Online Aquaculture Flow Field Estimator for Control of Local Underwater Robotic Operations

Svetlana Potyagaylo[1] and Savvas G. Loizou[1]

***Abstract*— This paper proposes an online estimation algorithm for the flow field in the proximal region about aquaculture fish-nets. The algorithm's intended use is to provide a fast online estimator of local water flow field modifications caused by aquacultures. This information is required to improve the performance of feedback based control algorithms - particularly feedback linearization based controllers - for underwater robotic operations in the proximity of aquaculture structures. The algorithm makes use of a dynamic 3D fish-net model based on a lumped-mass method. The 3D model is augmented with potential panels and uses the panel method, to provide estimates of the flow velocity. The model is validated through several simulations for a small-scale open cylinder exposed to steady uniform current.**

I. INTRODUCTION

Aquaculture is one of the fastest growing food producing sectors in the world and represents a great application field for underwater robots to replace humans. The current work is an ongoing research project aimed at developing an autonomous system for visual inspection of fish farm nets and moorings by using a tethered Remotely Operated Vehicle (ROV).

The ocean currents and flows impose additional complication in the control task for an underwater robot, since drift terms have to be included in the dynamic equations. The problem is even more difficult if the system is working in the proximity of underwater structures, since these structures locally modify the flow field. An effective way to feed-forward these effects in the control algorithm is required, an this is where this work is aimed at.

This work is divided in two stages. In the first stage, the geometry of the aquaculture net should be determined for a certain velocity of the ocean current. A solution to this problem was proposed by the authors in [1], and this solution is also adopted in this paper. At the second stage, the influence of the underwater structure on the flow field should be determined and this is the main contribution of this work. Factors such as net solidity, cage design and biological effect of fish [2] can be taken into account in the proposed work if their current penetration effect is provided.

II. MODELING A FLOW FIELD ABOUT NETS

To model a flow around a fish net, we apply a potential-based panel method for incompressible inviscid low-speed flows [3]. This method is based on solving the Laplace's equation for the total potential $\nabla^2\Phi = 0$ by distributing "singularities" of unknown strength over the surface discretized into a number of elements (panels). The general solution to the potential equation may be found as a superposition of solutions for each panel along with boundary conditions.

For the fish net model, the "lumped-mass method" concept is used [1], according to which the net is divided into discrete net elements with lumped masses at the element nodes connected by massless springs. Each net element represents a structure of four interconnected bars that are subject to the external non-linear forces applied at the center of the element. The internal (structural) forces are incorporated into the model as well in order to address the flexibility of the net structure.

For the flow field modeling, the fish net cells are represented as three-dimensional quadrilateral source panels with constant strength. In this model, only the source elements are used since the fish net can be considered as a non-lifting symmetric surface with nonzero thickness. At each panel, a collocation point is specified at the centroid of the element and represents a point, where the Neumann boundary condition is applied at.

In this work, several additional modifications were used in order to apply the described panel method for underwater aquacultures. Since the top of the net is laid in the plane of the water surface so the water cannot flow over it. This situation was modeled by placing a "mirror" in the horizontal plane on the net top. The second issue addressed in this model is the penetration through the net cells. Since the fish net represents a porous medium, the Neumann boundary condition of the zero penetration normal velocity should be modified. We introduce a penetration coefficient K_p that describes the percentage of the water that can pass through the net:

$$(\mathbf{v}_k + \mathbf{U}_\infty) \cdot \mathbf{n}_k = K_p \mathbf{U}_\infty \cdot \mathbf{n}_k. \tag{1}$$

where $\mathbf{v}_k$ is the velocity induced by all panels at the collocation point k, $\mathbf{U}_\infty$ is the velocity of the undisturbed flow, $\mathbf{n}_k$ is the normal to the net surface at the point k (see Fig. 1).

In this case, the current velocity $\mathbf{v}_c$ at an arbitrary ROV position $\boldsymbol{\eta}_1$ in the environment is calculated as:

$$\mathbf{v}_c^G = \mathbf{U}_\infty + \sum_{i=0}^{N} \mathbf{v}_i\,(\boldsymbol{\eta}_1), \tag{2}$$

where $\mathbf{v}_i$ is the velocity induced by a quadrilateral element i at the point $\boldsymbol{\eta}_1$ calculated according to the expressions

---

*This work was co-funded by the European Regional Development Fund and the Republic of Cyprus through the Research Promotion Foundation under research grant ΑΕΙΦΟΡΙΑ/ΓΕΩΡΓΟ/0311(BIE)/08

[1] S. Potyagaylo and S. Loizou are with Mechanical and Materials Science and Engineering Department, Cyprus University of Technology, Limassol 3041, CYPRUS `svetlana.potyagaylo, savvas.loizou@cut.ac.cy`

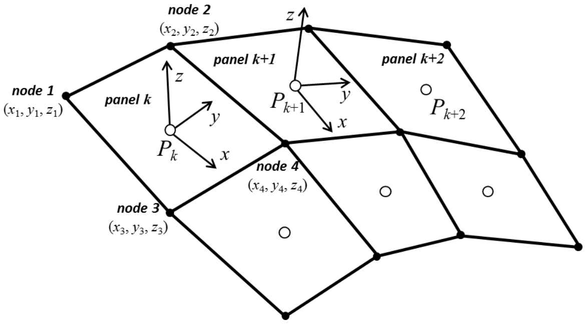

Fig. 1. Geometry of quadrilateral source elements with constant strength.

derived by Hess and Smith [4], N is the number of panels.

The flow distribution around the fish net is shown on Fig. 2 for the net of an open cylinder form with sixteen panels around the circumference and four panels along the Z-axis. The current velocity was of 0.2 m/s along the X direction, the penetration coefficient is 0.8.

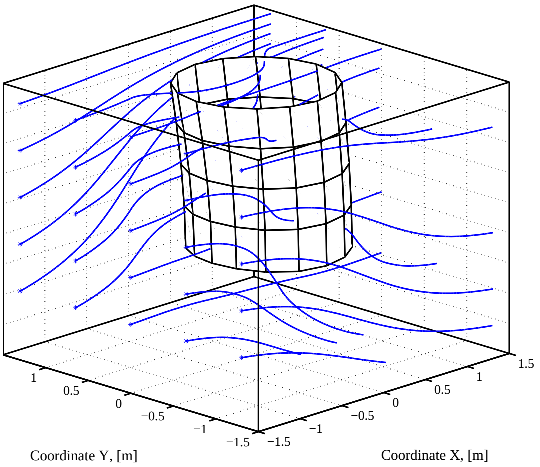

Fig. 2. Flow field around the fish net shown at three slices along the Z-axis.

III. USING FLOW FIELD ESTIMATIONS IN THE CONTROL DESIGN

The influence of irrotational ocean currents on the ROV's dynamics can be modeled as [5]:

$$\begin{aligned}\mathbf{M}_{RB}\dot{\boldsymbol{\nu}}+&\mathbf{C}_{RB}\left(\boldsymbol{\nu}\right)\boldsymbol{\nu}+\mathbf{g}\left(\boldsymbol{\eta}\right)+\dots\\ &+\mathbf{M}_{A}\dot{\boldsymbol{\nu}}_r+\mathbf{C}_{A}\left(\boldsymbol{\nu}_r\right)\boldsymbol{\nu}_r+\mathbf{D}\left(\boldsymbol{\nu}_r\right)\boldsymbol{\nu}_r=\boldsymbol{\tau},\end{aligned} \tag{3}$$

where $\mathbf{M}_{RB}$ and $\mathbf{M}_A$ is the inertia matrix of the rigid body and added mass; $\mathbf{C}_{RB}$ and $\mathbf{C}_A$ is the coriolis-centripetal matrix for the rigid body and added mass; $\mathbf{D}$ is the damping matrix, $\mathbf{g}$ is the vector of gravity and buoyancy, $\boldsymbol{\tau}$ is the control vector, $\boldsymbol{\nu}$ is the velocity vector in body fixed coordinates, $\boldsymbol{\eta} = \left[\boldsymbol{\eta}_1^T\boldsymbol{\eta}_2^T\right]^T$ is the pose vector in global coordinates, $\boldsymbol{\eta}_1$ is the ROV's position, $\boldsymbol{\eta}_2$ is the ROV's orientation, $\boldsymbol{\nu}_r = \boldsymbol{\nu} - \boldsymbol{\nu}_c$ is the relative velocity vector in body fixed coordinates between the ROV velocity and the current velocity $\boldsymbol{\nu}_c$ in the body frame.

Assuming a feedback linearization control scheme for compensating a vehicle drift caused by the current in the form:

$$\boldsymbol{\tau} = \left(\mathbf{M}_{RB} + \mathbf{M}_A\right)\left(-\boldsymbol{\tau}_{FL}\left(\boldsymbol{\nu}, \boldsymbol{\nu}_c, \boldsymbol{\eta}\right) + \boldsymbol{\tau}_{des}\right), \tag{4}$$

where $\boldsymbol{\tau}_{FL}$ is the feedback linearizing control that depends on the ROV's state and the current, $\boldsymbol{\tau}_{des}$ is the underwater robotic task controller.

The undisturbed flow $\mathbf{U}_\infty$ may be measured by e.g. current velocity meters or doppler current sensors, or ocean current predictions can be utilized. Local flow field modification especially in the proximity of the underwater structure can be significant, and failure to appropriately compensate for them will cause a deterioration in the underwater robotic task.

The current velocity in body coordinates $\boldsymbol{\nu}_c$ at the ROV's position $\boldsymbol{\eta}$ is calculated as a transformation of the current velocity in the global frame calculated by Eq. (2):

$$\boldsymbol{\nu}_c = \left[\left(\mathbf{v}_c^b\right)^T, \boldsymbol{\omega}_c^T\right]^T, \tag{5}$$

where $\mathbf{v}_c^b = \mathbf{R}_G^b\left(\boldsymbol{\eta}_2\right)\mathbf{v}_c^G$ is the linear current velocity in body fixed coordinates and $\boldsymbol{\omega}_c = 0$ is the rotational current velocity assumed to be zero due to irrotational flow assumption.

IV. CONCLUSION AND FUTURE WORK

This paper presents an algorithm for estimation of the flow field around underwater aquaculture structures for the purpose of compensating for local flow field modifications in feedback based control algorithms for underwater robotic tasks in the proximity of such structures. The algorithm is based on a numerical dynamic model of the fish net for establishing the net geometry for a given current velocity and on a suitably adapted panel method for calculating the flow velocity in the proximity of the net. The algorithm was validated through a series of simulations for a small-scale net model. Currently a number of experiments have been scheduled to tune the model parameters in offshore aquaculture installations.

REFERENCES

[1] S. Potyagaylo and S. G. Loizou, "Online Adaptive Geometry Predictor of Aquaculture Fish-Nets," in *Mediterranean Conference on Control and Automation (MED)*, June 2014.

[2] P. Klebert, P. Lader, L. Gansel, and F. Oppedal, "Hydrodynamic Interactions on Net Panel and Aquaculture Fish Cages: A Review," *IEEE Journal of Ocean Engineering*, vol. 58, pp. 260–274, 2013.

[3] J. Katz and A. Plotkin, *Low-Speed Aerodynamics*. Cambridge Aerospace Series, Cambridge University Press, 2nd ed., 2011.

[4] J.L. Hess and A.M.O. Smith, "Calculation of Potential Flow About Arbitrary Bodies," *Progress in Aeronautical Sciences*, vol. 8, pp. 1–183, 1967.

[5] T. I. Fossen, "How to Incorporate Wind, Waves and Ocean Currents in the Marine Craft Equations of Motion," in *IFAC Conference on Manoeuvering and Control of Marine Craft (MCMC)*, September 2012.