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# Velocity estimation of valve movement in oysters for water quality surveillance

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**Abstract:** The measurements of valve opening activity in a population of oysters under natural environmental conditions are used to estimate the velocity of their valve movement activity. Three different differentiation schemes were used to estimate the velocity, namely an algebraic-based differentiator method, a non-homogeneous higher order sliding mode differentiator and a homogeneous finite-time differentiator. The estimated velocities were then used to compare the performances of these three different differentiators. We demonstrate that this estimated velocity can be used for water quality monitoring as the differentiators can detect very rapid change in valve movements of the oyster population resulting from some external stimulus or common input.



*Keywords:* Velocity estimation, water quality monitoring, Oyster population.

## 1. INTRODUCTION

Since the last century, the environmental quality of our world is changing rapidly causing significant changes in the water quality. For this reason, nowadays, national and international legislation has strict recommendations on the protection of aquatic environment against the release of dangerous substances. In order to abide by these recommendations for the protection of aquatic environments, the large scale monitoring of water quality is essential. However, to implement such an extensive network of monitoring is very costly. Researchers are then working on an indirect ecological monitoring from behavioral and physiological responses of representatives of the marine fauna. Hence, bio-indicators are increasingly being used and showed high efficiency, for instance through bioaccumulation of contaminants in their tissues. Nevertheless, until now, large scale monitoring with bio-indicators do not seem feasible and realistic as it involves intensive exploitation of human resources for the collection of samples, complex chemical analysis and so on [Telfer et al. (2009)]. A solution is to develop unmanned systems using bio-sensors, able to work 24/7, at high frequency by remote control. As of today, networks of such online sensors, operating at large scale do not exist and are still a matter of research.

To fulfill that objective, an installation of numerous online remote sensors is required, working at high frequency for instant collection of information on a daily basis in marine environment [Krger and Law (2005)]. Behavioral and physiological responses of wildlife to pollution are very sensitive and can be estimated for an indirect ecological monitoring. However, a limiting factor today is the analysis of data that needs sufficiently accurate models of animal behavior in natural conditions. Other difficulties lie in the fact that animals may be heavily influenced by environment, group interactions and internal rhythms (*e.g.* feeding, breathing, spawning).

Observation of the opening and closing activities of bivalves is a possible way to evaluate their physiological behavior in reaction to environment. The deviations from a normal behavior can be used for detection of a contaminant in surrounding water. The pioneer work that analyzes bivalve's activities through the record of their valve movements (*e.g.* valvometry) was realized by F. Marceau [Marceau (1909)] with smoked glazed paper. Today, valvometers are commercially available and are mainly based on the principle of electromagnetic induction, like the Mossel Monitor [Kramer et al. (1989)] or the Dreissena Monitor [Borcherding (1992)]. In recent years,

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the interest for modeling and estimation of behavior of marine animals directly in real marine conditions has intensively increased [Riisgard et al. (2006); Robson et al. (2007); Garcia-March et al. (2008); Galang et al. (2012)].

A remarkable monitoring solution has been realized in the UMR CNRS 5805 EPOC Laboratory in Arcachon, France [Sow et al. (2011); Tran et al. (2003); Schmitt et al. (2011)], where a new framework for noninvasive valvometry has been developed and implemented since 2006. The designed method is strongly based on bivalve's respiratory physiology and ethology. The developed platform for valvometry was built using lightweight electrodes (approximately 100 mg each) linked by thin flexible wires to high-performance electronic units. These electrodes are capable to measure the position of the opening of a mollusk shell with an accuracy of a few $\mu$m. This system allows the bivalves to be studied in their natural environment with minimal experimental constraints. Statistical approaches have already been used for the analysis of this data [Sow et al. (2011); Tran et al. (2003); Schmitt et al. (2011)].

The goal of the present work is to estimate the velocity of the valve opening/closing activities of the bivalve (*i.e.* an oyster in our case) from the measured position of shell. We have used the experimental data obtained from a population of 16 oysters living in the bay of Arcachon (France). We have tried to examine whether there exist any relationship between the velocity and the contamination of water as the quality of the water influence the behavior of the oyster population. Three different methods of differentiation were used for estimating the velocity, namely: an algebraic differentiator [Mboup et al. (2009)], a higher order sliding mode (HOSM) based differentiator [Efimov and Fridman (2011)] and a homogeneous finite-time differentiator [Perruquetti et al. (2008)]. Their performances were then compared. The methods were chosen because of their individual merits. For example, HOSM differentiator has the global differentiation ability independently on the amplitude of the differentiated signal and measurement noise, but it has some chattering in the response, while the homogeneous finite-time differentiator has no chattering, but it is more sensitive to the amplitudes of the signals to be differentiated. The differentiator based on the aforementioned algebraic method is very useful in noisy settings, but it presents some delay in online applications.

The organization of the paper is as follows: a brief description on the measurement and data collection activity is given in section II. Section III presents a summarized version of the three differentiation schemes, while section IV describes the result, i.e velocity estimation from the experimental data, and discusses the relation of velocity estimation with contamination level in water. Finally, section V concludes the present work.

## 2. MEASUREMENT SYSTEM DESCRIPTION

The monitoring site was located in the bay of Arcachon, France, at the Eyrac pier (Latitude: 44°40 N, Longitude: 1°10 W). Sixteen Pacific oysters, *Crassostrea gigas*, measuring from 8 cm to 10 cm in length were permanently installed on this site. These oysters were all from the same age group (1.5 years old) and came from the same local supplier. They also all grew in the bay of Arcachon. They were immersed on the sea bottom (at 3 m to 7 m deep in the water, depending on the tide activity). We analyzed the data for the year 2007.

The electronic equipment has been first described in [Tran et al. (2003)] and slightly modified (adapted to severe open ocean conditions) in [Chambon et al. (2007)]. A considerable advantage of this monitoring system is that it is completely autonomous and made to work without *in situ* human intervention for one full year. Each animal is equipped with two light coils (sensors) of approximately 100 mg each, fixed on the edge of each valve. One of the coils emits a high-frequency sinusoidal signal, that is received by the other coil. One measurement is performed every 0.1 sec (*i.e.* at 10 Hz) for one among the sixteen animals. So the behavior of a particular oyster is measured every 1.6 sec. EPOC's website MolluScan-Eye [2] can be consulted to see the recorded data sets of information. So, every day, 54000 triplets (1 distance, 1 stamped time value, 1 animal number) are collected for each oyster. The strength of the electric field produced between the two coils is proportional to the inverse of distance between the point of measurement and the center of the transmitting coil leading to the measurement of the distance between coils. A schematic description of the monitoring system can be found in [Ahmed et al. (2014, 2015)].

## 3. DIFFERENTIATION METHODS

For our problem of velocity estimation of the valve activity in oysters, we have considered three different methods of derivative estimation that are summarized below.

### 3.1 Algebraic differentiator

The algebraic time derivative estimation presented here is based on concepts of differential algebra and operational calculus. A more detailed description of the approach can be found in [Mboup et al. (2009); Ushirobira et al. (2013)]. A moving horizon version of this technique is summarized below adapted from the references mentioned just before.

For a real-valued signal $y(t)$, analytic on some real interval, consider its approximating $N$th degree polynomial function, originated from its truncated Taylor expansion:

$$y(t) = \sum_{i=0}^{N} \frac{a_i}{i!} t^i, \qquad (1)$$

where the terms $a_i$'s are the unknown constant coefficients representing the derivatives of the signal. The aim is to estimate these time derivatives of $y(t)$, up to order $N$. This estimation can be done by restarting the algebraic combinations on moving time horizon of integrals of $y(t)$. The summarized result of this method is given below taken from [Mboup et al. (2009)]:.

For any $T > 0$, the $j$-th order time derivative estimate $\widehat{y}^{(j)}(t)$, $j = 0, 1, 2, \cdots, N$, of the signal $y(t)$ defined in (1) satisfies the following convolution

$$\widehat{y}^{(j)}(t) = \int_0^T H_j(T, \tau) y(t - \tau) d\tau, \; j = 0, 1, \cdots, N,$$

[2] http://molluscan-eye.epoc.u-bordeaux1.fr/