence; in this case, they are referred to as **Autonomous Surface Vehicles (ASVs)**. ASVs aim to make journeys *safer*, *reduce costs*, *increase operational continuity*, and carry out *prolonged missions* in *complex* and even *risky* situations for humans.

All this has been made possible thanks to significant technological evolution in **sensors** (satellite, IMU, cameras, LIDAR, radar, etc.), major developments in **robotics libraries**, and onboard **computational power** that is increasingly greater and more affordable. Despite this, the **marine environment** presents major challenges. For example, the *plane of the sea surface* is not a fixed reference but changes independently of the boat's movements; the surface creates *reflections* that can interfere with instrumentation; and *wind and waves* can put stability control systems to the test. In the marine context, therefore, **attitude estimation** (roll, pitch, and yaw) is essential, as it is decisive both for the *success of the journey* and for the *precision required in maneuvers*, such as docking.

The main challenges concern **sensors and algorithms**. The first challenge involves **navigation with GNSS** (Global Navigation Satellite System), which degrades in proximity to port infrastructures, bridges, or areas with many vertical obstacles, as part of the visible satellites are lost. This problem has been partly mitigated with **inertial sensors (IMU)**, which, however, suffer from another issue: *drift*. The second challenge is the **detection of possible obstacles** at sea, such as buoys, debris, or even other vessels, often under conditions of *reduced visibility* or *reflections*. The third challenge is **control and stability**, made complex by *wave motion* that often causes very rapid variations. The last challenge is the ability to make **real-time decisions**, including very quick changes dictated by sudden shifts in the operational situation.

Despite the criticality of these challenges, ASVs are used in various **applications**. In the **industrial field**, they are employed for *infrastructure* *inspection* or *short-range logistical support.* In **defense and security**, they are used in *special operations* such as *explosive ordnance disposal.* In the **environmental field**, they are used for *monitoring environmental parameters* and *collecting meteorological data* over extended time horizons, thereby reducing risks for crews.

Within this framework, the present thesis focuses on one main issue: obtaining an **accurate real-time estimation** of the boat's attitude. To achieve this, **computer vision techniques** (stereo vision and ArUco markers), **inertial measurements** through the IMU, and an **Extended Kalman Filter** will be used to fuse the data, with the aim of *improving the reliability of the estimation.* Vuoi che ti prepari anche una versione con colori (ad esempio blu per concetti tecnici e

Figure 1.1: Image caption

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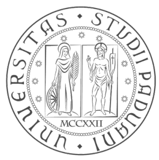

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Inserimento bibliografico [1] [2] [3]

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