Experiment on Simultaneous Localization and Mapping Based on Unscented Kalman Filter for Unmanned Underwater Vehicles

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This paper proposes a simultaneous localization and mapping (SLAM) scheme applicable to the autonomous navigation of unmanned underwater vehicles (UUV). A SLAM scheme is an alternative navigation method for measuring the environment through which the vehicle is passing and providing the relative position of the unmanned vehicle. An unscented Kalman filter (UKF) is utilized in order to develop a SLAM that is suitable for estimating the locations of the UUV and the surrounding objects when the UUV's motion is highly nonlinear. A range sonar is used as a sensor for collecting the data of the spatial information of the environment in which the UUV navigates. The proposed UKF-SLAM scheme was tested in experiments that used various 3 degrees-of-freedom motion conditions with a real UUV under a tank environment. The results of these experiments showed that the proposed SLAM algorithm was capable of estimating the position of the UUV and the surrounding objects in real environments, and that the algorithm will perform well in various conditions.

INTRODUCTION

Unmanned underwater vehicles (UUV) have become a main tool for underwater survey operation in scientific, military and commercial applications; the usage of these vehicles has also extended to the inspection of ship hulls (Walter et al., 2008) and underwater man-made structures (Martinez-Cantin and Castellanos, 2005; Kondo et al., 2006; Ribas et al., 2008) because of the ability of autonomous navigation. Since a GPS signal is not accessible underwater, the position of the UUV has usually been estimated via dead reckoning using an inertia measurement unit (IMU) and a kinematics model for vehicle motion. However, method-based dead reckoning is disadvantageous in that the error of navigation grows to be unbounded as navigation time elapses due to the drift produced when integrating the IMU's output; thus it is necessary to provide some assisting measure to prevent further accumulation of error so that ground-fixed relative positioning information can be obtained (Lee et al., 2005). Simultaneous localization and mapping (SLAM) is one of the techniques using measured data for resetting navigation error. SLAM is designed to simultaneously identify distinct objects of an unknown environment for which a prior map is not available, and then utilize the information to localize the vehicle’s trajectory (Smith et al., 1997).

Although any Bayesian estimation theory can be used in SLAM, many studies have applied an extended Kalman filter (EKF) to SLAM for indoor ground vehicles (Newman, 1999; Tardos et al., 2002), outdoor ground vehicles (Dissanayake et al., 2001) and underwater vehicles (Smith et al., 1997; Carpenter, 1998; Leonard and Feder, 2001; Hwang and Seong, 2005; Maki et al., 2006; Folkesson et al., 2008; Ribas et al., 2008) because EKF may be considered optimal when the assumptions that the system is locally liner and the probability density function (PDF) is the Gaussian distribution are satisfied (Welch, and Bishop, 2006). However, since if a nonlinear system cannot satisfy the locally linear assumption, the result estimated by EKF for that nonlinear system might yield a divergence, it is not adequate to apply EKF to SLAM for highly nonlinear systems. One of the alternatives to SLAM-based EKF is SLAM with an unscented Kalman filter. UKF (Julier and Uhlmann, 1997, 2004) estimates only the mean and covariance of the nonlinear system, as EKF does, but obtains the transformed PDF from the weighted sum of the evaluation of the nonlinear system equation in samples of prior PDF, the so-called sigma points instead of the Jacobian matrix of the nonlinear system equation.

Up to now, since UKF can produce a consistent, unbiased estimate even if the system is highly nonlinear, recent studies have tried to implement UKF into SLAM of UUV (Lee et al., 2006; Andrade-Cetto et al., 2005) and unmanned aero vehicles (Langelaan and Rock, 2005) with simulation and experiment. However, studies about SLAM with UKF for UUV have considered only simulation for performance verification. Thus a SLAM based on UKF for UUV will be proposed and will be verified through various experiments under tank conditions in our work. This paper proceeds as follows: Section 2 describes the SLAM based on the UKF suitable to a UUV with a range sonar system. Below we present the results of experiments under tank conditions, conducted to verify the proposed SLAM method. An experiment in the tank with a real UUV concludes this paper.

SLAM-BASED UKF

State Model

Let us consider the SLAM problem in which a UUV is navigating in the ocean with multiple objects located adjacent to where