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DETECTION OF ARTEFACT REDUCED PIV DATA IN THE FLOW AROUND BIONIC SPECIMEN

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Abstract

Investigations of biological specimen have become an interesting topic in modern fluidmechanics. Several theoretical and experimental studies have been carried out from different points of view, for example flow induced by microorganisms, insects, theoretical and experimental analysis of the kinematics and the coordination of multi-fin system, research of maximum swimming speed of fish, manoeuvring ability of underwater organisms etc. Ciliates play an important role for biogranulation and mixing process in micro-scale. Seahorses due to their high manoeuvrability, high stability of underwater locomotion as well as highly precise locomotion control become an interesting object also in respect to bionic inspired control and locomotion of AUV (Autonomous Underwater Vehicles). The anatomy of seahorses results in production of small forces due to low ratio of locomotive active (fins) and passive parts. The major aim of the present work is to analyse the fin movements as well as to study the flow induced in the surrounding fluid. Studies of motion of seahorse fins and of the surrounding fluid flow are carried out by using Particle Image Velocimetry (PIV). Given that the measurement of this kind is influenced by erroneous artefacts occurring during the processing of PIV data, a novel approach for reduction of artefacts is going to be implemented. Previous studies of Delgado and co-workers of biological flow induced by *Opercularia asymmetrica* proved the utilised neuronumerical hybrid to be an efficient tool allowing to predict artefacts and correct them. It bases on the implementation of numerically expressed *a priori* knowledge on the flow field (Taylor-Hypothesis) as functional node into artificial neural network used for the analysis of measured velocity field.

Introduction

Bioflow investigations become an interesting topic in fluid mechanics. Understanding the motion of biological flow gives basics in controlling complicated processes like mixing, transport phenomena or even locomotion of Autonomous Underwater Vehicles. Several studies have been carried out with insects flights (Dickinson, 2008, Liu and Kawachi, 1998), flow induced by ciliates (Delgado et al., 2007, Hartmann et al. 2007, Kowalczyk et al., 2007, Petermeier et al. 2007), fish locomotion (Barretti et al., 1999, Drucker and Lauder, 2003, Lauder et al., 2002, Wöhl and Schuster, 2007) etc. Studies of Delgado and co-workers with *Opercularia asymmetrica* indicate a significant role of ciliates in wastewater treatment (granules formation) and mixing process. Fish locomotion has been studied by several scientists (e.g. Barretti et al., 1999, Lauder et al., 2002). However, among different underwater organisms seahorses have precise manoeuvrability in difficult terrain. Their anatomy enables production of small forces due to a low ratio of locomotive active (fins) and passive parts. Dorsal and pectoral fins undulating with the frequency up to 50 Hz cause translational movement of seahorse. These properties make seahorses an interesting object in respect to bionic inspired control and locomotion of AUV (Autonomous Underwater Vehicles). Several studies have been carried out with seahorses from different points of view. Pioneering work concerning their locomotion has been done by Breder and Edgerton (1942) by using high speed cinematography. Lighthill and Blake (1990) as well as Daniel et al. (1992) gave theoretical fundamentals of the biofluid dynamics of swimming according to the undulatory and oscillatory fin movement. Lourie et al. (2004) and Kuiter (2001) contributed to the biological classification of all known seahorses. Moreover, Sfakiotakis et al. (2001) and Consi et al. (2001) modelled the kinetics of a dorsal fin of seahorse. However, further investigations of the movement of all active parts are recommended. Ashley-Ross (2002) studied mechanics of the dorsal fin of *Hippocampus*. Furthermore, Kowalczyk and Delgado (2007) presented numerical studies of undulatory, oscillatory and combined fin-like movement.

The characteristic undulatory fin movement of a seahorse is sketched in Figure 1. However, flow induced by seahorses is poorly investigated in literature and intensive research is necessary for making progress towards a better understanding of these natural phenomena. Thus, the major aim of the present work is to analyse the fin movements as well as to study the flow induced in the surrounding fluid.

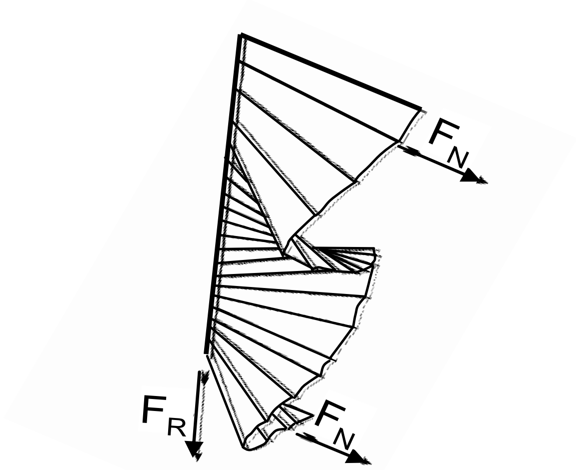

Figure 1 Undulatory fin movement of seahorse

Analysis of fluid flow generated by seahorse is carried out by using Particle Image Velocimetry. However, those investigations can be influenced by erroneous artefacts occurring during the processing of PIV data. Because of these difficulties we will apply here a new neuronumerical hybrid that efficiently predicts and corrects artefacts.

Experimental Setup

Seahorses (*Hippocampus reidi*) are kept in a laboratory scale aquarium (see Figure 2). In order to analyse fin movements of *Hippocampus reidi* and flow induced in the surrounding fluid, optical in-situ techniques are employed.

A frequency-doubled cw Nd:YAG laser with a wave length of 532 nm and cylindrical lens is used as light source. The plane of the Nd:YAG laser light sheet is arranged perpendicular to the camera optical axis.

Images are acquired by a high–speed CCD camera (Mikrotron GmbH) with a maximum speed of 520 frames/s. In the present case, the images of flow patterns with a size of 1060x1024 pixels are taken with speed of 25 frames/s. The frames from the CCD camera are directly transferred and recorded on a PC.

Hollow glass spheres with a density of 1.1 g/cm^3 and a diameter of 2–20 µm (Dantec Dynamics) are employed to visualise the flow pattern. The principal idea of measurements is shown in Figure 3.

Figure 2 Aquarium with seahorses

The calculation of the fluid velocity is carried out with help of the software PIVview2C (PIVTEC GmbH), developed by Raffel et al. (1998). The cross–correlation mode is used to extract particle displacement. PIV investigations are carried out by the multiple–pass interrogation algorithm which is built in the PIVview2C software. This method increases the data yield due to the higher number of matched particles and reduces the bias error (Westerweel et al. 1997). In the present work, the interrogation window size is chosen as 48x48 pixels and the grid size is 23x23 pixels. Sub–pixel displacement of the correlation peak is obtained by a 3–point Gauss fit. This selects the four closest neighbours of a correlation maximum and fits a three–point Gaussian curve for each of the major axes (Willert and Gharib, 1991).

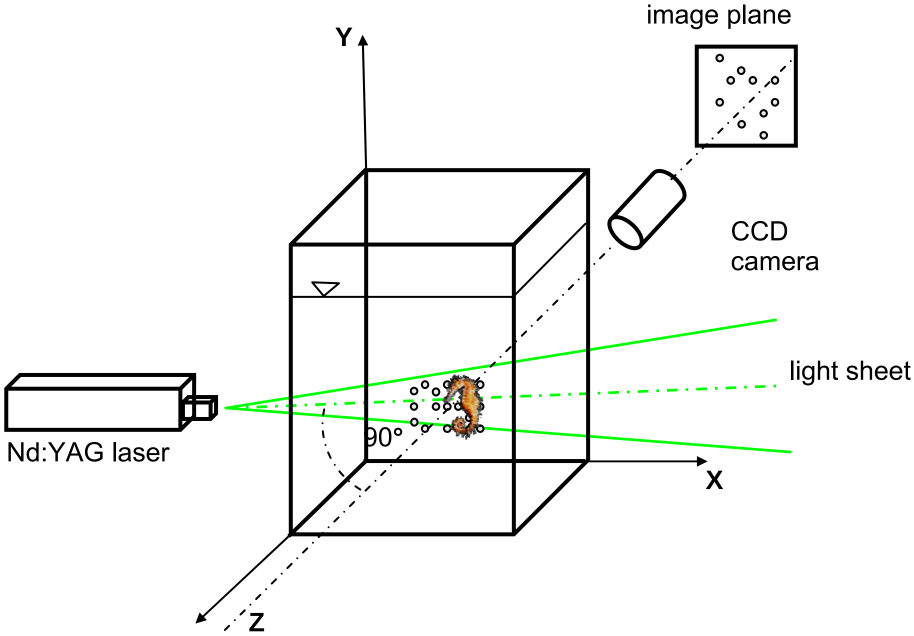

Figure 3 Optical system with Nd:YAG laser

It should be pointed out that biological flow investigations (in our case seahorse) can be influenced by erroneous artefacts occurring during the processing of PIV data. Thus, as shown in the previous work of Delgado and co-workers of flow induced by *Opercularia asymmetrica,* a novel neuronumerical hybrid is an efficient tool allowing to predict artefacts and correct them. It is based on the implementation of numerically expressed a priori knowledge on the flow field (Taylor's hypothesis) into an artificial neural network (ANN) as a functional node. Equation 1 expresses the Taylor's hypothesis

$$\left.\frac{\partial \tilde{u}}{\partial t}\right| + \left.\left[(u+\varepsilon_u)\frac{\partial \tilde{u}}{\partial x} + (\nu+\varepsilon_v)\frac{\partial \tilde{u}}{\partial y}\right]\right|_{(x_0,y_0)} = Ta(x_0,y_0). \tag{1}$$

Where ε_u, ε_v depict the velocity field corrections, $\left.\frac{\partial \tilde{u}}{\partial t}\right|_{(x_0,y_0)}$ the temporal derivative, $\left.\frac{\partial \tilde{u}}{\partial x}\right|_{(x_0,y_0)}$ and $\left.\frac{\partial \tilde{u}}{\partial y}\right|_{(x_0,y_0)}$ the spatial derivatives, $(\tilde{u},\tilde{v})$ the velocity field obtained from PIV evaluation. The classic ANN is connected with the functional node part of the network using weights with the constant value of 1, what means that they are excluded from the training but propagate the error back to the classic ANN part to minimise the sum squared error. ANN consists of one input layer with seven nodes (x, y coordinates, two velocity components, one temporal and two spatial derivatives of velocity), three hidden layer with three nodes (two velocity components and Taylor value) and one functional node (see Figure 4).

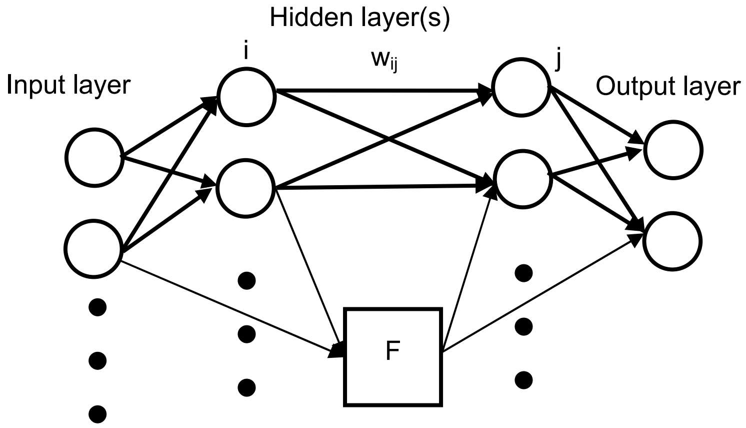

Figure 4 ANN. The circles represent classical nodes (neurons), the square a functional node. The weights are represented by w_{ij} weighting the connection between nodes i and j

Results and Discussion

As explained in the introduction part, the major aim of the present work is to analyse the fin movements of seahorses as well as to study the flow induced in the surrounding fluid. As shown in Figure 5 three different fins (pectoral, dorsal and anal) initiate the motion of seahorses.

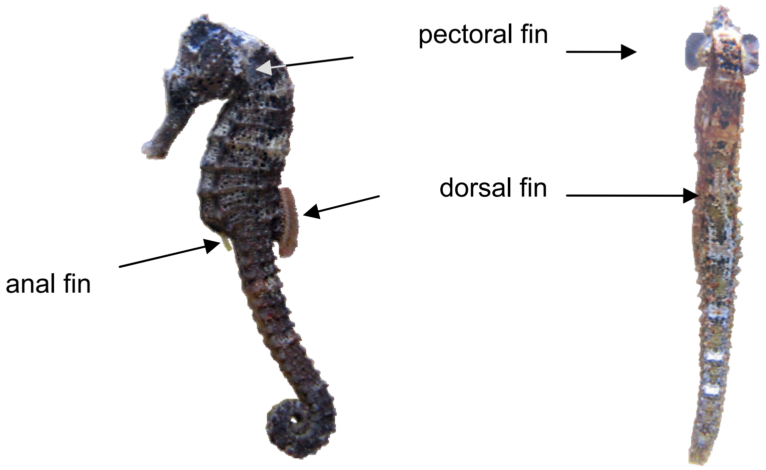

Figure 5 Fin movement of sehorses

First experimental investigations indicate characteristic flow pattern around moving fins (see Figure 6 and Figure 7).

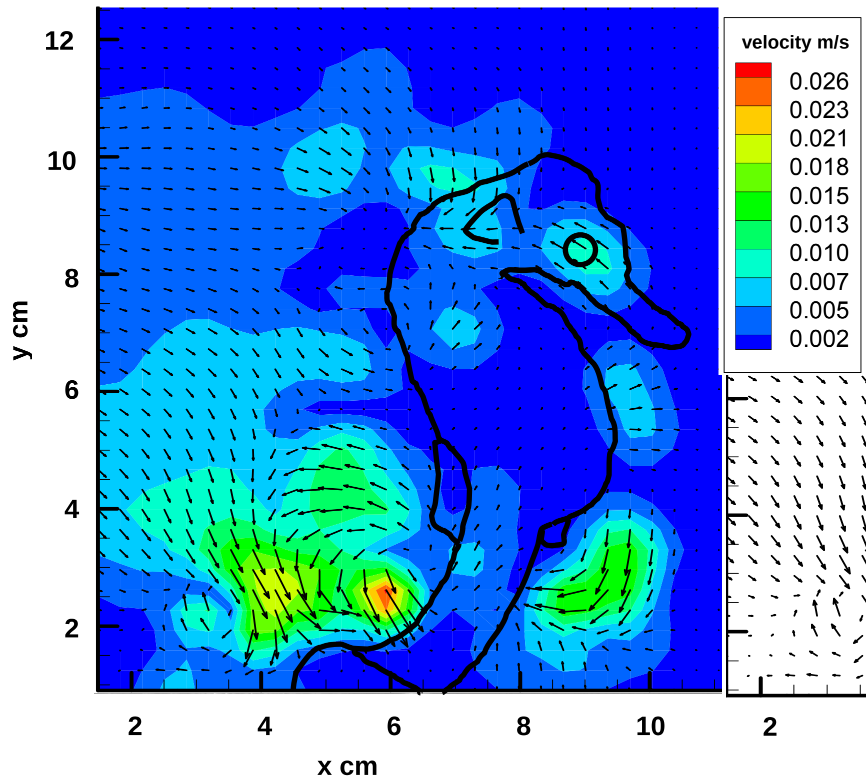

Figure 6 Velocity field around seahorse

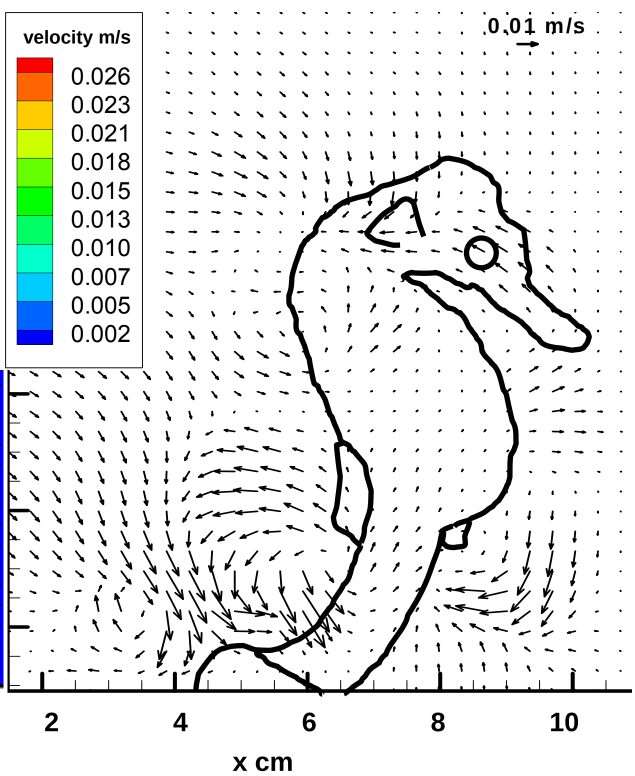

Figure 7 Flow induced by fins movement

The above figures indicate that maximal velocity of u_{max}=0.026 m/s appears close to the dorsal fin. Lower velocity u_{max}=0.016 m/s is observed around the anal fin and the lowest one u_{max}=0.010 m/s near the pectoral fin. Analyzing the same example at different moment of time (after 0.8 s), flow pattern and range of velocity distribution are different (see Figure 8). However, similar as in the previous case the highest velocity is observed close to the dorsal fin (u_{max}=0.024 m/s). Lower values appear for the pectoral (u_{max}=0.022 m/s) and the anal fins (u_{max}=0.023 m/s).

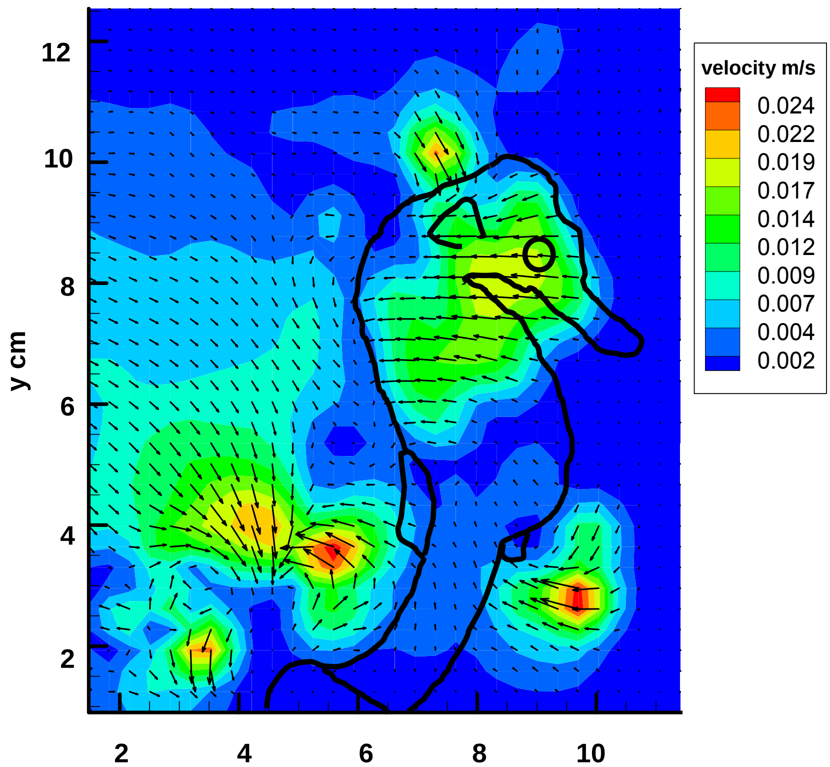

Figure 8 Velocity distribution around seahorse

Characteristic undulatory dorsal fin movement of seahorse can be observed in Figure 9. Here, the maximal velocity is equal to u_{max}=0.013 m/s.

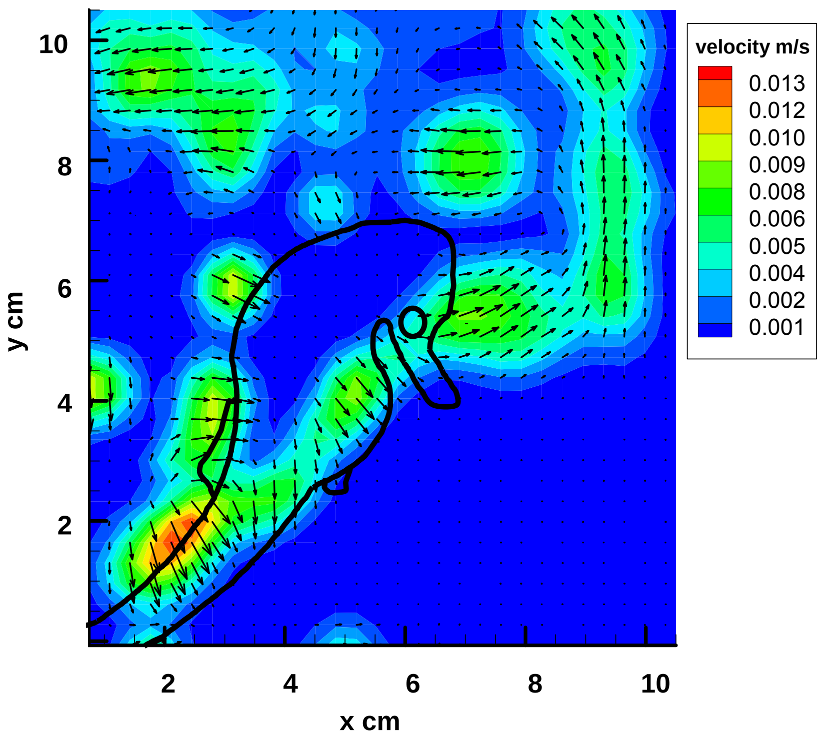

Figure 9 Undulatory fin movement of seahorse

In order to improve the quality of PIV evaluation and to detect possible artefacts occurring during the processing of data, novel approach for reducing artefacts will be implemented.

Conslusions

This work presents, for the first time, biofluid mechanical studies of the flow induced by seahorses. The results indicate a characteristic flow pattern around the fins. The highest velocity equal to u_{max}=0.026 m/s appears close to the dorsal fin. Moreover, undulatory movement of the dorsal fin is observed. However, in order to understand the important and complicated phenomenon of the fin movements and its influence on the surrounding fluid flow further experimental investigations are needed. In the future a novel neuronumerical hybrid is going to be implemented to predict and correct possible artefacts.

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