Motion planning and guidance for unmanned underwater vehicles operating in aquaculture

Problem description

Aquaculture is an important global contributor to the production of seafood for human consumption, and in 2022 produced more than 1.6 million tons of marketable fish meat in Norway. Current state-of-the-art technologies and operations for sea-based aquaculture farms are highly dependent on manual labor. However, as salmon farm sites are moved further offshore and to more exposed locations, working conditions are increasingly challenging, which highlights a need for more autonomous operations [1]. A key enabler to this shift is the use of unmanned underwater vehicles (UUVs) such as remotely operated vehicles (ROVs), which are used to inspect the net cages for holes, biofouling, or structural failures [2, 3].

In the CHANGE project, SINTEF Ocean is targeting the development of autonomous control systems for UUVs operating in dynamically changing environments such as fish farms. Autonomous operations in aquaculture are highly safety-critical, as any collisions can harm the fish or damage the net cage, which has severe environmental consequences. **It is therefore essential that any autonomous system for UUV operations in aquaculture has the capability to plan safe trajectories and mitigate the risk of collisions.** This is further complicated by the fact that one is operating in a very dynamic environment consisting of flexible net cages, multiple mooring lines and cables, and dense biomass [4].

Motion planning has been a widely researched problem of PSPACE complexity [5]. In general, algorithms need to balance needs such as safety, minimal energy or time consumption, and real-time performance. While there exist multiple suggested methods, only a few address dynamic environments [6, 7] and state uncertainty that might arise from poor localization or tracking [8, 9, 10].

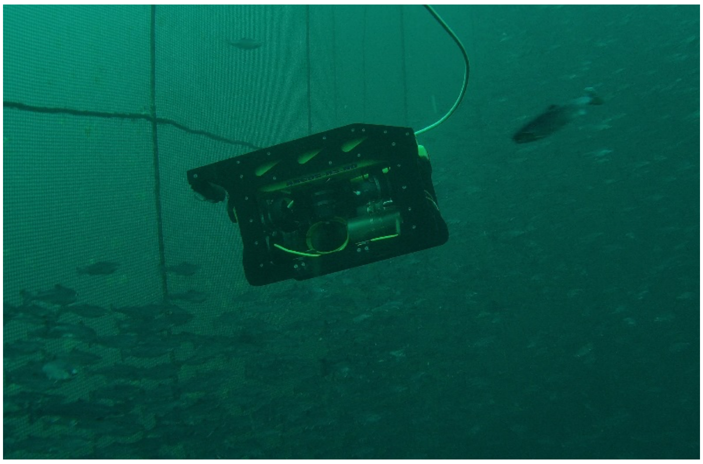

Figure 1: SINTEF Oceans ROV operating inside a net cage

Recently, there has been broad research on automating UUV operations in aquaculture [3]. Many of the methods developed take a simplifying approach by using a local estimate of the relative position between the vehicle and the net cage (usually the distance and orientation) and plan relative to this [11, 12, 13]. This approach, however, does not plan outside the immediate surroundings of the vehicle, and it is hard to maintain optimality and safety. Another approach, developed for a net-crawling robot, has utilized a cylindrical coordinate system, as the global position of the robot inside the net can be represented with a depth, radius, and azimuth angle [14]. Both approaches differ from most methods in motion planning, which commonly use a Cartesian coordinate system.

The main goal of this project is to design a motion planning and guidance framework for a UUV operating inside a net cage. The motion planner shall be able to plan safe trajectories in dynamically changing environments. Further, the motion planner and guidance system shall adopt state-of-the-art methods to an aquaculture setting, where alternatives to a Cartesian coordinate system might be a better fit.

The performance of the proposed method is to be analyzed numerically through simulations and validated via sea trials. The student has access to a C++ simulation framework with models of vehicles, net cages, and control systems. The project can be continued as a master project, and **the student will be given the opportunity to participate in a field trip to the SINTEF ACE fish farm** infrastructure (Fig. 2) for field testing of the implemented method.

The subtasks of the project are:

1. Literature review in relation to:
    a. Motion planning methods such as sampling-based methods [15, 16], trajectory optimization [6, 17, 18], and mathematical stability-based approaches [19, 20].
    b. Guidance systems [21].
    c. UUV operations in aquaculture [3, 11, 12, 13, 14].
2. Identification of the most suited design for the motion planning and guidance system.
3. Implementation and simulation analysis of the chosen design.

Potential future developments as a master thesis project:

4. Improvement of the chosen design with a focus on improved robustness to highly dynamic surroundings [6,7], and uncertainty in the environment and vehicle state [8,9,10].
5. Mitigation of tether entanglement risk through motion planning.
6. Field validation of the design with an ROV at SINTEF ACE fish farm.

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Figure 1: Rataren fish farm, SINTEF ACE full-scale laboratory.