Coordinated Path-Following Control of Multiple Autonomous Underwater Vehicles

A. Pedro Aguiar, Reza Ghabcheloo, António M. Pascoal, and Carlos Silvestre
Institute for Systems and Robotics and Department of Electrical Engineering
Instituto Superior Tecnico
Lisbon, Portugal

ABSTRACT

The concept of multiple Autonomous Underwater Vehicles (AUVs) cooperatively performing a mission offers several advantages over single vehicles working in a non-cooperative manner such as increased efficiency, performance, reconfigurability, robustness and the emergence of new capabilities. This paper introduces the concept of coordinated path-following control of multiple AUVs. The vehicles are required to follow pre-specified spatial paths while keeping a desired inter-vehicle formation pattern in time. We show how Lyapunov-based techniques and graph theory can be brought together to yield a decentralized control structure where the dynamics of the cooperating vehicles and the constraints imposed by the topology of the inter-vehicle communications network are explicitly taken into account. Path-following for each vehicle amounts to reducing an appropriately defined geometric error to a small neighborhood of the origin. Vehicle coordination is achieved by adjusting the speed command of each vehicle along its path according to information on the positions of a subset of the other vehicles, as determined by the communications topology adopted. We illustrate our design procedure for underwater vehicles moving in three-dimensional space. Simulations results are presented and discussed.

KEY WORDS: Coordination of autonomous vehicles; Path-following; Autonomous Underwater Vehicle (AUV); Nonlinear control;

INTRODUCTION

The ever increasing sophistication of autonomous underwater vehicles (AUVs) is steadily paving the way for the execution of complex missions without direct supervision of human operator. A key enabling element for the execution of such missions is the availability of advance systems for motion control of AUVs. The past few decades have witnessed considerable interest in this area (Fossen, 1994; Leonard, 1995; Encarnação and Pascoal, 2000; Alonge et al., 2001; Jiang, 2002; Peteressen and Nijmeijer, 2003; Aguiar and Hespanha, 2004; Aguiar and Hespanha, 2007; Aguiar and Pascoal, 2007b). The problems of motion control can be roughly classified into three groups: point stabilization, where the goal is to stabilize a vehicle at a given target point with a desired orientation; trajectory tracking, where the vehicle is required to track a time parameterized reference, and path-following, where the vehicle is required to converge to and follow a desired geometric path, without a timing law assigned to it. For underactuated AUVs, i.e., vehicles with a smaller number of control inputs than the number of independent generalized coordinates, motion control is still an active research topic.

Current research goes well beyond single vehicle control. In fact, recently there has been widespread interest in the problem of coordinated motion control of fleets of AUVs (Stilwell and Bishop, Dec. 2000; Encarnação and Pascoal, 2001; Lapiere et al., 2003; Skjetne et al., 2002; Ghabcheloo et al., 2006b; Ihle et al., Dec 2006). The concept of multiple AUVs cooperatively performing a mission offers several advantages (over single vehicles working in a non-cooperative manner) such as increased efficiency, performance, reconfigurability, robustness, and the emergence of new capabilities. Furthermore, each vehicle can in principle carry only a single dedicated sensor (per environmental variable of interest) making it less complex, and consequently increasing its reliability.

From a theoretical standpoint, the coordination of autonomous robotic vehicles involves the design of distributed control laws in the face of disrupted inter-vehicle communications, uncertainty, and imperfect or partial measurements. This is particularly significant in the case of underwater vehicles for two main reasons: i) the dynamics of marine vehicles are often complex and cannot be simply ignored or drastically simplified for control design purposes, and ii) underwater communications and positioning rely heavily on acoustic systems, which are plagued with intermittent failures, latency, and multi-path effects. It was only recently that these subjects have started to be formally tackled, and considerable research remains to be done to derive multiple vehicle control laws that can yield good performance in the presence of severe communication constraints.

Motivated by the above considerations, this paper introduces the concept of coordinated path-following (CPF) control of multiple AUVs. The vehicles are required to follow pre-specified spatial paths while keeping a desired inter-vehicle formation pattern in time. This problem arises, for example, in the operation of multiple AUVs for fast acoustic coverage of the seabed. In this application, two or more vehicles are required to fly above the seabed at the same or different depths, along geometrically similar spatial paths, and map the seabed using identical suites of acoustic sensors. Larger areas can be covered