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Path Planning and Decision-making Control for AUV with Complex Environment

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Abstract—Efficient path planning algorithms and decision-making control system are crucial issues for modern autonomous underwater vehicle (AUV) in complex underwater environment. In this paper, Fast Marching (FM) algorithm is used to extract cost optimal paths from complex and continuous environments, and meanwhile, we design a decision-making control system with reactive structure based on behavior. This system divides AUV's behavior into two classes—Rational Behavior set and Perceptual Behavior set. Furthermore, in order to avoid dynamic obstacles, improved artificial potential field (APF) is used to implement secondary path planning in local environments. At last, we combine path planning method based on FM with decision-making control system with reactive structure based on behavior. This approach is not only capable of path planning but also of obstacle avoidance and navigation in complex environments which include fast moving obstacles. The effectiveness of proposed methods is verified by simulation results.

Keywords-AUV; Path planning; Fast Marching algorithm; Decision-making control system; Artificial potential field

1. Introduction

AUV is developed as powerful underwater vehicle with capacities of autonomous navigation and path planning [2]. In recent years, AUV is widely used in the field of marine scientific research and military. Efficient path planning and decision-making control system determine AUV's intelligence level, and are the key factors for AUV completing varieties of tasks successfully. Path planning provides a basis for decision-making control system, and decision-making control system controls the AUV's behaviors, such as Goal Directed Behavior, Obstacle Avoidance Behavior, Pose Holding Behavior, etc. In this paper, we take a new tool—Fast Marching algorithm (FM) for global path planning. FM is known to be efficient for finding cost optimal path in complex environments because of its reliability, precision, and simple implementation. Also, we present a simple and efficient control system—Decision-making Control System with reactive structure based on behavior. In this control system, behaviors are overlapped by weighting coefficient which shows off AUV's personality factors. Path planning based on FM is not enough for AUV to copy with the complex underwater dynamic environments, so we take improved APF as a tool for local path planning—secondary path planning. By efficiently integrating above methods, finally, we successfully get a simply and efficient navigation system for AUV.

The structure of the paper is as follows: Section Ⅱ is a simple introduction of the whole AUV's system. We propose in section Ⅲ FM based global path planning and present results using the FM algorithm. Section Ⅳ presents Decision-making Control System, improved APF and the corresponding simulation results. Finally, section Ⅴ presents the combined simulation results of path planning and Decision-making control system.

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2. The Whole Auv'S System

Figure 1 is the block diagram of AUV's system. The AUV's control system is a modular structure of layering. From top to down there're 4 layers: task layer, navigation layer, control layer and the AUV entity. Ten function modules are included: task manager, path planning, decision-making control (divided into rational behavior system and perceptual behavior system), SLAM, motion controller, sensor data acquisition subsystem, self-rescue subsystem, data storage subsystem, thrusters and all kinds of sensors.

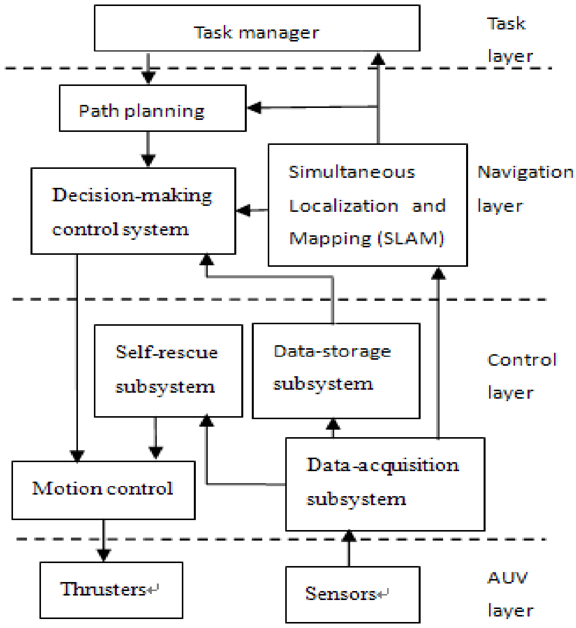


Fig.1. the block diagram of the whole AUV's system

Working process of this system can be described as follows: Firstly, task manager receives an artificial task and path planning generates a global quasi-optimal path from start to the destination in specific environment according to the task layer. Then, on the planned path, decision-making system produces a series of AUV control information according to the maps and other related information. These control information are sent to the motion controller, which can generate information to control AUV directly. Sensors are used to collect data about AUV's attitude and environmental information. After being processed, these data are delivered into SLAM to build the environmental map which provides the next decision-making information for task manager, path planning and decision-making system. Self-rescue subsystem produces control information when AUV is in danger, which can ensure AUV's safety. The above process occurs circularly to navigate for AUV in complex underwater environments.

As can be seen from the diagram, path planning and decision-making control are laid in the navigation layer, which means that they are the brain of AUV and can tell AUV what to do and how to do. The main purpose of this paper is to discuss the technology of path planning and decision-making control for AUV, making the obstacle avoidance and autonomous navigation come true.

3. Fm Based Path Planning

3.1. Environment representation

Environments can be represented by various methods. FM algorithm is a path planner based on grid method. Grid representation divides space into a series of grid units with two values information. As figure2 shows [2], non-obstacles grids represented by white are called free grids, obstacles ones represented by black are called non-free grids. Black and white are corresponding to zero and one in computer store system, which is convenient for computer to handle the maps information.

Here, we represent the AUV as a point, called configuration. An AUV configuration is a vector of parameters specifying position, orientation and all the characteristics of the AUV in the environment. FM algorithm process which finds the optimal path is to explore grids in free space from starting point to the destination.

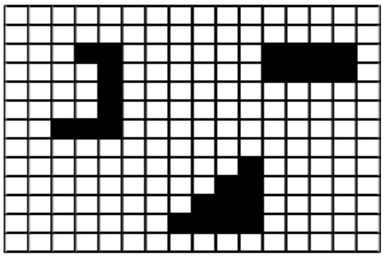


Fig.2. Grid method: white grids represent non-obstacles, black grids represent obstacles.

3.2. Path planning algorithm procedure

FM algorithm was first proposed by Sethian[3] and was also improved by many scholars. References [3],[4],[5] give the details of the FM algorithm. In this paper, we only discuss the path planning algorithm procedure.

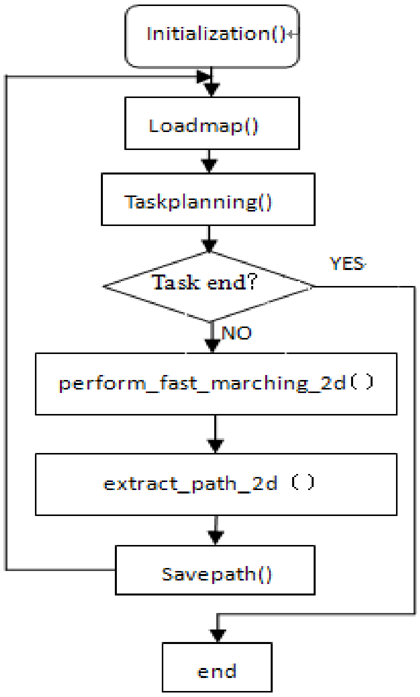


Fig.3. programming flow chart of path planning algorithm

Figure3 is the programming flow chart of path planning algorithm. The details are as follows:

1). Loadmap(): Loading maps information from the database which is built by SlAM, updating the obstacle map information.

2). Taskplanning(): Setting the starting point and the global goal by the given task, using heuristic formula to compute the sub-goal.

3). Task end: Terminating the procedure if the overall task is completed.

4). Calling the function perform_front_propagation() to compute distance of every pixel, then get the distance function matrix D(i,j).

5). Calling the function extract_path_2d(), extracting the optimal path.

6). Loop: Saving the path by appropriate method, go back step 2 to loop when AUV arrives the sub-goal.

We deal with AUV as a point, so obstacles on the maps should be dilated of a certain degree to ensure the effectiveness of obstacle-avoidance in the path planning process.

3.3. Simulation results.

FM based global path planning is efficient with complex obstacle maps such as the one illustrated figure 4. The black areas represent obstacles and the start point represents sub-goal of each step.

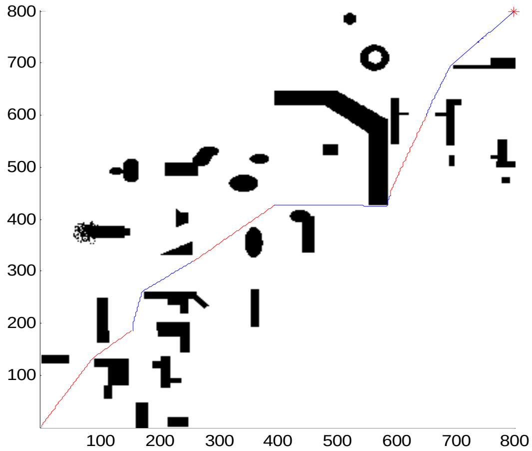


Fig.4. the simulation result of FM based path planning: the optimal path on complex obstacle map (800×800 pixels)

4. Decision-Making Control System with Reactive Structure Based on Behavior

4.1. The structure of decision-making control system

The structure of decision-making control system is illustrated as Fig 5. Decision-making Control System consists of two parts—Rational Behavior System and Perceptual Behavior System. The former includes four models: Mission Planning Behavior, Path Planning Behavior, Deployment Behavior, Diagnose&Correct Behavior. Deployment Behavior is responsible for the interaction with Perceptual Behavior System, and setting the attributes of it, meanwhile, it receives the feedback from Perceptual Behavior. Perceptual Behavior System consists of four parts—Goal Directed Behavior, Obstacle Avoidance Behavior, Pose Holding Behavior, Depth Holding Behavior. System output generates the ultimate control information for AUV. Rational Behavior System tells AUV what to do, and Perceptual Behavior System tells AUV how to do**.**

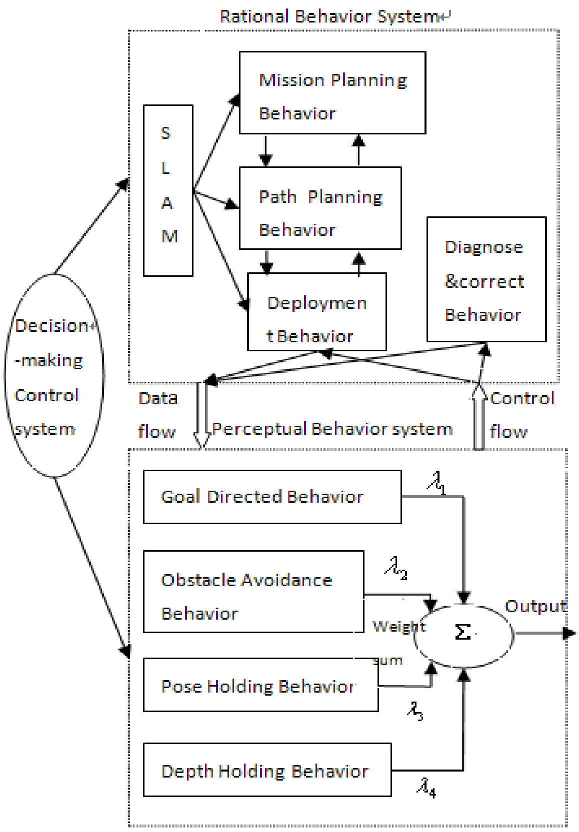


Fig.5. the structure of decision-making control system

The characteristics of behavior-based reactive decision-making control system are as follows: the control system outputs several behaviors at one time, and the result is the behaviors' weight sum. The weighting coefficient is λ_i which represents AUV's personality factor. AUV's behavior and overall performance can be improved by adjusting coefficient λ_i. Appropriate weighting coefficient is critical for AUV to fulfill task perfectly.

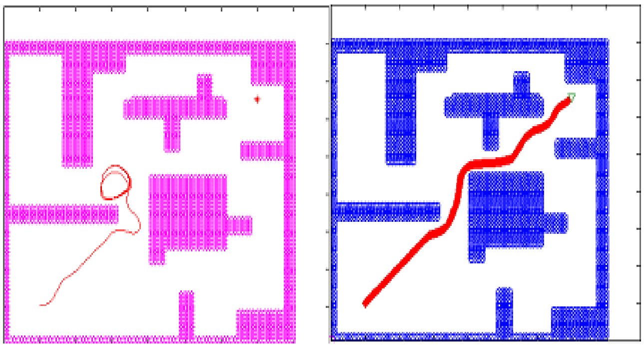
4.2. Improved artificial potential field

In construction of decision-making control system, an improved APF was adopted for real time obstacle avoidance in dynamic environment. After FM based path planning finding an optimal path from start to destination, the control system chooses a series of sub-goals on the path. Between two random points of the various sub-goals, APF based local path planning finds the AUV's walk path.

The potential way defines AUV's motion space as a abstract potential field, which is overlapped by gravitational field—generated by target location and repulsive field—generated by obstacles. The vector synthesis of gravitation and repulsion guides AUV moving from start to destination without collision.

The APF was illustrated by many scholars. References [6],[7] give the details of the APF. On the basis of improved potential field function, in this paper, we modified the repulsion's direction by redefined the direction of repulsion to solve various typical local minimum problems of the traditional APF. The repulsive function is composed of two parts, one's direction is tangency with the control area of the obstacle and the angle between gravitation and repulsion is not more than 90^0 while the others direction is consistent with the gravitation. This method can overcome the local minimum problem completely, because the resultant force of the AUV couldn't be zero before it reaches the goal.

A. Simulation results



a. b.

Fig.6. the simulation result of decision-making control system: a) based on the traditional APF. b) based on the improved APF

As Fig.6b, the simulation result with MATLAB proved the effectiveness of Behavior-based reactive decision-making control system with complex environment. We choose three rational behaviors— Mission Planning Behavior, Path Planning Behavior, Deployment Behavior and two perceptual behaviors—Goal Directed Behavior, Obstacle Avoidance Behavior to simulate. The simulation system based on following hypothesis: a. The SLAM map is available, b. Not add noise, c. Invariable water depth, best pose. Fig.6a shows the simulation result based on traditionally APF, as can we see from the Fig, AUV run into the local minimum. Fig.6b shows the result based on improved APF, AUV succeeded avoiding the obstacles and arriving at the destination.

5. The Combined Simulation of Fm Based Path Planning and Decision-Making Control System.

We construct a simulation system, which combines FM based path planning with decision-making control system with reactive structure based on behavior. Figure 7 is the software flow chart, the details are as follows:

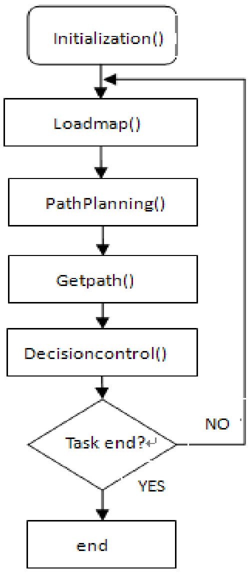


Fig.7. software flow chart of path planning and decision-making control system.

1). Initialization(): Initializing various parameters.

2). Loadmap(): Loading obstacle map information.

3). PathPlanning(): Using FM based Path planning to find optimal path and storing it.

4). Getpath(): Getting optimal path from the database and dealing with it to provide information for the control system.

5). Decisioncontrol(): including following functions: goalPlaning() planning task；

compute_Angle() compute angles of gravitation and repulsion;

compute_Gravitation() compute gravitation;

compute_Repulsion() compute repulsion;

Velocity_Synthesis() synthesize velocity；

Velocity_Constrain() constrain velocity；

6) Loop: if the task is completed, then end the program, else go back 2) step to loop.

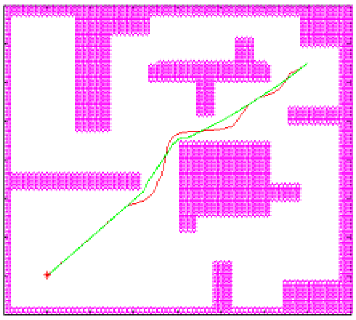


Fig.8. the combined simulation result with MATLAB of path planning and decision-making control system

Figure 8 shows the simulation result with MATLAB. The AUV starts from point (10,10) to destination(65,70). The pink areas represent the obstacles, green line represents the path which is found by FM based path planning. Red line represents the AUV's heading trajectory at the control of decision-making control system. From the figure can be seen in areas away from the obstacles, green line and red line are almost coincident. When the AUV is close to the obstacles areas, red line has a trend away from the obstacles. The result verifies the effectiveness of decision-making control.

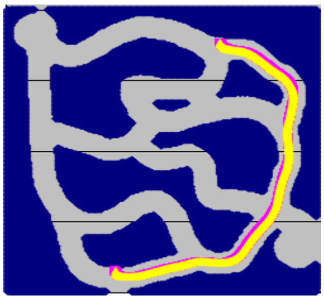


Fig.9. the combined simulation result with C++ language of path planning and decision-making control system with more complex environment.

Also, we implement the combined simulation in C++ language. In order to prove the effectiveness of our designed system, a more complex obstacle map is given. Figure 9 shows the result.

Simulation results show that by combining FM based path planning with Decision-making control system, it can be effective for AUV to complete its heading task with complex environments.

6. Conclusion

This paper contributes to address two key issues for AUV's navigation, which are path planning and decision-making control. Simulation results show that FM based path planning has characteristics of reliability, precision and good real time, etc. And behavior-based reactive decision-making control system has characteristics of good robustness and flexibility. Improved APF is used to implement secondary path planning in local environments, which can overcome the problem caused by local minimum in traditional APF and navigate for AUV in dynamic complex environment. By efficiently integrating the path planning with the decision-making control system, we successfully get a simply and efficient navigation system for AUV.

However, this paper also has many defects, such as some behaviors which are not took into account, the underwater world is took as 2D and without considering 3D. So further researches are required.

7. Acknowledgment

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