Underwater Scenes: the Applications and Trends of Biomimetic Robots Based on Slam

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Abstract. With the constant development of modern science technologies, the research in decisive positioning of robots in various environments is an emerging area in the fields nowadays. This paper analyses and discusses the existing ocean exploration problems from the perspective of a bionic robot incorporating the slam algorithm. Comparative analysis of the more prevalent bionic robotic fusion vision slam techniques and bionic techniques for the slam algorithm itself through different underwater scenarios, such as the seabed, simulation of oil simulation environments, and confined spaces, further understanding the development and application of Simultaneous localization and mapping(SLAM) for robots based on the slam algorithm, which is used in different underwater scenarios. exploring the universality problems during the experimental process, proposing assumptions for existing problems, and prospects for its future development.

Keywords: Slam; Underwater; Orb-slam; Dolphin-slam; Bionic Robot.

1 Introduction

Simultaneous localization and mapping is one of the crucial technologies applied to autonomous robot navigation. At present, biomimetic robots have been largely used in lots of fields. Ocean, the largest ecological unit on Earth, with its vast area, complex terrains, and susceptibility to various extreme climates, there is a high degree of resistance to surveying. Due to the complexity of the terrains, the resistance is mainly due to the inability of conventional robots to probe deeply and navigate for localization to collect data in real time. Unlike terrestrial or indoor controlled environments, the underwater environment is highly unstructured, which brings multiple difficulties and challenges like various light and noise interferences to underwater visual slams. Therefore, based on the slam algorithm and its extended use, bionic robots will be optimized for underwater detection.

Slam technology has gone through roughly three phases.1986-2004 is the traditional era of slam development, where the concept of slam was proposed to be solved as a state estimation problem; 2004-2016 then came the era of algorithmic analysis to study the basic properties of slam; from 2016 to today is the era of predictability and robustness of slam. Traditional slam sensors can be broadly classified into three categories, like LiDAR, vision cameras, and multi-sensor fusion slam technologies.

Y. Wang (ed.), *Proceedings of the 2024 International Conference on Artificial Intelligence and Communication (ICAIC 2024)*, Advances in Intelligent Systems Research 185,
https://doi.org/10.2991/978-94-6463-512-6_14

Nowadays, with the ongoing development of science and increasing demand for multi-scenario use， several slam+ techniques adapted to different scenarios have been derived from traditional slam techniques. In this paper, for the underwater application scenarios, a comparative analysis is made based on the theory of bionic robots integrating with Oriented Fast and Rotated BRIEF slam (ORB-SLAM), and dolphin-slam. They are the two aspects of underwater applications, to better solve the existing problems.

2 The Application of the Profiling Robot Integrates with Visual-slam Underwater

2.1 Overview of the Underwater Visual-slam Algorithm

Since 2000, underwater visible SLAM has gradually matured and moved towards large-scale visible SLAM; after 2010， researchers are beginning to optimize the algorithm related to visual slam underwater. Visual slam includes monocular cameras, likes Mono-slam, ORB-slam, Large Scale Direct monocular SLAM (LSD-slam) and Fast Semi-Direct Monocular Visual Odometry (SVO); Binocular cameras, likes Parallel Tracking and Mapping (PTAM), ORB-slam2, and Direct Sparse Odometry (DSO); RGB-D (Red, Green, Blue-Depth) cameras, includes Kinect-Fusion and Real-Time Appearance-Based Mapping (RTAB-MAP).

ORB-SLAM is a 3D localization and mapping algorithm based on ORB features, it is one of the visual slam algorithms, and also one of the most successful and advanced visual slam systems, this is the main reason why this slam system was selected for this paper. ORB-SLAM based on a frame of PTAM, adding the functions of map initialization and closed-loop checking, optimizing the ways of keyframes selecting and map construction, good results have been achieved in terms of map accuracy, processing speed, and tracking effectiveness. The ORB-SLAM system algorithms, as a typical visual slam algorithm, all use the principle of feature extraction, which has certain advantages.

2.2 The Development of ORB-SLAM System Algorithms in Underwater Environments

The challenge for SLAM in confined space underwater is to acquire environmental information [1]. The traditional orb-slam technique has high positioning accuracy and good robustness and is the most complete monocular vision slam system based on feature points. Franco Hidalgo et al. Testing orb-slam in shallow water, found that in the same position, the features are extracted still have huge differences when the time only between 100ms. From this, it can be seen that, in shallow water, ripples and light have comparatively large differences in feature extraction. When the light is enhanced, the particles in the water are more reflective and feature extraction is better. From this, they tested at different depths for both structured and partially structured environments on the seafloor and found that shallow water is highly affected by solar flicker, but when depths greater than 3 meters, the lighting problem is reduced [2]. However, for another complex non-structural environment, traditional orb-slam is far from an idealized state. Then, extend orb-slam2, compared to traditional slam technology， It has high positioning accuracy at the centimeter level, and a wider range of applications, so it can ensure real-time detection underwater. To a certain extent, orb-slam2 extends binocular and depth cameras. when it arrives at a region with any characteristic points, this algorithm will lose its effectiveness and cannot be recovered. So far, orb-slam3 is the most advanced algorithm in orb-slam systems, it can achieve real-time robust operation, 2 to 10 times more accurate than previous methods. Orb-slam3 has mainly two innovations: one is that it is the first system to use monocular, stereo, RGB-D cameras, using pinhole and fisheye lens models to perform vision, visual inertia, and multi-graph SLAM; The other one is it can make slam system independence from the camera used [3], Making it widely applicable to underwater complex environments.

2.3 The Application of Bionic Robot Integrates ORB-SLAM in Underwater Environments

For the ever-changing, fully 3D environment underwater， researchers can also be assisted by bionic robots, especially in small, confined underwater environments. Wael Gorma designed a robot fish, which integrate with the orb-slam algorithm in their experiment [4]; Zhan et al. using bionic squid robot fuses ORB-SLAM2 for underwater localization and navigation, ORB-SLAM2 can work in real-time on the CPU. It can be used for mobile robots, cell phones, drones, cars, and other mobile terminals, and can calculate camera poses in real-time and generate sparse 3D reconstruction maps of the scene. It does not have high requirements on the number of feature points, but its recognition of feature points is still not precise enough, and ORB-SLAM2 still has some challenges in underwater environments, which are greatly affected by light, plankton, and so on. From this, it can be seen that orb-slam2 has good performance in the structured or feature-rich seabed, sufficient light, and low flicker performance. However, the robust performance of ORB-SLAM2 is poor in regions with large changes in illumination dynamics, a high number of moving objects, or low texture, such as sand beds [5]. Elizabeth Vargas' team demonstrated a visual-acoustic fusion slam system that can somewhat compensate for orb-slam2's deficiencies in low-light and low-texture detection [6]. In an underwater environment, slam not only needs to resolve the problem of harvesting environmental information but also needs to tackle the environment point cloud data collected before. F. Hidalgo used an autonomous localization method for underwater robots based on ORB-SLAM2 and point cloud processing to localize a confined room underwater, testing and verifying the feasibility of the method, which solved the point cloud data processing problem to a certain extent. [7].

Diamanti et al. used the ORB-SLAM3 algorithm combined with a submarine snake robot to research marine archaeology-related localization and navigation and found that the bionic snake robot has a high degree of freedom in automation and vision contributes to efficient photogrammetric reconstruction [8]. Orb-slam3 has good robustness in underwater complex environments, in dark and low visibility environments, it can distinguish well between environment and objects, and perform well in depth prediction. However it is dependent on visual features, although the ORB-SLAM3 system can be operated during the execution of the task, it will increase the measurement error if there are not enough visual features to match. The system can resume tracking when sufficient visual features exist, but each time, it initializes a new map, so the successful tracking rate of ORB-SLAM3 needs to be greatly improved.

3 Neural Grid-like Bionic Slam for Underwater Environments

Learning from previous studies, for navigation and localization, the most successful solution is based on the core probability method, which uses a large number of map representations from distance to topology. These probability-based methods have good SLAM performance, but rarely fully address the entire map construction and navigation problem. In contrast, biological systems are almost unknown， and simulation computational modeling has very limited application to robotic platforms in various extreme environments. A basic fact is: that many animals can still resolve whole slam problems well without having high-precision sensors and high-resolution maps. Rat-SLAM is a slam system inspired by biology. It stimulates the hippocampus of rats and constructs a set of SLAM and navigation systems, giving another research idea to solve the problem - based on biological mechanisms to solve the navigation problem. For underwater slam-related issues, the concept of dolphin-slam was proposed by Luan Silveira et al. in 2015[9], which extends the use of rat-slam from 2D ground localization to 3D underwater stereoscopic environments.

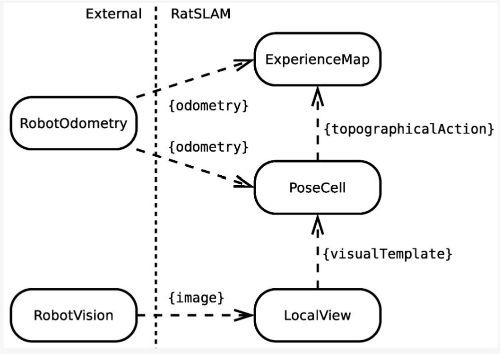

Fig. 1. Rat-slam architecture [10].

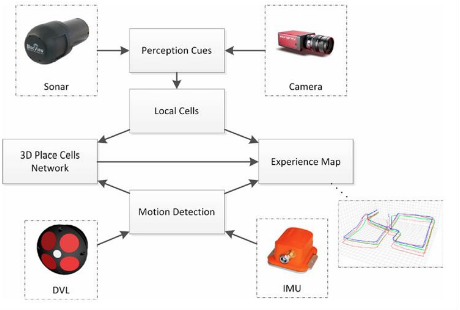

Fig. 2. Dolphin slam architecture [9].

As shown in Fig.1,the external Robotvision first passes the image to the LocalView module, then passes the processed visualTemplate to PoseCell, and finally passes the topographicalAction to ExperienceMap for map construction. At the same time, rat-slam external Robotodometry transfers the calculated odometry to PoseCell and ExperienceMap module for real-time correction. As shown in Fig.2, it is not difficult to know that, in contrast to rat-slam, the architecture of Dolphin-SLAM includes a perception cues module, which is important for the bionic SLAM, and utilizes feature detection and characterization algorithms specific to the sensors used. It also has a modular architecture, which improves the map growth, ambiguous environment robustness, and the ability to use integrated optical and acoustic sensors.

This work describes the dolphin-slam, a new biologically inspired underwater SLAM algorithm. Dolphin SLAM has the particular advantage of working well with low-resolution sonar and visualized image data in contrast to other available underwater navigation systems that focus on probabilistic approaches.Silveira's team in a simulated OIL environment suggested that the limitations of Dolphin SLAM may be related to the underwater environment, such as water turbidity affecting the optical sensors, and making feature detection and characterization more challenging. In addition, under long time online operation, DolphinSLAM may need to fine-tune the parameter tuning sensitivity to enhance its performance and reduce human adjustment and modification of parameters. Meanwhile, considering the complexity of the biologically inspired approach, While the algorithm complexity is related to the number of local views captured, other factors can slow down the processing speed of the algorithm, such as extracted image resolutions [9].

There is no case for dolphin-slam to be fully open source at this time. This inhibits its development and makes it impossible to analyze thoroughly in comparison with other slam algorithms. Therefore if dolphin slam is to be comparatively analyzed among many slam algorithms， and then to choose a more appropriate algorithm, it becomes a hindrance at present.

4 Challenge

From the current state of research, there are still fewer studies that adequately combine bionics with slam technology for robots, most of them are monolithic studies. However, with the development of the demand for robots in different scenarios, the combination of bionic robots, slam technology and bionic slam algorithms is an inevitable trend. In subsequent studies, especially in unstructured environments, Unlike visual slam, sonar slam is rarely affected by underwater low lighting conditions and visibility issues. So, for the visual slam, perhaps introducing the sonar sensors with a vision system to detect errors, and match the laser equipment for real-time correction. In an underwater environment, using sonar sensors to detect whether there are obstacles around the environment. On this basis, if there are some data discrepancies shown by visual slam and sonar slam, the laser equipment will be turned on to stably light up the error region to enhance its visibility, so that increasing the number of features extracted.

As for the biomimetic slam algorithm, researchers should bionic robots from more different perspectives. Try as many replicas as possible, checking whether they will produce similar effects with natural systems, such as animal vision slam technology then combined with flexible bionic robots, better adapted to the underwater environment. Finally, it is also necessary to continuously improve its autonomy and continuity in underwater operations, reducing too much human intervention.

5 Conclusion

In this paper, the author reviews the application of bionic robots underwater from two aspects: bionic robots based on SLAM technology and bionic SLAM algorithm. Although bionic robots have already made significant progress, there's still a lot of room for improvement before they can be applied to diverse and complex dynamic environments. Underwater environment sensing and modeling is important for implementing underwater missions. The information fusion techniques of various sensors, combined with slam, artificial intelligence and underwater environment modeling, will facilitate the autonomy and intelligence of bionic underwater robots. In addition, the cooperation of multiple bionic underwater robots will help to improve operational efficiency, which is a very challenging problem.

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