Underwater Crowd Flow Detection Using Lagrangian Dynamics

Umair Soori, Mohammad Rizal Arshad

USM Robotics Research Group (URRG), School of Electrical and Electronic Engineering
Universiti Sains Malaysia, Engineering Campus
14300 Nibong Tebal, Seberang Perai Selatan, Pulau Pinang, Malaysia
Tel: +604-5996074,
E-mail: umairsoori.lm07@student.usm.my, rizal@eng.usm.my

Abstract

Group movement is the most important tool to study the animal behaviors, which allow animals to respond their condition with respect to environment. Crowd flow in underwater scene is used to study fish schooling characteristics. The hydromechanics of fish schooling is quite complicated it varies in the types of fishes in underwater. Fish schooling detection contributes to study their locomotion, perception and behavior. For this scenario we opt to Lagrangian particle dynamics, inspiration comes from fluid mechanics, which examine the trajectories of individual particle in the flow. The mathematical algorithm of Lagrangian Coherent Structure (LCS) is the Finite-time Lyapunov Exponent (FTLE) field, which measures the divergence of the particles from each other. FTLE field is a boundary which separates the flow with respective to their dynamics. The algorithm is also able to do real-time video analysis which can easily implement in AUV's (Autonomous Underwater Vehicle). The system is efficient enough to detect the fish schooling as a group flow.

Keywords

Fish schooling, Lagrangian Coherent Structure (LCS), Finite-time Lyapunov Exponent (FTLE) field.

Introduction

Computer vision playing a virtual role in marine world, particularly in tracking pipe lines and fiber optic wires but on the other hand it also using widely for tracking the variety of fishes to study their momentous movement, especially the movement of fins, sophisticatedly swimming around the oceans among the aquatic plants and other predator fishes. Schools of fish are composed of many fishes they jointly travel around their dynamical world in search of food. Schooling is a complex behavior where all the fishes swim in generally the same precise and analogous pattern. Each fish adjust its speed and direction to match the other members of the school they establish a certain constant distance from each another [3] this is achieved by sensory perception and locomotion. School forms when a few fish swim towards a leader fish, leader fish knows the destination. The rest of fish understand the position which leader shows and try to keep the position. When the leader fish move to target point [3], there is an elliptical orbit around it. The leader fish guide the other fishes in the elliptical orbit with the proper destination according to the number of fish. The fishes follow the information of the destination while the leader has the properties to keep the position for the alignment and unity [3].

Advantage towards schooling is helping them to reduce the friction of water over their bodies, there motion is the to-and-fro motion and their tails produces tiny current. Each one can use this tiny current to its neighbor to assist in reducing the water friction [By Prentice K. Stout]. Another advantage is the predator protection strategy. Locomotion is classified as the parts of the body move and fins undulate or oscillate. Three oscillatory forms of swimming found in common fish are anguilliform, carangiform, and subcarangiform [14]. Figure 1 illustrates the density of fish schooling flow.

(a) (b)

Figure 1. Examples of large fish schooling flow.

Our effort is focus to develop an algorithm to detect and track fish schooling in a dense crowded environment and observe their dynamical movement according to their spatiotemporal characteristics. Our more interest is to extend this work in a monitoring system for fish schooling detection and their movability, which can espouse for AUV's (Autonomous Underwater Vehicle). Such tracking system used the concept from dynamical systems called Lagrangian particle dynamics, idea is taken from computational fluid dynamics CFD analysis. While widely applications used in the study of CFD analysis is Eulerian and Lagrangian, Eulerian analysis examines fluid velocity at fixed positions, whereas Lagrangian analyses examine individual particles trajectories [7]. LCS generally used in turbulence theory [9, 11] 2D and 3D fluid mechanics [12, 5].

Modeling of a dynamical system in a LCS scene gives boundaries in the spatiotemporal separating regions, these organization separate dynamically distinct behavior in the flow which is unseen in the vector field. The boundaries of flow region can be determined by tracking the flow particles during advection which pointed the material lines that are boundaries, which divided flow regions with different characteristics. This flow boundary in unsteady flows was introduced in a series of papers by Haller [4-6] the boundaries are referred as Lagrangian coherent structures (LCS). Newly method to evaluate LCS is Finite-Time Lyapunov Exponent field (FTLE) was developed by Shadden [1, 8]. LCS can be calculated from various ways one of these methods based on the FTLE field. The FTLE field evaluates a value that corresponds, how quickly two imaginary particles would separate from each other as the flow progress, it measures the maximum linearized growth rate of the distance perturbation between neighboring flow particles over the time interval to its trajectories.

Notations

Let the open set $\boldsymbol{D} \subset \mathbb{R}^2$ be the domain of the flow of crowd under study. Given a time dependent velocity field defined on $\boldsymbol{D}$, classify a trajectory $\mathbf{x}(t;t_0,\mathbf{x}_0)$ starting at point $\mathbf{x}_0 \in \boldsymbol{D}$ at time t_0 to be the solution of

$$\begin{cases} \dot{\mathbf{x}}(t;t_{0,}\mathbf{x_0}) = \mathbf{v}(\mathbf{x}(t;t_0,\mathbf{x_0}),t), \\ \mathbf{x}(t_0;t_{0,}\mathbf{x_0}) = \mathbf{x_0} \end{cases} \tag{1}$$

The velocity field $\mathbf{v}(\mathbf{x},t)$ is satisfying the continuity assumptions C^0 in time and C^2 in space, where assumption is responsible for smoothness of the flow field. A trajectory of a particle $\mathbf{x}(t;t_0,\mathbf{x}_0)$ depends on the initial position $\mathbf{x}_0$ and the initial time t_0 to their final position at time t. From velocity field $\mathbf{v}(\mathbf{x},t)$ and its continuity assumptions, it follows that trajectory is C^1 in time and C^3 in space. The solution of the dynamical system define in equation (1) view as a map which takes points from their position $\mathbf{x}_0$ at time t_0 to their position at time t. This referred as a *flow map* and denoted by $\phi_{t_0}^t$ and satisfies

$$\phi_{t_0}^t : D \to D : \mathbf{x}_0 \mapsto \phi_{t_0}^t(\mathbf{x}_0) = \mathbf{x}(t;t_0,\mathbf{x}_0) \tag{2}$$

Furthermore, flow map $\phi_{t_0}^t$ satisfies following properties

$$\phi_{t_0}^t(\mathbf{x}) = \mathbf{x}, \tag{3}$$

$$\phi_{t_0}^{t+s}(\mathbf{x}) = \phi_s^{t+s}(\phi_{t_0}^s(\mathbf{x})) = \phi_s^{t+s}(\phi_{t_0}^t(\mathbf{x})) \tag{4}$$

Now after a time interval T passes advection of particles moves to $\phi_{t_0}^{t_0+T}$, to calculate the amount of stretching to its trajectory, consider the evolution of the perturbed point

$$\mathbf{y} = \mathbf{x} + \delta\mathbf{x}(0) \tag{5}$$

Where $\delta\mathbf{x}(0)$ is infinitesimal and arbitrarily oriented. After a time interval T, this perturbation becomes

$$\delta\mathbf{x}(T) = \phi_{t_0}^{t_0+T}(\mathbf{y}) - \phi_{t_0}^{t_0+T}(\mathbf{x}) \tag{6}$$

$$= \frac{d\phi_{t_0}^{t_0+T}(\mathbf{x})}{d\mathbf{x}}\delta\mathbf{x}(0) + O(\|\delta\mathbf{x}(0)\|^2)$$

Since $\delta\mathbf{x}(t_0)$ is infinitesimal, from which the growth of linearized perturbations is obtained. The magnitude of the perturbation is given by

$$\|\delta\mathbf{x}(t_0+T)\| = \sqrt{\left\langle \delta\mathbf{x}(t_0), \frac{d\phi_{t_0}^{t_0+T}(\mathbf{x})}{d\mathbf{x}}^* \frac{d\phi_{t_0}^{t_0+T}(\mathbf{x})}{d\mathbf{x}} \delta\mathbf{x}(t_0) \right\rangle} \tag{7}$$

Where * denotes the transpose of matrix of the matrix,

$$\Delta = \frac{d\phi_{t_0}^{t_0+T}(\mathbf{x})}{d\mathbf{x}}^* \frac{d\phi_{t_0}^{t_0+T}(\mathbf{x})}{d\mathbf{x}} \tag{8}$$

Δ is a *finite-time* version of the Cauchy Green deformation tensor. Maximum stretching occurs i.e. the maximum separation of advected particles initially located at $\mathbf{x_0}$ $\boldsymbol{t_0}$ when $\delta\mathbf{x}(t_0)$ is aligned with the eigenvector which associated with the maximum eigenvalue of Δ, hence

$$\max_{\delta\mathbf{x}(0)} \|\delta\mathbf{x}(T)\| = \sqrt{\lambda_{\max}(\Delta)}\,\|\overline{\delta\mathbf{x}}(0)\| \tag{9}$$

Now introducing the finite-time Lyapunov exponent $\sigma_t^T(\mathbf{x})$

$$\sigma_{t_0}^T(\mathbf{x}) = \frac{1}{|T|}\ln\sqrt{\lambda_{\max}(\Delta)} \tag{10}$$

Above equation is of Finite-time Lyapunov exponent (FTLE) with a finite integration time T, which is related to point $\mathbf{x}_0 \in \boldsymbol{D}$ at time t_0. This technical and mathematical explanation of FTLE field with respect to eigenvalue is first given by [1, 8].

Approach and Methods

Optical flow field

In implementation we compel to consider the computational cost at every step process. The input prerequisite for FTLE analysis is the velocity vector field, we opt to optical flow technique Lucas-Kanade [10], which is a two frame differential methods to estimate motion in a moving object. Data smoothing is one of the process which makes facile LCS implementation, based on noise filtering and mean flow field. The task for noise reduction is performs by medial filtering, which is a non-linear spatial signal enhancement technique. While mean flow field is calculating by taken mean in time series or running mean, defined as the ongoing calculation of a statistic using progressively more of the available data values. We denoted E_u as optical flow field under observation and its running mean as RM_u, here u denoted as the number of frame in real time video sequence. Figure 2 shows the running mean of optical flow field.

Advection of particles and flow mapping

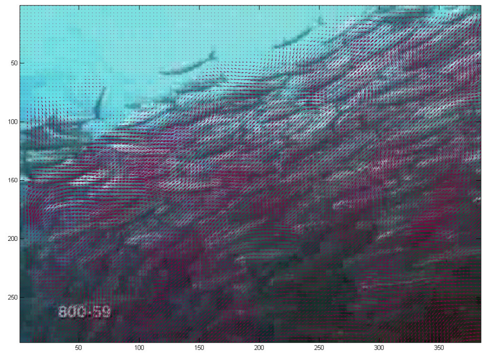


Figure 2. Running mean field of optical flow

For advection of particles under persuade of fish's flow field, we launched a cartesian grid of particles, where particles have certain (constant) distance between them, on running mean RM_u of flow field F_u , initially particle position is $\mathbf{x_0}$, at time *t*. As the time *T* pass flow of crowd stake to flow field RM_u^{u+T} and its mean F_u^{u+T} final particle position becomes $\mathbf{x}(t+T,t,\mathbf{x}_0)$. Each particle advection computed with forth-order Runge-Kutta-Fehlberg algorithm of the flow field. This advection of particles is mapped by flow map. The flow map used to maps flow particles from their initial position at time t_0 to their final position at time hence Flow map ϕ_x and ϕ_y track position of particle *x y* respectively, under persuade of flow field generated by the movement of fish. Note that we reset the running mean after few frames to get the exact information of moving objects. In our formulation the time interval *T* represent as the next frame in real-time video sequence.

FTLE field

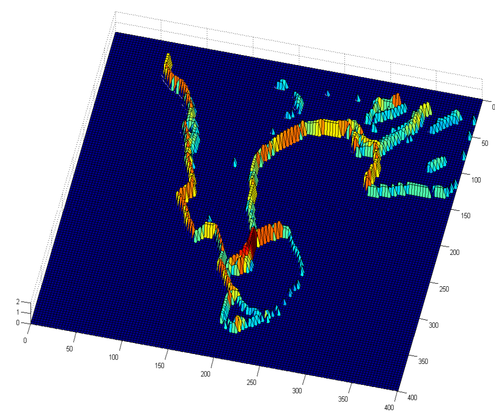
To obtain the FTLE field we have to meditate the gradient of the flow map, the spatially gradient as in equation (11)

$$\frac{d\phi_x}{dx}, \frac{d\phi_x}{dy}, \frac{d\phi_y}{dx} \; and \; \frac{d\phi_y}{dy} \tag{11}$$

Can be calculated by finite derivatives with values at the neighboring grid points, this first explain by [8]. Once all of the particles are mapped and their spatially gradient calculated from initial to final position, the gradient of flow map ready to compute Cauchy-Green deformation tensor as shown in equation (8). We compute the maximum eigenvalue on the Cauchy-Green deformation tensor which gives maximum stretching of the particle that separate with each other. Finally formulation is ready to calculate the FTLE field on equation (10). FTLE returns the edges that are ridges where the schooling flow showing distinct behavior, this shows in Figure 3.

LCS is an imaginary boundary through which amount of

(a)



(b)

Figure 3. Illustrates the FTLE results, boundaries occur where flows having incoherent dynamics, inside the boundary region all particles have similar fate. (a) Side view of fish schooling and predator fish following them. (b) FTLE field of sequence

fluid cannot pass which separates two regions that do not mix and all particles within the divided region have similar behavior, which is known as coherent behavior. The FTLE differentiate the amount of flow particle stretching about the trajectory over the given time interval, which is defined by the local maxima of the FTLE field which specify regions with distinct dynamics in the flow

LCS can define as ridges on the flow field where particles having incoherent behavior i.e. higher eigenvalue at certain region of the flow field, these boundaries separate two regions and known as separatrices.

Results and Discussion

Fish schooling detection is a significant tool to study their behavior in a dense environment. We utilized Lagrangian analysis to examine fish flow to study their dynamical activities. We tested the algorithm in a range of videos taken from [2] including the videos extracted from the Motion Gallery. Figure 4 enclosed with the most challenging sample video, in which the density of fish schooling is quite high and fishes have rapidly fast movement around the circle, the method track their dynamical movement as shown by the FTLE boundaries along with the another boundary demonstrate the center point of the flow.

The algorithm is implemented on MatLab environment and all tests have been conducted on a 3 GHz core2duo Pentium IV computer, executing Windows XP. The processing time for single frame, size of 400x400 RGB image, is approximately 0.5 seconds. That means 2 frames per seconds, while we can increase the execution time up to 5 frames per second by reducing the image size but it causes to loss image information spatially.

Conclusion

This paper provide general framework for underwater crowd flow detection and tracking also applicable in real-time scenarios by using Lagrangian based approach. LCS can calculate by the FTLE field which would returns the boundaries where flow experiences the dynamical change.
There are significant dynamic parameters that must be measured and considered for reasonable decision-making process. The variability of the image captured will also introduce significant noise source to the overall analysis.
The developed monitoring system successfully tracks a range of objects, which can easily be useful for actual monitoring requirements and easily implement in AUV's (Autonomous Underwater Vehicle). The method suggested is very robust and can easily be adapted to various horde scenarios.

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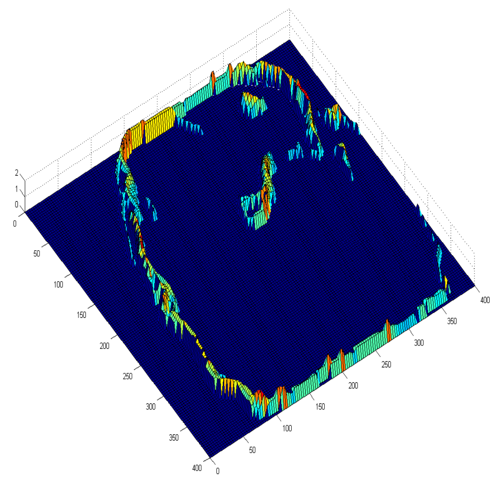
(a)



(b)

Figure 4. Explain the robustness of the algorithm. (a) Top view of dense fish schooling (b) FTLE field of the sequence, where in middle there is another boundary shows the center point of the flow.

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