Motion Estimation of Glass Eels by Differential Methods

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ملخص:

ان تحليل الحركة للحيوانات الحية قد يساعد على فهم الخطر الذي يهددها، ولكنه في بعض الأحيان يمثل تحديًا من الناحية الفنية. وهذا ينطبق بشكل خاص على علماء الأحياء الذين يدرسون الأسماك المهاجرة في حوض آدور. هنا، نقوم باستخدام الرؤية بالكمبيوتر من اجل التتبع التلقائي ومعرفة سلوك هجرة سمك الانقليس الزجاجي. لهذا الغرض، يتم وضع علامة لونية على بعض من هذه الأسماك، ثم إدخالها في نجربه تحاكي ظروف المد والجزر ومن ثم يتم تسجيلها في مقاطع فيديو. وللحصول على معلومات حول سلوكه يتم تتبع حركته بواسطة تطبيق طرق التدفق البصري. والنتائج الأولية تظهر كيفية تقدير سرعة وسلوك الحيوانات.

الكلمات الرئيسية: الانقليس الزجاجي، تحليل الحركة، الطرق التفاضلية، تتبع، سلوك السباحة، الأسماك، هورن وشونوك، لوكاس وكناد.p

Abstract

Motion analysis of living animals might help to understand the dangers that threaten the species, but it is sometimes technically challenging. This is particularly true for biologists who study migrating fishes of the basin of Adour. Here, we investigate the use of computer vision for automatic tracking and acquisition of knowledge about the migratory behavior of glass eels. For that purpose, some glass eels are color-marked, then introduced into an experimental medium reproducing tidal conditions. Observations are collected in video sequences. To get information about fish behavior, one can track their motion by optical flow methods. Preliminary results show that one can estimate the velocity but also the swimming behavior, hence eventually leading to energetic information about the animals.

Keywords: glass eel, Motion analysis, Differential methods, Tracking, Swimming behavior, Fish, Horn and Schunck, Lucas and Kanade.

Introduction

In computer vision and image processing, motion estimation is of increasing interest because of the large number of applications: object tracking (military, video-surveillance, robotics), complex behavioral analysis (modeling of human body motions, meteorology), medical analysis (cardiac contraction follow-up, infarction detection) [1][2]. In biology, tracking the motion of animals sometimes poses technical problems, related to the characteristics of species and stages of development. For example, the European glass eel (Anguilla anguilla) has a complex life cycle, with reproduction in the sea of Sargasso, a larval phase that crosses the Atlantic Ocean and a juvenile stage, the glass eel, which goes up the estuaries to grow in the river [3]. To study the estuarine migration of glass eel, it is possible to reproduce the tidal currents in the laboratory and observe the swimming behavior of individuals [4]. The major difficulties concern the animal itself, which is transparent, and moves mainly at night or at very low light intensity. To follow glass eels, each individual is tagged with VIE Tag (*Visible Implant Elastomer*) [5]. This marking consists in implanting under the skin a tip of colored elastomer, visible under UV. Tracking individuals is done on video recordings but it is a tedious job because currently not automated. The parameters that interest biologists are mainly the motion direction of glass eels (with or against the current) and their velocity. Any measure to assess energy expenditure is also sought, as glass eels do not eat during migration, and their energy status could play an important role in the migration potential. In this work, we have chosen differential methods for their many advantages. These methods are at first robust and precise, while being easy to implement. Because of its differential nature, the optical flow equation also allows a sus-pixellic estimation of the motion [6]. The advantages of these methods are: firstly, robustness and precision, the equation of the optical flow, because of its differential nature, allows a sub-pixellic estimation of the movement. The measurement of the motion requires only a local calculation of the spatio-temporal derivatives of the sequence as explained in a recent study [7]. The main disadvantage of differential methods is their foundation based on constant light intensity assumptions, and small displacements. During larger trips, however, it is possible to solve the problem by multi-resolution iterative approaches. In this case, we do not only process the image sequence at its acquisition resolution, but we build from each frame, a pyramid of images successively filtered and subsampled [8] [9]. The relevance of such an approach requires, however, that the images at the coarsest levels of the pyramid should not be too degraded by the lowering of the resolution. The purpose of this preliminary work is to use differential methods to estimate the motion of glass eel, determine the direction of their motion and assess their velocity. The article is structured as follows: section 2 presents the experimental context of the study. Then we recall the two motion estimation algorithms, namely Lucas and Kanade algorithm and briefly H&S algo. Section 4 describes the proposed processing approach. Then we present the results. Finally, we end with a conclusion and perspective.

Experimental context

To make this study, an oval-shaped aquarium, 1.50 m in length and 50 cm wide, is separated by a rigid wall at its center. [4] (Fig.1).

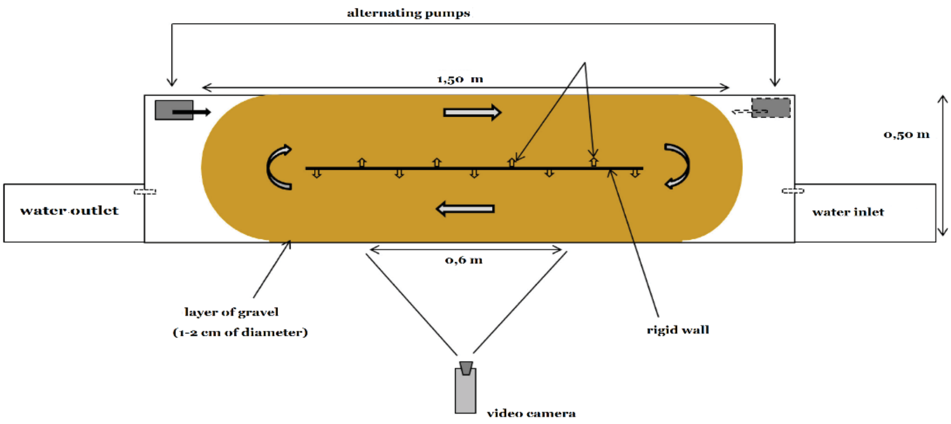


Figure 1 _ Diagram of the aquarium [10]

Two pumps, located at opposite ends of the aquarium, allow alternating water currents every 6.2 hours to replicate the rhythm of the tides. The temperature of the water is maintained at 11± 0.5° C, and a layer of gravel covers the bottom of the aquarium. The velocity of the water flow is on average 11 cm/sec. Half of the glass eels are marked with color combinations (VIE marker system: Visible Elastomer Implant) visible under UV regardless of the light conditions [11].

The average size of an glass eel is 7cm. The filmed area concerns the entire water column, over a width of 60 cm. Video recordings of 15 seconds are made every 40 minutes. The video frame rate is 15 frames/s. The database contains several hundred videos.

Motion estimation

Lucas and Kanade Algorithm

Their method is based on a local regularization of the velocity field [12] [13]. They assume that the optical flow equation remains constant in small regions Ω of the image. This is expressed by:

$$\big(u(x),v(x)\big)=argmin_{u,v}\sum_{P\in\Omega}W^2(P)\big[I_x(p)u+I_y(p)v+I_t(p)\big]^2$$
(1)

where W(p) is a window function (weighting) to give more influence to the center of the neighborhood rather than to its periphery. we note that $I_x=\frac{\partial I}{\partial x}$, $I_y=\frac{\partial I}{\partial y}$, $I_t=\frac{\partial I}{\partial t}$ are the gradient components according to (x, y, t) and $u=\frac{dx}{dt}$, $v=\frac{dy}{dt}$ are the velocity components according to (x, y). W is the diagonal matrix of W(p)

$$W=diag[w(p_1),\dots,w(p_n)]$$

Applying the least squares method, we find:

$$\begin{bmatrix}u\\v\end{bmatrix}=\begin{bmatrix}\sum W^2I_X^2 & \sum W^2I_xI_y\\ \sum W^2I_xI_y & \sum W^2I_y^2\end{bmatrix}^{-1}\begin{bmatrix}-\sum W^2I_xI_t\\-\sum W^2I_yI_t\end{bmatrix}$$
(2)

These local differential methods are interesting because each calculation on a small window is independent of the others. The results are also less sensitive to noise and allow the calculation of local motions, in particular using a pyramidal implementation.

Horn and Schunck Algorithm

The first optical flow calculation method, developed in 1981 by Horn and Schunck [5], combines the motion constraint equation with an overall regularization, using a smoothing term on the sum of the modulus squares of the velocity component gradients by minimizing the following equation:

$$\iint_D(\nabla I.V+I_t)^2+\alpha^2(\|\nabla u\|^2+\|\nabla v\|^2)dxdy$$
(3)

where the scalar α is a weighting coefficient that adjusts the influence of the smoothing (regularization) term. An iterative algorithm minimizes the integral defined on the domain D.

The iterative equations are:

$$u^{k+1} = \overline{u}^{k} - \frac{I_x[I_x\overline{u}^{k} + I_y\overline{v}^{k} + I_t]}{\alpha^2 + I_x^2 + I_y^2} \quad (4)$$

$$v^{k+1} = \overline{v}^{k} - \frac{I_x[I_x\overline{u}^{k} + I_y\overline{v}^{k} + I_t]}{\alpha^2 + I_x^2 + I_y^2} .$$

where k represents the iteration index, I_x, I_y, I_t are the components of the gradient according to x, y, t and $\overline{u}, \overline{v}$ are the average values calculated on a weighted neighbourhood. As differential methods rely on partial derivative calculations, the quality of the estimate is strongly dependent on the derivation formulae chosen. Since a derivative calculation is sensitive to noise, spatio-temporal low pass pre-filtering is often required.

Proposed processing method

As shown in (Fig.2)., our algorithm essentially consists of the following steps:

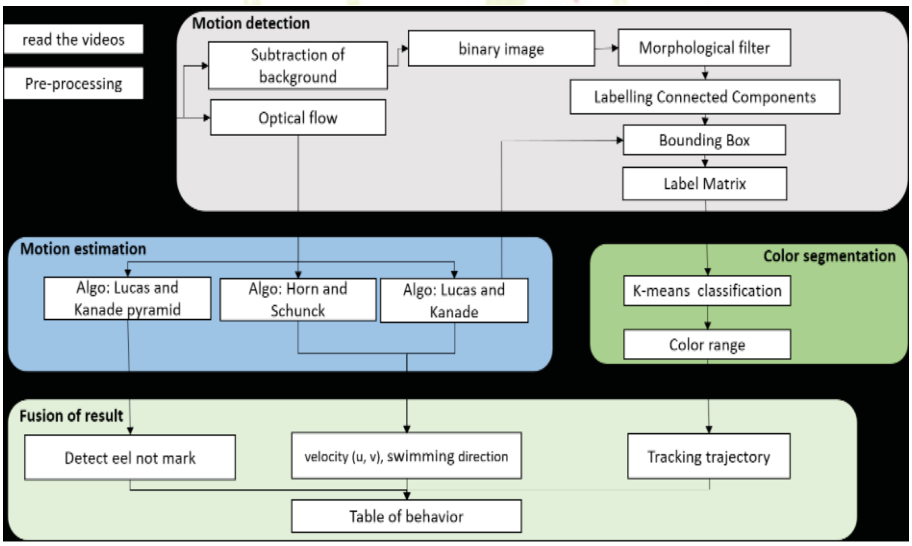


Figure 2 _ processing schema.

- **acquisition step:** The size in bytes of an image is 1280 X 960 X 3 (Fig.3). These RGB images are transformed into HSV images because of the independence between the colors in this color space.

Figure 3 _ A sequence of 6 consecutive images

- **pre-processing step:** during acquisition of the real scene by the sensor, noises appear and distort the visual rendering of the scene. It is therefore necessary to pre-process the images in order to bring out the most relevant information. Conventional filtering techniques are applied to the raw data, in particular the low-pass filter, the averaging filter.
- **Motion detection**: In this stage our goal is to detect the moving objects in a video sequence [14]. Two methods are used: the optical flow method and the subtraction method. The optical flow is used in two steps: object detection and motion estimation. The motion estimation is applied by the two Lucas and Kanade algorithms and Horn and Schunck to determine the velocity vector fields, we also used the pyramidal implantation of Lucas and Kanade to detect some glass eels not marked in the aquarium (we are going to explain more detail in the results).
- **connected Components**: After the morphology operation we detected the groups of connected pixels (objects) and determined the parameters of each object such as: number of pixels, left edge, right

edge, top edge, bottom edge. With these parameters, we define a bounding box for each object and then we build a label matrix of the sequence containing all these parameters.

- **K-means classification**: From this matrix, we used the K means method on the hue of each frame in the video sequence to determine the range of each color (the elastomer marking is done with four colors: blue, green, red and orange) [15]. At this stage of our study, we try to track the trajectory of each glass eel by Kalman filter and merge all the results in a behavior table that contains all the information about the glass eels.
- **fusion**: after extraction of the information by the motion detection, motion estimation and color segmentation, it can be merged to determine the swimming direction and the velocity of the fish and to follow the trajectory of the glass eels. At this stage of our study, we merged the results of the color segmentation step, it is to determine the colors of each marking and calculate the velocity by the motion estimation step.
- **archive**: finally, we store the results of this fusion in a table that contains all the information on the behavior of glass eels.

Results

First of all, in order to determine the basics of swimming behavior of glass eels (sense and velocity), we start by explaining the results obtained with the local method of Lucas & Kanade that meets the first need of biologists. Next, we present the results of the global method from Horn & Schunck, which shows in more details the motion of the glass eels. To apply these algorithms, we use two successive images. This is illustrated in Fig. 4. The original image (a) has four marked glass eels: the first two are at the bottom left in the image, one with a short orange marking (close) coded OOS, and the second with a double orange marking and long red (spaced) coded ORL; the third is in the middle of the image with a long green double marking (code GGL), and the fourth is on the right in the image with a double green and short blue marking

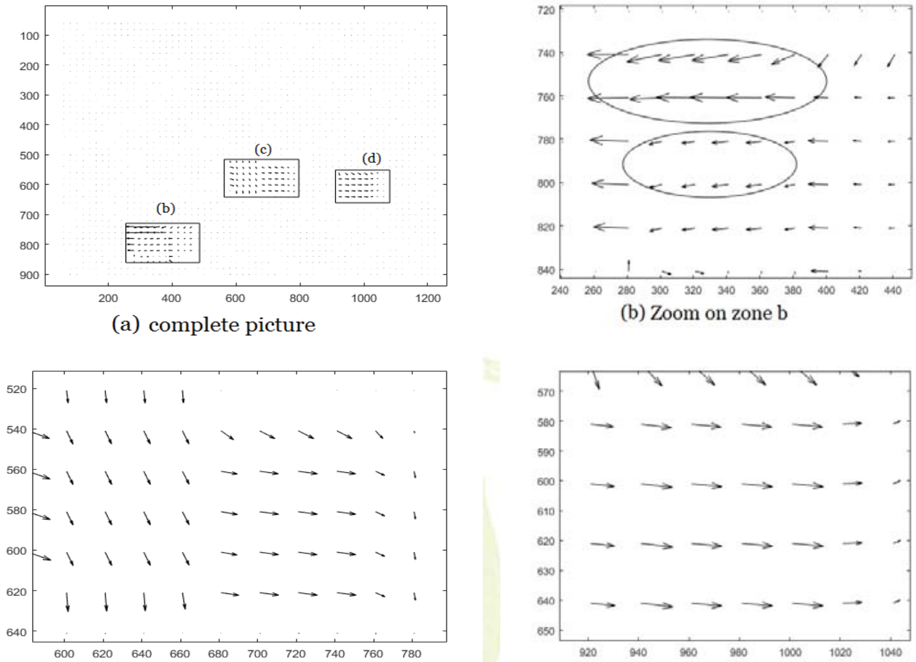
(GBS code); image (b) corresponds to the next instant. The direction of the water current in this sequence goes from the right to the left of the image.

(a) (b)

Figure 4_Two successive images: (a) at the instant t and (b) at the instant t+dt With four marked eel (OOS, ORL, GGL and GBS).

Results with Lucas & Kanade

The differential method of Lucas & Kanade is interesting because each calculation on a small window is independent of the others. In the algorithm we use small windows of size 40 X 40 pixels. In Fig. 5 (a), we notice in each window that the arrows have a general orientation corresponding to the direction of motion of the glass eels. To better visualize the velocity vector fields, we chose and enlarged three zones (b), (c), (d). Fig. 5 (b) shows the area (b). There are two different sizes of arrows, which reflect the presence of two individuals. These two glass eels move to the left of the image, the one characterized by the larger arrows swimming faster than the other. In the figure 5 (c) the size of the arrows is identical which means the presence of a single glass eel that moves to the lower right side of the image. Similarly, in the figure 5 (d), we see that the arrows are identical revealing a single glass eel moving to the right. As a result, we can distinguish the mean velocity of different glass eels.



(a) complete picture (b) Zoom on zone b (c) Zoom on zone c (d) Zoom on zone d

Figure 5_ Vector-velocity field by the Lucas & Kanade algorithm.

Calculating the velocity of glass eels

To calculate the velocity of glass eels, we chose a sequence of 6 images with a shift between each pair of successive images of 14 images, Fig. 6 (a). The principle of our algorithm is based on two phases. The first is to detect glass eels in the video sequence as described in the section 4 and to calculate the centers of gravity of *bounding boxes*, Fig. 6 (b). In the second phase, the Lucas & Kanade algorithm is used to estimate the velocity vector field in each center of gravity and calculate the velocity V of each glass eel thanks to the following equation: $\|\vec{V}\| = \sqrt{u^2 + v^2}$

The results obtained in Fig. 6 (c) make it possible to distinguish two different velocities: glass eels in the direction of the water current swim with a weak undulation and consequently they have a low velocity field. On the other hand, glass eels going against the direction of water flow swim with a strong undulation and the field of velocities is more important.

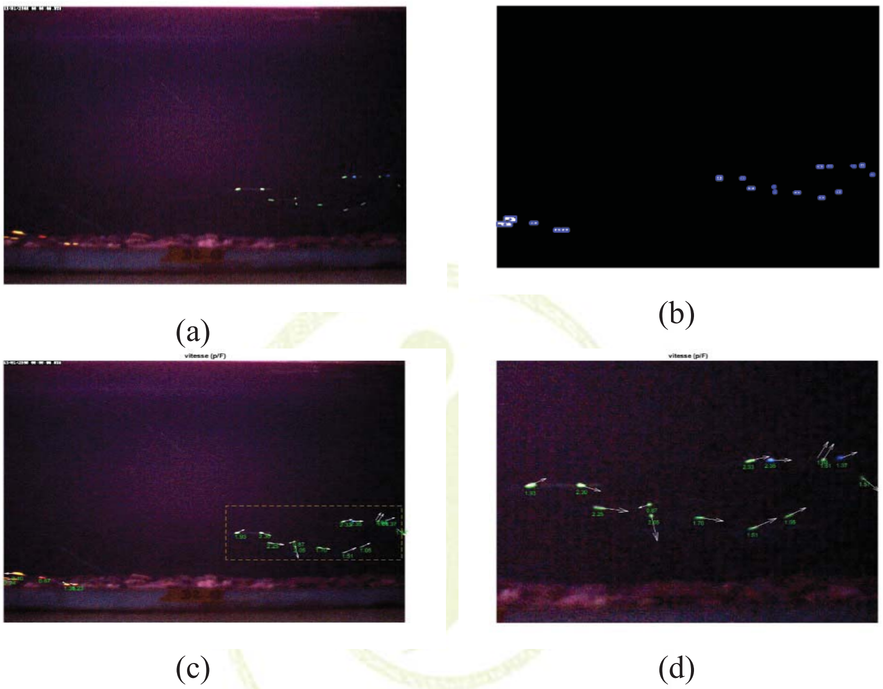


Figure 6-Calculate the speed of glass eels, (a) Sequence of 6 superimposed images, (b) Bounding boxes and centers of gravity, (c) velocity $\|\vec{V}\|$ calculated in pixels/frame, (d) Zoom on the rectangle of the figure (c)

In order to observe the undulation of the glass eels swimming [15], for each mark detected we calculate the angle of undulation by the relation:

$$\theta = \arctan(\frac{v}{u})$$

knowing that each eel has two marks, on the results of Fig. 7, we note two undulations different from eel: if the swim is against the current, a significant shift occurs between the two angles of undulation [16] [17]. On the other hand, with the direction of water current, the two angles are very similar.

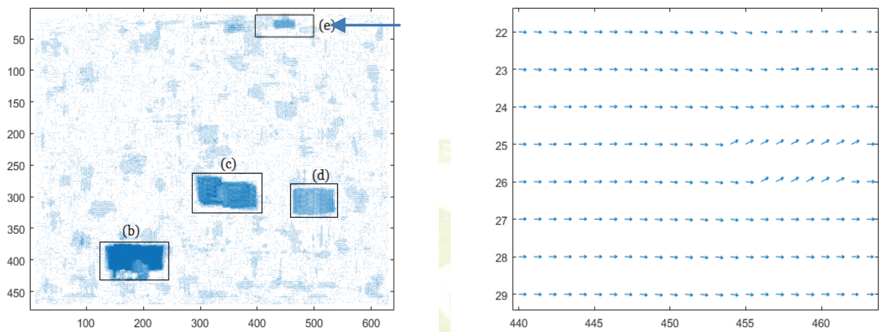
Figure 7-The θ angles of the undulating of glass eels; two different swimming sense: WC (with current) and AC(against current)

Pyramidal implantation

A pyramidal implementation of the Lucas & Kanade algorithm has been implemented with iterative refinement at each level. The main steps of this pyramid algorithm are:

- A Gaussian pyramid is formed up to a three level (n=3), filtering the image with a Gaussian mask, then scaled by a factor of 0.5.
- The size of the integration window is maintained at Ω=20 X 20 and the number of iterations is i=10.
- The Lucas & Kanade algorithm is executed first at the highest level of the pyramid using an initial zero estimate of the vector field.
- The optical flow, calculated at the top level of the pyramid (L=n), is then scaled by a factor of 2 and propagated to the lower level (L=n-1), as the initial value for calculate the optical flow at the lower level. This process continues to the lowest level (L= 0).

Large motion can be correctly estimated with a small window of integration thanks to this approach; the problem of limitation of displacements with the classical method can thus be solved. Fig. 8 (a) shows the four glass eels already detected previously (b, c and d) and in addition, a new glass eel (zone e) which moves near the surface of the water. This unlabeled glass eel was not detected by the two main algorithms because its intensity is very low, which means a weak undulation too. Fig. 8 (b) shows its weak passage to the right side of the image in the direction of the current.

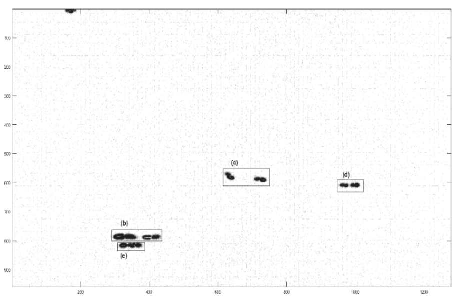


(a) (b)

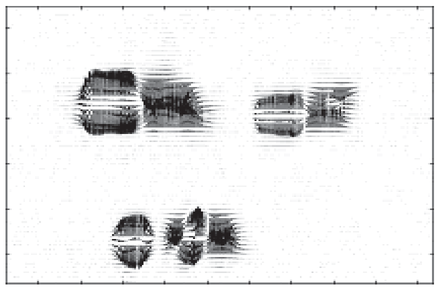
Figure 8- pyramidal of Lucas & Kanade, (a) direction of the water current goes from right to left: (b) Zoom on the chosen area(e)

Results with Horn & Schunck

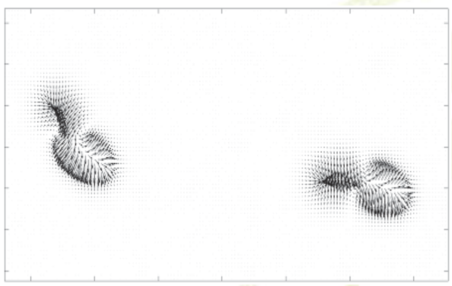
In this algorithm, we optimized the results by playing on the number of iterations (i=11) and the smoothing parameter (α=1). We obtain in Fig. 9 (a) a vector-velocity field superimposed on the initial image. To better visualize the optical flow, each vector field has been zoomed in Fig. 9 (b, c, d).



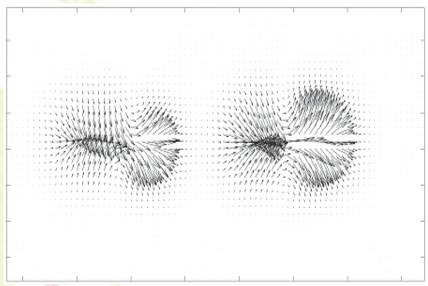
(a)global field superimposed on the initial image (1280X960)



(b) zoom on the area ORL field and OOS (WC)



(c)Zoom on the area (c) GGL (AC) field



(d) Zoom on the area (d) BGS (AC) field

Figure 9_Velocity vector field with the Horn & Schunck algorithm

In zone (b): we see two glass eels, the first with double long marking (ORL) and the second with two short marking (OOS): for each, we have a velocity vector field with two different orientations of arrow: the one is orientated inside to the origin which corresponds to the departure position of the glass eel (convergence) and the other is oriented of the origin to the outside which corresponds to the position of its displacement (divergence). We can also identify the direction of motion that will be from convergence to divergence. For example, here, the glass eel moves to the right of the image. The difference between the intensity of the convergent fields and the intensity of the divergence fields demonstrate the undulating motion of the glass eel [16] [17]. Moreover, the head of the glass eel has a greater field intensity than the tail.

Conclusion et perspective

The differential methods of Horn & Schunck and Lucas & Kanade are used in this article. The computation time of the optical flow of a pair of images obtained with Matlab is typically: 0.14s for the Horn & Schunck method, 0.51s for the Lucas & Kanade method. The flow obtained by the Lucas & Kanade local method makes it possible to determine the motion direction of the glass eels because the arrows of the vector-velocity field computed. The application of the Lucas & Kanade algorithm to the center of gravity of each glass eel also allows to obtain a superimposed sequence on which it is possible to calculate the velocity of displacement. The procedure of iterative refinement by a multi-resolution structure makes it possible to estimate the small incremental motions of glass eels, undetectable by the general differential methods. This result reflects a more accurate optical flow and suggests the possibility of detecting and tracking unmarked glass eels.
Horn & Schunk's global method specifies the undulatory motion of glass eels that could be used as a proxy for energy expenditure related to swimming. The glass eels adopt different swimming strategies (with or against the current), with more or less high velocity. In order to better understand these different migration tactics and their energy costs, biologists hope to couple these measures of velocity and range of motion with the weight loss of glass eels and their metabolism. Finally, the ultimate goal of this project is the automation of these measures in order to reduce the working time of the observer. For that purpose, we have in perspective, thanks to the fusion of the results obtained by the main phases of processing of section 4, to build a tool allowing the automatic tracking of glass eels integrating sense of swimming, velocity and undulation energy.

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