Publications of the Institute of Geophysics, Polish Academy of Sciences
Geophysical Data Bases, Processing and Instrumentation
vol. 439 (E-12), 2022, pp. 53-55
DOI: 10.25171/InstGeoph_PAS_Publs-2022-015
Webinar on Methods for Ecohydraulics: Remote Sensing, 17–20 May 2022

Study on Fish Swimming Behavior Based on Image Velocimetry

Huhu LIU✉, Yu HAN, Yi ZHOU, and Yue ZHANG

China Agricultural University, Haidian District, Beijing, China

✉ sy20213091843@cau.edu.cn

Abstract

The fish passage is an effective way for fish to pass through dams and obstacles, but most fish passes are currently not used, and the energy used by fish to pass through them is too great to meet the conditions for passage. This paper focuses on the factors that affect the fish swimming energy expenditure. The factors include the hydraulic conditions of the fish passage, the fish swimming speed, and the fish tail swing frequency. A baffle is set up in a U-shaped channel with different barriers on either side of the baffle, making the hydrodynamic conditions different on each side of the channel. HD cameras were set up to observe and record the fish swimming behaviors in the channel, and deep learning YOLOV5 algorithm was used to identify the fish swimming speed and the frequency of the tail swing. The data was analyzed to derive an equation for calculating the fish swimming energy consumption. FLUENT was used to simulate the fish energy consumption in the channel during high flows and to obtain the route with the lowest energy consumption of the fish, which will provide suggestions for the subsequent construction of fish passage and fish crossing facilities.

Keywords: deep learning, fish swimming energy consumption equation, tail swing frequency, model simulation.

1. INTRODUCTION

The fish passage is an artificial channel for fish to travel upstream through a structure such as a lock or dam or a natural structure. The ecological significance of the fish passage is to mitigate the impact of dam construction on fish and to help impeded fish to pass through the barrier and reach their important habitat for breeding and overwintering. At present fish passages are not working very well (Cao et al. 2016). The fish use too much energy to swim in them to meet the conditions for their passage and therefore the fish passages are not working as well as they could.

Fish accomplish most of their basic behaviors by swimming. The fish swimming behaviors can be influenced by hydrodynamic conditions in the channel. Additionally, the active metabolic rate (AMR) is a valuable parameter that can be used as an indicator of the fish swimming efficiency (Xia et al. 2013). Ohlberger et al. (2006) analyzed the relationship between the fish swimming speed and AMR in the channel and derive the equation (Ohlberger et al. 2005, 2006). This paper focuses on the relationship between the fish energy consumption and the hydraulic conditions in the channel and the fish own factors, and get the fish swimming energy consumption equation.

2. EXPERIMENTAL SET UP

A baffle in the U-shaped channel divides the channel into two identical parts, with different barriers on each side, making the hydrodynamic conditions different on each side (Kerr et al. 2016). Instantaneous flow velocities and water depths are measured at multiple cross sections. Turbulent kinetic energy is obtained using these data. A HD camera was set up at the upper end of the observation area to observe and record the fish swimming behaviors in the channel.

2.1 Animals

The fish used in the experiment is Cyprinus Carpio haematopterus, a freshwater fish belonging to the cyprinid family, which is an active omnivorous fish and easy to observe. Thus it is widely used in biological research. And a pre-experiment was needed to determine the state of adaptation of the fish in the channel and to take valid data for analysis.

2.2 Deep learning

The camera takes the image sequence of fish swimming, and YOLOV5 uses the image processing technology to analyze the image. Then the computer establishes the mapping relationship between the pixel coordinates of the image and the coordinates of corresponding points in space through calibration. It can obtain the fish actual displacement in a short time, so as to calculate the fish swimming speed.

A fish tail swing action is taken as the initial movement and the recognition number is taken as the number of swimming tail swing. So the fish tail swing frequency is obtained by combining the number of fish tail swing and the fish swimming time.

3. DIMENSIONAL ANALYSIS

The fish swimming energy expenditure is related to the fish swimming speed (Ohlberger et al. 2005, 2006), tail swing frequency (Chen et al. 2009), fish length (Marras et al. 2015), flow velocity, water depth, turbulent kinetic energy, etc. The fish swimming energy expenditure can be expressed by the following functional equation.

$$F\,(J, U, H, \mathrm{TKE}, f, m, v, l) = 0\ ,$$

where J is the joule, f is the tail swing frequency, U is the flow velocity, H is the water depth, TKE is the turbulent kinetic energy, m is the fish weight, v is the fish swimming speed, and l is the fish length. Based on the π theorem, using l, v, m, as the fundamental physical quantities, the above equation can be expressed in dimensionless form as follows:

$$F = \left(\frac{J}{mv^2}, \frac{U}{v}, \frac{H}{l}, \frac{TKE}{v^2}, \frac{f \cdot l}{v}\right)$$

Ohlberger et al. (2006) analyzed the relationship between the fish swimming speed and AMR in the channel. The fish weight is 100 g and fish length is 10 cm, so the AMR equation is:

$$\mathrm{AMR} = U^{2.53} \times 2.33 + 10\ .$$

Consider the AMR as the fish swimming energy consumed expenditure.

$$\frac{J}{mv^2} = \left(\frac{U}{v}\right)^x \left(\frac{H}{l}\right)^y \left(\frac{TKE}{v^2}\right)^z \left(\frac{f \cdot l}{v}\right)^w$$

All parameters can be obtained through instrumentation and calculation. Use these parameters to get x, y, z, w and the fish swimming energy consumption equation is derived.

4. DISCUSSION

The fish swimming energy consumption in the channel when high flow occurs in the channel is simulated by FLUENT. The route that consumes the least amount of energy for the fish is get. Fish swimming energy consumption equation can be used to inform the construction of fish passage and fish crossing facilities.

References

Cao, N., Z.G. Zhong, X.H. Cao, S.L. Zhang, and Y.C. Zhang (2016), Status of fishway construction in China and typical case analysis, *Water Resour. Protect*. **32**, 6,156–162.

Chen, J.J., G. Xiao; X.F. Ying, and H.B. Zhou (2009), Fish activity model based on tail swing frequency, *J. Image Graph*. **14**, 10, 2177–2180.

Kerr, J.R., C. Manes, and P.S. Kemp (2016), Assessing hydrodynamic space use of brown trout, Salmo trutta, in a complex flow environment: a return to first principles, *J. Exp. Biol.* **219**, 21, 3480–3491, DOI: 10.1242/jeb.134775.

Marras, S., S.S. Killen, J. Lindström, D.J. McKenzie, J.F. Steffensen, and P. Domenici (2015), Fish swimming in schools save energy regardless of their spatial position, *Behav. Ecol. Sociobiol*. **69**, 2, 219–226, DOI: 10.1007/s00265-014-1834-4.

Ohlberger, J., G. Staaks, P.L.M. Van Dijk, and F. Holker (2005), Modelling energetic costs of fish swimming, *J. Exp. Zool. A* **303A**, 8, 657–664, DOI: 10.1002/jez.a.181.

Ohlberger, J., G. Staaks, and F. Holker (2006), Swimming efficiency and the influence of morphology on swimming costs in fishes, *J. Comp. Physiol. B* **176**, 1, 17–25, DOI: 10.1007/s00360-005-0024-0.

Xia, J.G., S.J. Fu, Z.D. Cao, J.L. Peng, J. Peng, T.T. Dai, and L.L. Cheng (2013), Ecotoxicological effects of waterborne PFOS exposure on swimming performance and energy expenditure in juvenile goldfish (Carassius auratus), *J. Environ. Sci*. **25**, 8, 1672–1679, DOI: 10.1016/S1001-0742(12)60219-8.

Received 9 May 2022
Accepted 16 May 2022