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Planar path-following tracking control for an autonomous underwater vehicle in the horizontal plane

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ABSTRACT

The combined problems of path-following tracking control for an under-actuated autonomous underwater vehicle (AUV) on the horizontal plane are addressed in this paper. Given three types of smooth and 2-D desired trajectory including straight line path, curve path and circular path in the horizontal plane, the designed path-following control algorithm uses AUV kinematic and dynamic models with cross-track error method and line of sight to compute the desired orientation and velocities, at the same time it also forces the AUV to tracking the desired three types of path which are specified in advance. Numerical simulation is presented to validate the proposed control approach. Simulation results illustrate the good performance of the control system proposed with tracking errors converge to zero fast and smoothly in exponential form at last, which show that the tracking effect remains good and satisfactory that can provide an effective theoretical guidance and technical support for the control system design of the AUV in future.

1. Introduction

The sea covers approximately two-thirds of the earth surface area which contains a large amount of resources. Unfortunately, the extent and depth exploration of the ocean is still in a relatively superficial stage. The sea which is also one of the four human strategic development spaces has been the world's major power strategic competitive position for long. Nowadays the thalassocracy is paid more and more attention by more countries. The ocean not only has a great influence on the ecological environment, but also it has a profound impact on human society. With the increasing depletion of land resources, the ocean is more concerned to the country's major interests and it also has become the focus attention of the world. Entering the 21 st century, the coastal countries accelerate the development of marine science and technology, adjust the military strategy and strengthen the maritime rights and interests struggle. The marine development is an important research area and also becoming one of the main battlefields of the world in the 21 st century [1–3].

Autonomous underwater vehicle (AUV) is a very effective tool in the human sea activities. The AUV which has no towing cable can be autonomous navigating in three-dimensional space in the water according to the requirements of the task of the pre mission with its own power. It has the characteristics of far range, intelligence, concealment, mobility and economy. It also has a wide range of applications in both civilian and military areas. Military aspects are such as theater reconnaissance, detection and eliminate mine, submarine warfare, maritime warning, blockade routes or ports, assault to the enemy ships or submarines, damage to enemy oil facilities and communication network, underwater relay communication and so on; civil

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aspects are such as marine resources exploration and exploitation, monitoring of temporal and spatial changes of marine environment, submarine topography investigation and surveying and deep-sea technology, underwater facilities inspection, ocean rescue and salvage and so on [4–6].

AUV technology is a new field in the development of marine engineering technology which is of great military and economic value and also has been widely concerned. Therefore, many countries are competing to develop high technology underwater equipment. AUV's research began in 1950s and developed to a considerable level from 1970s to 1980s. At the end of the 1980s, with the development of microelectronics, computer, artificial intelligence, small navigation equipment, high precision control system, high performance software technology, dense energy and other high technology development and marine engineering and military needs, the AUV has become hotspot research of marine technology in the developed countries.

The United States is one of the earliest countries in the research and development of the AUV and has most product types and research units with the highest technology level. At present it has formed a series of mature products. Britain has mainly developed two kinds of underwater unmanned vehicle series, which is the unmanned underwater vehicle "Autosub" series for civil use and the "Tailsman" series for military use. ECA Company is the main R & D unit of France which has rich experience in the research and development of the AUV. In 1970s, the world famous PAP104 was developed by it. Germany has developed three types of unmanned underwater vehicles of MK "SeaOtter" which are marked as "SeaOtter" MKI, "SeaOtter" MKII and "SeaOtter" MKIID. The main R & D units are ATLAS MARIDAN and Germany's ATLAS group. Norway has mainly developed the "Hugin" series of unmanned underwater vehicles which "Hugin" 3000 is mainly used for civilian areas and "Hugin"1000 is mainly used in the military field. The main R & D units are the Norway National Defense Research Institute and Konsberg Company. Japan Marine Science and technology research and development center and the University of Tokyo are the main R & D units of the AUV which is mainly used in the field of civil field in Japan. China started this research late and the technology is relatively backward. Based on domestic and foreign technology progress, high starting point for the development of AUV technology to promote the development of marine science and technology and improve the level of marine development and utilization and protection of maritime rights and interests has important significance [7–9].

Over the past few decades, rapid progress in the AUV is steadily affording some scientists advanced tools for ocean exploration, long range survey, underwater pipelines tracking, scientific sampling and mapping maintenance and construction, search and rescue military applications and so on [10–13]. Besides their numerous practical applications, the AUV presents a challenging control problem since most AUVs are under-actuated because they have more degrees of freedom to be controlled than the number of independent control inputs. In addition, the AUV's kinematic and dynamic models are highly nonlinear, time-varying and strong coupled, which making the control design a hard work. If classical control systems designed for fully or over-actuated systems are directly used on the under-actuated AUV system, the resulting performance is significantly deteriorated or the control objectives cannot be achieved. The control method used should get rid of the dependence on the precise mathematical model, so it has great important theoretical and practical significance to study this issue. Path-following tracking requires the design of control laws to force the AUV to track an inertial desired trajectory. The 6-DOF AUV is decoupled into two reduced dynamical systems: a depth-pitch model that considers the motion in vertical plane and the plane-yaw model in the horizontal plane. The trajectory tracking problems of the AUV have been discussed in the last few years. The major solution methods of the trajectory tracking problems for the AUV are sliding mode control [14,15], cascade system method [16,17], backstepping technique [18,19], robust contro l [20], switching control [21], Lyapunov's direct method [22,23] and so on. A dynamic formation model was proposed and several algorithms were developed for the complex underwater environment in Ref [24]. where virtual potential point based formation-keeping algorithm was employed by incorporating dynamic strategies which were decided by the current states of the formation. The design of an output feedback controller for an AUV to achieve the task of path-following in vertical plane was presented in [25], where a static output feedback controller is designed and implemented on the nonlinear plant based on the linearized model, but this method cannot guarantee the tracking error to a minimum. In Ref. [26], it provides an experimental implementation and verification of a hybrid controller for semi-autonomous and autonomous underwater vehicles in which the missions imply multiple task robot behavior, but the authors didn't consider the influences which were caused by the non-diagonal term, nonlinear damping and time-varying environmental disturbance. The path-following tracking control of the AUV in the horizontal plane is more complicated compared with that in the vertical plane, because the displacement of the AUV on the horizontal plane can't be measured directly. It leads to the path-following tracking carry out only through the measurement of yaw angle and yaw angle rate.

Motivated by the work above, a solution to the path-following tracking control problem for an AUV in 2-D space was proposed. In this paper, we are especially interested in the combined problems of path-following control in 2-D space for an AUV. The goal of path-following tracking control is forcing the AUV to tracking the desired path and making the tracking errors converge to zero fast and smoothly. In order to design a controller that can meet the requirements of low tracking error and high stability, a sliding mode controller with line of sight and cross-tracking method was designed for the horizontal path-following tracking control of the AUV based on the kinematic and dynamic models. We specify three types of path-following tracking in the horizontal plane including a straight line path, curve path and circular path respectively to verify the performance and effectiveness of the proposed controller. Simulation results show that the path-following tracking control remains very satisfactory and the results that demonstrate the performance of the developed sliding mode control design which uses line of sight guidance and cross-track errors of the AUV are also presented and discussed.