論 文 の 内 容 の 要 旨

論文題目　A Method for Wide Area Survey of Seafloor
Using Multiple Autonomous Underwater Vehicles
(複数の自律型海中ロボットの連携による海底広域探査手法)

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Introduction

This paper proposes a new method for wide area survey of seafloor using multiple Autonomous Underwater Vehicles (AUVs). It has been difficult for conventional navigation method such as dead reckoning or inertial navigation to achieve wide area survey with high positioning accuracy only by AUVs and without any support. The proposed method is implemented to actual AUV “Tri-Dog 1” and “Tri-TON 1”. The performance of the method is verified using these AUVs through the tank test and sea experiment.

There are many observation targets in the environment of seafloor such as mineral resources, seafloor life colonies, and artificial lost objects. AUVs have a potential to observe the targets automatically, approaching them. Several navigation methods have been proposed in several research groups [1-2]. The survey have been conducted using multiple AUVs with surface aid [3]. Many of these existing studies are supported by surface aid or artificial references such as LBL (Long Base Line), and wide seafloor survey only by AUVs is difficult for limited observation coverage mainly caused by positioning range, low date of sound communication.

Proposed method

AUVs have to estimate self-position and pose to observe seafloor automatically. In the proposed method, one AUV is keeping stationary on the seafloor as a landmark and the other AUVs observe seafloor based on the landmark AUV. All AUVs have acoustic positioning sensors which can measure relative position among them. Wide area survey can be realized by alternating the landmark role among AUVs. Fig. 1 shows the concept of the method.

AUVs are divided into two groups, main AUVs and sub AUVs. The main AUVs consist of two AUVs which alternatively perform the landmark role. Sub AUVs constantly perform the moving role. All moving AUVs observe the seafloor with high positioning accuracy due to the landmark AUV. Fig. 2 shows the architecture of the proposed method for main and sub AUVs. The required technologies to realize the proposed method are the state estimation, state communication among the main AUVs, and mode control for alternating landmark navigation.

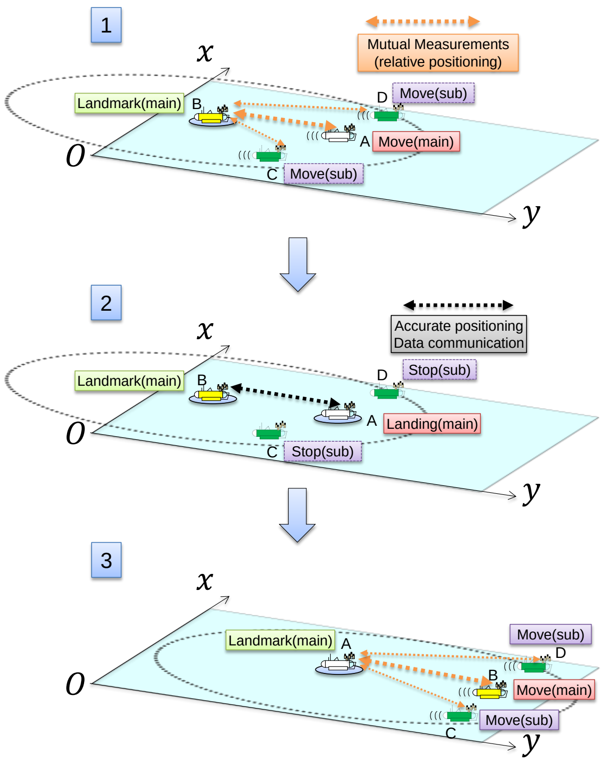

Fig. 1 Seafloor surveys using multiple AUVs.

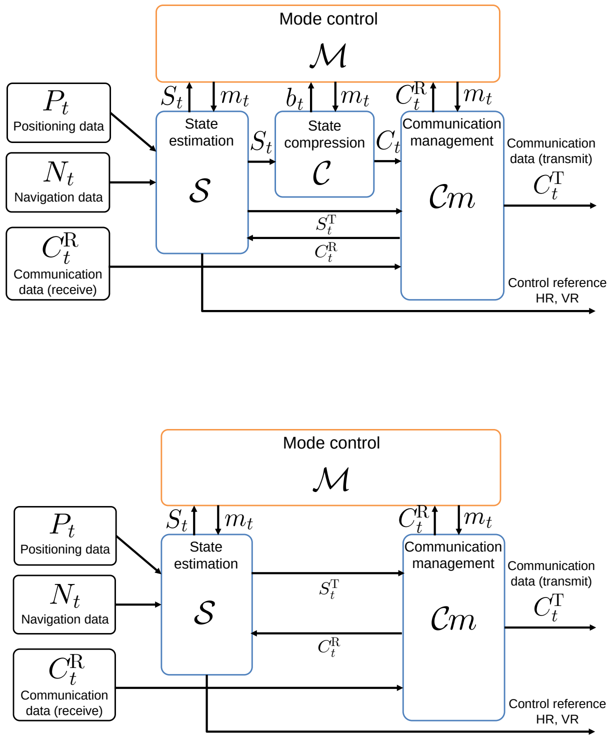

Fig. 2 Architectures of the multiple AUV navigation (Upper: Main AUVs, Lower: Sub AUVs).

State estimation

The moving AUV estimates the states using a particle filter, a stochastic state estimator that expresses the probability density of the states by a set of particles [4]. In the main AUVs, the moving AUV estimates the state of the landmark AUV as well as own state to express the states including positional relation between the landmark AUV and itself. It enables main AUVs to estimate the states accurately. Sub AUVs estimate only own state based on the landmark AUV in the main groups. It enables them to estimate the states accurately.

The particle filter updates the states through two phases: the prediction phase and the observation phase. In the prediction phase, the moving AUV estimates the states from its navigation sensors (the ground velocity sensor and one-axis heading rate gyro). In the observation phase, the states are updated from relative acoustical positioning measurements between the moving and landmark AUVs. Although standard state estimation alternatively performs the prediction and observation phase, in the proposed approach, AUVs estimate the states in the prediction phase, and update the states in the observation phase only when positioning measurements are performed.

State communication

Main AUVs estimate the states of both moving and landmark AUV. When AUVs exchange the landmark role, they should share the states estimated by the moving AUV without information loss. However, as the states are expressed by particles, complete state sharing is precluded by the typically low data rates of acoustical communications in underwater environments. To overcome this problem, the previously moving AUV (called as AUV A) compresses its estimated states before transmitting the information to the next moving AUV (called as AUV B), as detailed in the following procedure. (1) A lands on the seafloor and measures the mutual acoustical positioning between itself and B to converge the state uncertainties. (2) To reduce the communication data size, A compresses its estimated states by "particle clustering" using a clustering approach and a model evaluation method. (3) A transmits the compressed information regarding its estimated states to B. The AUVs can share the accurate information about states with small amount of data size.

Mode control

Each AUV needs to decide the own role to perform alternating landmark navigation. The current role is defined as navigation mode. AUVs decide own role based on the states, sensor measurements, and mutual acoustic communication with other AUVs.

Performance analysis

The performance of the proposed methods are examined through tank tests and sea experiments using the actual AUVs.

Through the tank tests, "Tri-Dog 1" and "Tri-TON 1" succeeded in alternating the landmark role 13 times and navigated about 180 m with high estimation accuracy. Estimation accuracy was suppressed within 1.0 m which was about 0.5 % of distance traveled. Both AUVs also succeeded in state sharing with small amount of data size.

In the sea experiments, the AUVs succeeded in 4 dives. The AUVs performed the process of alternating landmark navigation automatically. Especially in dive 4, they succeeded in 200 m distance navigation and obtained environmental data near seafloor. Through the post-processing simulation, it was verified that the estimation errors were within about 1.0 m (0.5 % of distance traveled) through the mission. The errors in case of the conventional navigation method (dead reckoning) expanded up to 10.0 m (5.0% of distance traveled). Fig. 3 shows the results of the experiments. Therefore, it was verified that the proposed method has sufficient performance of conducting wide seafloor survey with high positioning accuracy, which is enough for seafloor photo mosaicing and many other applications in the field of seafloor survey.

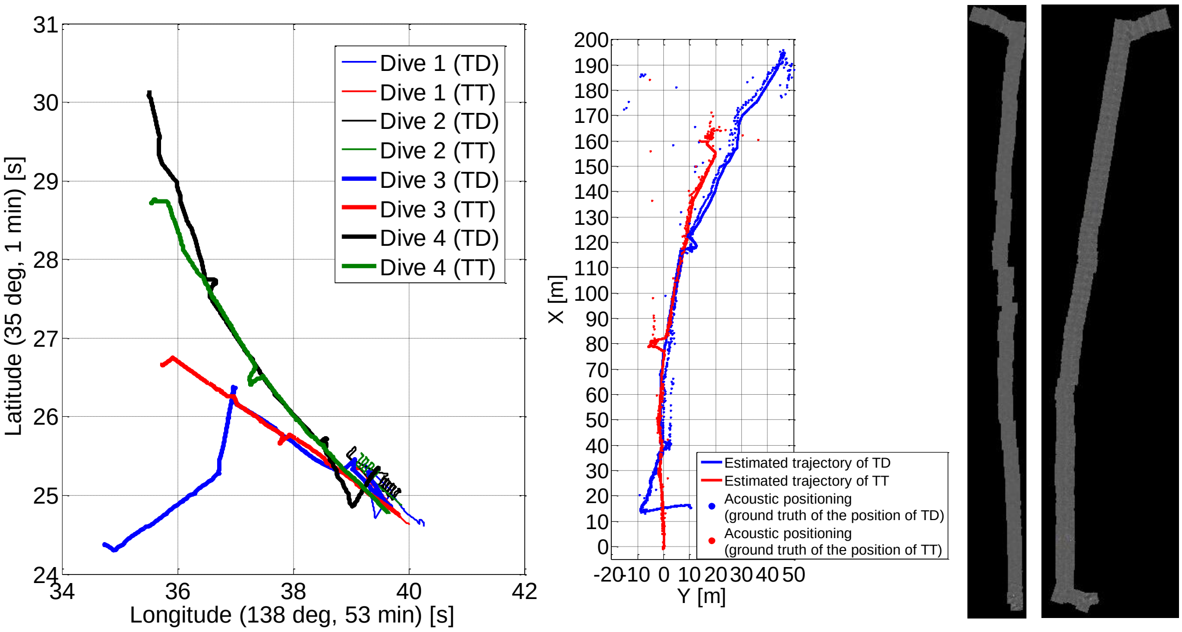

Fig. 3 Results of the sea experiments. Left: Estimated trajectory of the AUV Tri-Dog 1 (TD) and Tri-TON 1 (TT). Center: Estimation accuracy compared with acoustic positioning data. Right: Photomosaic of the seafloor obtained by two AUVs (10 x 80 m).

Conclusions

This study realized wide seafloor surveys only by AUVs which has been impossible for conventional navigation methods. The method can be applied to several types of the surveys such as bathymetry mapping, monitoring of seafloor life, resource survey, searching for lost objects, and so on. The method will certainly contribute to the field of seafloor survey and cooperative survey only by AUVs will certainly reveal several unknown facts of seafloor in the future.

References

[1]. B. Bingham, B. Foley, H. Singh, R. Camilli, K. Delaporta, R. Eustice, A. Mallios, D. Mindell, C. Roman, and D. Sakellariou, “Robotic tools for deep water archaeology: Surveying an ancient shipwreck with an autonomous underwater vehicle,” Journal of Field Robotics, vol.27, no.6, pp. 702-717, Jun. 2010.

[2]. T. Maki, H. Kondo, T. Ura, and T. Sakamaki, “Positioning method for an AUV using a profiling sonar and passive acoustic landmarks for close-range observation of seafloors,” in Proc. OCEANS Europe Conf., Jun. 2007, DOI: 10.1109/OCEANSE.2007.4302374.

[3]. C. Kunz, C. Murphy, R. Camilli, H. Singh, J. Bailey, R. Eustice, M. Jakuba, K. Nakamura, C. Roman, T. Sato, et al., “Deep sea underwater robotic exploration in the ice-covered arctic ocean with AUVs,” in Proc. Intelligent Robots and System (IROS 2008), Sept. 2008

[4]. S. Thrun, W. Burgard, D. Fox, et al., Probabilistic robotics. Cambridge, Mass. MIT Press, 2005.