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Intelligent behaviour-based team UUVs cooperation and navigation in a water flow environment

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Abstract

This paper considers the problem of intelligent behaviour-based team unmanned underwater vehicles (UUVs) cooperation and navigation, especially in a water flow environment. Animals often have behaviour which aims to maintain them living as groups. We learn from animals' typical group behaviour and develop behaviour-based rules for team cooperation of UUVs. We create simulation scenarios in which a team of vehicles cooperate to track a target in a water current environment. This paper customises several behaviour-based rules to satisfy the requirement of the desired scenarios. We use fuzzy logic controllers to set different priority weights for each rule on-line according to the situation that the vehicles meet. The decision of the vehicle's next step steering direction is made by the combination of these rules multiplied by the relative priority weights. The line-of-sight guidance law is modified as the navigation rule in a water flow environment. The dynamic manoeuvring model of a real small UUV, SUBZERO III, is used in the simulation. The simulation results indicate that the entire system is successful in reaching the target without any collision within the scenario. The different trajectories and travel times are compared and discussed when normal and modified line-of-sight guidance rules are applied.

Keywords: Underwater vehicles control; Water flow; Behaviour-based rule; Fuzzy logic; Cooperative control

1. Introduction

Unmanned underwater vehicles (UUVs) have been used to explore physical areas where humans are unable to go, such as a deep, dangerous and unpredictable ocean environment. However, a single UUV is usually large and expensive to run and can see only a limited area on any single mission.

A team (or 'swarm') of low-cost vehicles could cover a long-range area quickly and economically, e.g. for mine detection and clearance or for surveying an area of ocean water for pollution. Two application scenarios of cooperative underwater vehicles, hydrothermal Vent Fields and under Ice Exploration are discussed by Babb (2005). There are essential problems created, such as what is the method of interacting? How should the team be coordinated to achieve a mission without any collision? In order to solve such problems, learning from animal group behaviour has been an increasing recent tendency. For example, ants foraging (Bullnheimer et al., 1999), honeybee colony (Vries and Biesmeijer, 1998), birds flocking and fish schooling may hold clues as to the best way to operate in a team situation. The study of cooperative biological teams may lead to a shortcut in the development of engineering systems and may offer distinct advantages over traditional control methods. As one of the most familiar forms of animal social group behaviour, fish schooling has been researched by many researchers. Schooling fish maintain a constant geometric orientation to their fellows and with virtually equal spacing from fish to fish for most of the time when they are schooling (Shaw, 1962). They have the ability not only to chase food but also to avoid the rocks and predators when they are schooling. From the computer graphics field, Reynolds (1987) made a basic distributed behavioural model 'Boids' in 1987. This flocking model is based on three simple steering behaviours: separation, alignment and cohesion. Stephens et al. (2003) added more behavioural rules to Boids in order to create artificial fish to act autonomously in response to sensory input from the

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environment and other fish. However, these researchers only validated the behavioural method by computer simulation. It is difficult to find out whether the behavioural rules can be successfully applied in a UUV team mission when the situations become more complicated and inconstant in the realistic underwater environment. This paper describes a behaviour-based approach to ensure that the vehicles cooperatively work together without any collisions in a water flow environment. In order to verify the feasibility of the behaviour-based approach, we combine the dynamic manoeuvring model of a single vehicle with the approach and specify several behavioural rules which satisfy the requirement of a typical mission scenario. Fuzzy logic controllers are used to estimate the priority weights for each rule and to combine rules to generate the next step steering direction decision. The normal line-of-sight (LOS) guidance rule is modified since the water flow usually forces the vehicles away from the LOS direction. A simple team cooperation mission scenario is designed and simulated. The results indicate that the entire system is successful in achieving missions within the scenario. The different results with the normal and modified LOS guidance rules are compared and discussed.

2. Water flow environment

In our simulations, we simulate a simple water flow environment which is inviscid and irrotational. The inviscid flow means that the flow has no resistance to shear stress (Symon, 1971). The irrotational flow means that the flow does not move in circular or helical motions. Wejchert and Haumann (1991) produced four flow primitives (Fig. 1). Uniform flow is when the fluid velocity follows straight lines; source flow is when the fluid comes from a source and moves out from all directions; sink flow is the opposite of source flow; and in vortex flow fluid moves around in concentric circles. Most flow is constructed by a combination of these four flow primitives.

In addition, the model constructed by Tu (1999) of a non-turbulent flow field with low computational cost, using a uniform flow field with sinusoidal strength and a source flow at each cylindrical obstacle, is used as a basis for generation of the water flow fields for this study. In our simulation, the water flow field in the pool consists of only uniform flow with constant strength and source flow from cylindrical obstacles in a 2D environment. The velocity field of the uniform flow is

$$v_{\text{uniform}} = a\hat{\mathbf{u}}, \tag{1}$$

where a is the strength of the flow and $\hat{\mathbf{u}}$ is the unit vector indicating the orientation of the uniform flow.

The source flow velocity field at cylinder obstacles is defined as

$$v_{\text{source}} = \frac{a}{(d-r)^2}\hat{\mathbf{d}}, \tag{2}$$

where d is the Euclidean geometry distance from the current position to the centre of the source, r is the radius of cylinder obstacle and $\hat{\mathbf{d}}$ is the unit vector pointing outward from the centre of the source (Tu, 1999). The source flow is added to the uniform flow field in order to approximate the reflection effect of water flow around obstacles.

Fig. 2 simulates the water flow field in a 100 m × 100 m pool field with a cylindrical obstacle having a defined

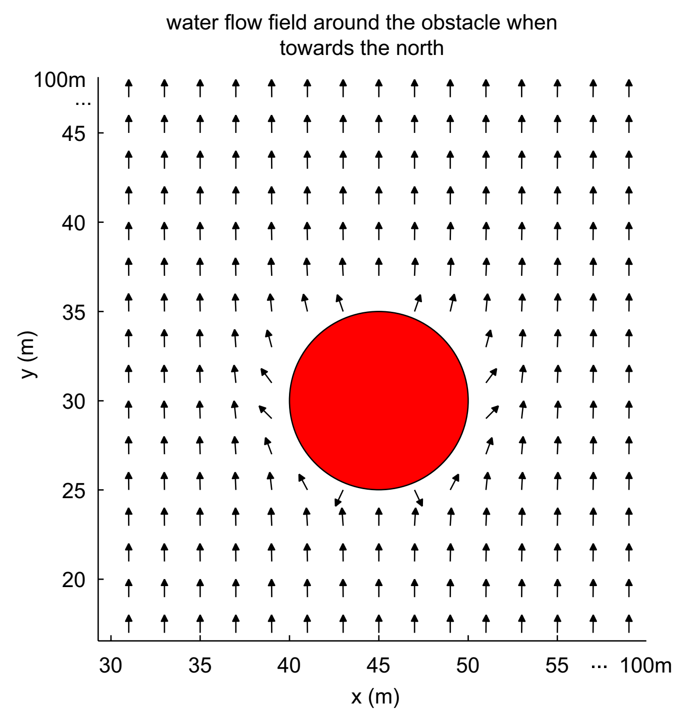

Fig. 2. Water flow field in our simulation with a defined obstacle.

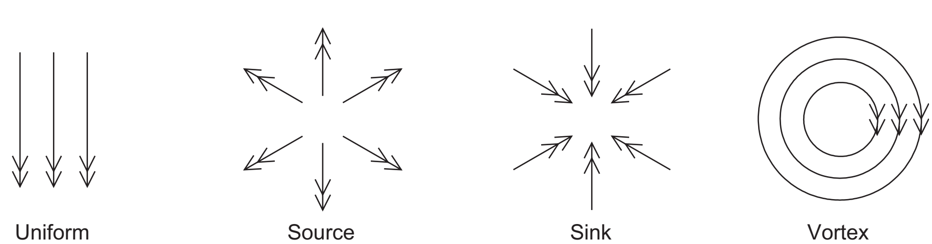

Fig. 1. The flow primitives.