IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received August 13, 2017, accepted August 28, 2017, date of publication September 8, 2017,
date of current version September 27, 2017.

Digital Object Identifier 10.1109/ACCESS.2017.2750322

Tracking a Duty-Cycled Autonomous Underwater Vehicle by Underwater Wireless Sensor Networks

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This work was supported in part by the Major Research Development Program of Hunan Province of China under Grant 2016JC2008, in part by the China Postdoctoral Science Foundation under Project 2016T90978, and in part by the National Nature Science Foundation of China under Grant 61604176, Grant 61633017, Grant 61773264, Grant 61471237, and Grant 61301223.

ABSTRACT The real-time position of an autonomous underwater vehicle (AUV) is always of great interest. With advances of technologies, underwater wireless sensor networks (UWSNs) become promising tools for AUV tracking. Due to the energy constraint of underwater nodes, energy saving is a key issue that affects all aspects of the design of a tracking scheme. In this paper, we propose a novel energy-efficient tracking scheme for an AUV to locate itself in time by UWSNs. We first design a tracking protocol considering the energy consumptions in both the AUV and sensor nodes (SNs). Particularly, the protocol is designed in two aspects: 1) the passive listening mechanism and duty-cycle strategy for the AUV and 2) the detection-based ranging packet transmission for SNs. Since the tracking protocol will inevitably affect the packet delivery between the AUV and SNs, we analyze the packet delivery success rate (PDSR) to shed light on the impact of system parameters on the tracking performance. To cope with non-linearity of the model and the intermittent observations mainly arisen from the effect of the tracking protocol, we adopt two extended versions of the original intermittent Kalman filter for tracking. They are intermittent extended Kalman filter and intermittent unscented Kalman filter. Simulation results demonstrate the effectiveness of the proposed tracking scheme, and reveal that the PDSR analysis provides a design guidance for parameter selection in system configuration.

INDEX TERMS Autonomous underwater vehicles (AUVs), tracking, energy-efficient, duty-cycle, underwater sensor networks (UWSNs).

I. INTRODUCTION

Autonomous underwater vehicles (AUVs) are becoming ubiquitous in oceanic applications for both commercial and military purposes, such as pipeline inspection, seafloor mapping, geohazard assessment, and anti-submarine warfare [1]. Location awareness enables the navigation, formation, and cooperation of AUVs [2], [3]. It is a key requirement for most AUV applications. However, the Global Positioning System (GPS) cannot be used underwater due to the rapid attenuation of radio frequency signals. The standard choice for underwater communications is to use acoustic waves. The AUV tracking resorts to inertial/dead reckoning (DR), acoustic transponder/modem based tracking, and geophysical techniques (e.g., optical and magnetic sensors) [2]. Most AUV tracking systems depend on DR sensors and transponder/modems. The main disadvantage of DR is that the estimation errors are cumulative. Thus, calibrations are usually performed by measuring the time of arrivals (TOAs) between AUVs and beacons via acoustic transponders/modem. With advances of sensing techniques, underwater wireless sensor networks (UWSNs) offer a promising calibration solution for AUV tracking. The main advantages of AUV tracking by UWSNs over conventional base line methods are flexibility, fault tolerance, and on-demand mission support [4]. However, to achieve AUV tracking by UWSNs encounters the following challenges. First, the energy constraints impose on the AUV and sensor nodes (SNs). Since both the AUV and SNs of UWSNs are usually built-in battery-supplied, it is difficult to replace or recharge it. Therefore, it is of great importance to reduce the energy consumption and maintain sufficient tracking accuracy. Second, variations of the sound propagation speed are introduced by the