Journal of Southeast University (English Edition) Vol. 25, No. 2, pp. 228 – 231 June 2009 ISSN 1003—7985

Fish maneuver analysis system based on sequence images

Jiang Ming[1,2] He Xiaoyuan[1]

([1] School of Civil Engineering, Southeast University, Nanjing 210096, China)

([2] School of Civil Engineering, University of Science and Technology of Suzhou, Suzhou 215011, China)

Abstract: The aim is to establish an automatic system to analyze the maneuver performance of fish. A high speed camera (1 000 frame/s) is employed to record fast-start maneuver. Three steps are taken to analyze the kinematics: first, the midline in the first image is partitioned into equal interval lengths and the coordinates of all inter segmental points are saved. Secondly, these points coordinates are searched in the next frame with the digital image correlation (DIC) method, then these points are fitted with a spline curve function. Repeat this step until all the midlines are figured out frame by frame. Finally, according to the variety of midlines, the kinematics of the fast-start is calculated. Using this system to test carp C-start, the duration is divided into two stages: stage 1 is defined as the formation of the C shape and stage 2 as the return flip of the tail followed with forward motion. By tracing the middle line, the kinematic parameters of turning rate, centre of mass (CM) turning rate, CM turning radius, etc. are obtained.

Key words: carp; maneuver; kinematics; digital image; correlation

Fast-starts are brief, sudden accelerations used by fish during predator-prey encounters. In the bionics field, fast-start maneuvers have received a lot of attention, such as the kinematics and performance of fast-starts in fish, kinematics types, distance-time performance characteristics, scale and temperature effects, turning angles and radii, and the relevance of fast-start performances in predator-prey interactions.

Although escape responses are continuous events, they are often classified into distinct kinematics stages[1]. Initially, the body of the fish is bent into a "C" shape due to a unilateral contraction of the body musculature. The C-bend is then followed by a corresponding return flip of the tail[2]. Though C-start duration occurs only in a second, high-speed camera can instantaneously record this process and fish body shape can be identified accurately in each frame. Most studies[1-5] manually found the midline (starting with the snout, along the spine and finishing at the tip of the tail) kinematics track. This is a tedious job, particularly when the dataset consists of hundreds or thousands of images. Obviously, the artificial frame-by-frame analysis method to obtain the midline track is unrealistic and inaccurate, so the aim of the present study is to establish an automatic system to analyze the maneuvering performance of fish fast-starts. This system includes three steps: First, partition the midline in the first image into equal interval lengths and each inter segmental point coordinate is saved. Second, search these points coordinates in the next frame with the digital image correlation (DIC) method, and then fit these points with a spline curve function. Repeat this step until all the midlines are figured out frame by frame. Finally, according to the variety of midlines, calculate the kinematics of the fish. Using this system involving the carp, we have obtained the parameters of the turning rate, the centre of mass (CM) turning rate, the CM turning radii, etc. The results show that this system can obtain more accurate kinematics data.

Received 2008-09-27.

Biographies: Jiang Ming (1961—), female, graduate, associate professor; He Xiaoyuan (corresponding author), male, doctor, professor, mmhxy@seu.edu.cn.

Foundation item: The National Natural Science Foundation of China (No. 10872139).

Citation: Jiang Ming, He Xiaoyuan. Fish maneuver analysis system based on sequence images[J]. Journal of Southeast University (English Edition), 2009, 25(2): 228 – 231.

1 Materials and Methods

1.1 Experimental carp

Carp were caught from a local dealer and held in a glass tank supplied with aerated water. The water temperature was maintained between 24 ℃ and 26 ℃. The position of the centre of mass (CM) was determined as follows: The killed fish was hung from one point along its body profile; the procedure was repeated for another point; the crossing point of the two straight lines descending from the hanging points indicated the CM. The CM point is from the tip of the head to 0.37 of the body length.

1.2 Experimental setup

Fig. 1 illustrates the experimental setup. A single carp is transferred to a glass tank placed in the middle of a glass tank (600 mm × 400 mm × 300 mm), surrounded by a black plastic screen. The fish can see neither the approaching stimulus nor the investigator. The fish is left in the experimental tank for at least 30 min prior to filming. The experimental tank is illuminated by two 100 W fiber optics illuminators and escaping responses are elicited by manually thrusting a pole towards the body of the fish. The filming rate is more than 1 000 frame/s, using a high-speed CCD camera on Photron Fastcam 512PCI.

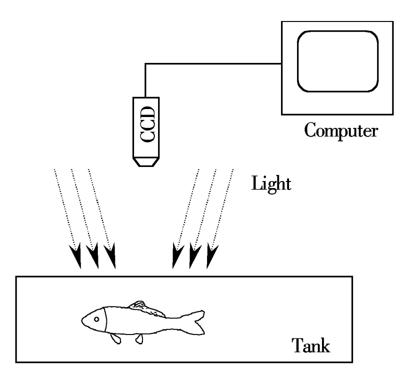


Fig. 1 Experimental setup

1.3 Digital image correlation method

The DIC method[6-7] is based on the statistical principle. For two images, one taken before and one after, the light intensity distribution at each point on the surface is unique and the distribution in light intensity about a particular point (x, y) can be described by the grayscale matrix $\boldsymbol{F}(x, y)$ over a selected subset of the digital image. With deformation of the object, each position of the surface (x, y) is assumed to exist at a new location (x^*, y^*). The in-plane surface displacement can be determined by finding the position of the light intensity distribution $G(x^*, y^*)$ that most closely resembles the original distribution $F(x, y)$. The location of $G(x^*, y^*)$ can be obtained by finding the position with the minimum correlation coefficient C according to Ref. [6] (For two $m \times m$ images, their distributions of gray values are $f(x_i, y_j)$ and $g(x_i^*, y_j^*)$ $(i, j \leqslant m)$, respectively):

$$C = 1 - \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} [f(x_i, y_j) - \bar{f}][g(x_i^*, y_j^*) - \bar{g}]}{\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{m} [f(x_i, y_j) - \bar{f}]^2} \sqrt{\sum_{i=1}^{m} \sum_{j=1}^{m} [g(x_i^*, y_j^*) - \bar{g}]^2}} \tag{1}$$

where

$$\bar{f} = \frac{1}{m^2} \sum_{i=1}^{m} \sum_{j=1}^{m} f(x_i, y_j) \tag{2}$$

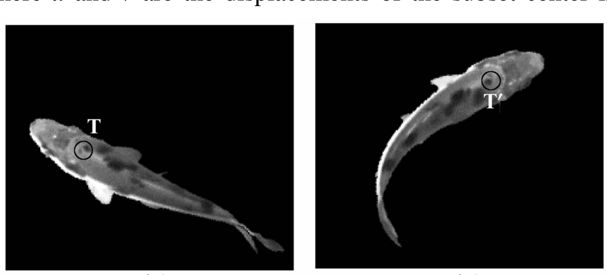
$$\bar{g} = \frac{1}{m^2} \sum_{i=1}^{m} \sum_{j=1}^{m} g(x_i^*, y_j^*) \tag{3}$$

The images are fully correlated if $C = 0$, and they are non-correlated if $C = 1$.

In digital image correlation, a set of neighboring points in an undeformed state is assumed to remain as neighboring points after deformation. Fig. 2 schematically illustrates the deformation process of an object. Circularity T (see Fig. 2 (a)) is a reference sub-image and circularity T' (see Fig. 2 (b)) is the corresponding deformed sub-image. In order to obtain in-plane displacements u and v of point M (the central point of T), sub-image T is matched with sub-image T' using a correlation operation. If subset T is sufficiently small, the coordinates of points in T' can be approximated by the first-order Taylor expansion as follows:

$$\left.\begin{aligned} x^* &= x + u + \frac{\partial u}{\partial x}\Delta x + \frac{\partial u}{\partial y}\Delta y \\ y^* &= y + v + \frac{\partial v}{\partial x}\Delta x + \frac{\partial v}{\partial y}\Delta y \end{aligned}\right\} \tag{4}$$

where u and v are the displacements of the subset center in x and y directions, respectively. In the traditional DIC, the quantities u, v, $\partial u/\partial x$, $\partial u/\partial y$, $\partial v/\partial x$ and $\partial v/\partial y$ are evaluated iteratively and determined from the position with the minimum correlation coefficient C.



(a) (b)

Fig. 2 Schematic diagrams of the deformation relation (Circularity represents template). (a) Before deformation; (b) After deformation

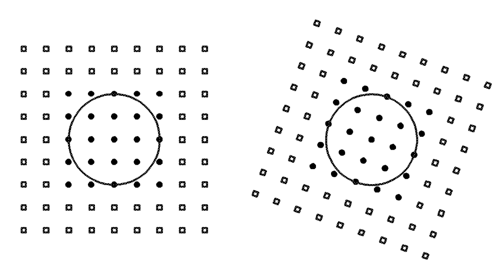
Minimization of the correlation coefficient C is a non-linear optimization process and the Newton-Raphson iteration method is used in the implementation of the process.

To achieve sub-pixel accuracy, interpolation schemes should be implemented to reconstruct a continuous gray value distribution in the deformed images. Normally higher-order interpolation provides more accurate results, with the limitation of requiring more computation time. The choice of different schemes depends on different requirements; the bi-quartic spline interpolation scheme is used in this paper.

The high-speed camera system collects a series of images and saves these images with automatic numbering. Normally, the more images collected at a unit, the less deformed distinctions in two neighbor images. In order to obtain significant correlations, the frequency of the high-speed camera operating over 1 000 frame/s is necessary for catching fish fast-start maneuver frames.

The series images are ordered by time. Through figuring out the position of the selected point in the serial images by the DIC, the trace of the point varying with time can be obtained.

This paper implements the relevant search by taking a circular subset as the template, and a calculation point as the center. This will avoid any influence on correlation results from rotation of the test object, especially the fast turns of the fish, as shown in Fig. 3.



(a) (b)

Fig. 3 The circular subset before and after rotation. (a) Before rotation (0°); (b) After rotation (rotating 20°)

2 Experimental Results

2.1 The serial midlines of fish in C-start

The serial silhouettes of carp escape responses are shown in Fig. 4. The frame at the time of 36 ms is the end of stage 1. The midline of the carp in the first frame is partitioned into $0.05L$ equal interval lengths and all the inter-segmental points (the solid dots) are shown in Fig. 5. The displacements of these inter-segmental points in the next image can be obtained with the DIC method, and then these data are applied to form the midline using a spline based on a curve fitting technique. Repeat these steps to process two neighbor images until all the midlines can be figured out, as shown in Fig. 6. The time interval is 4 ms. Fig. 7 shows the track of CM.

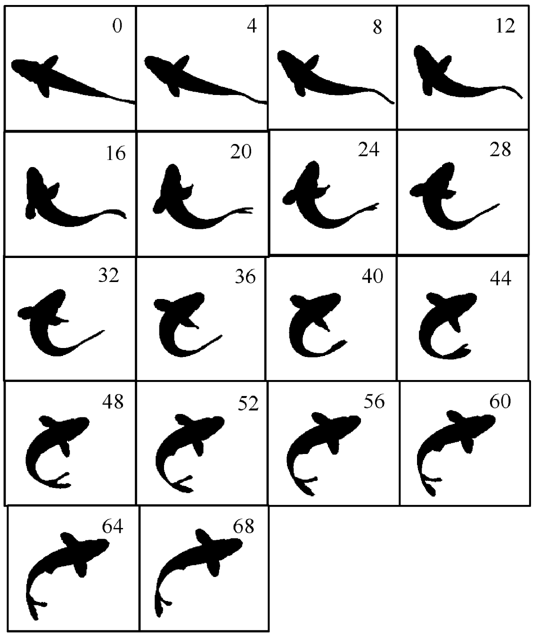


Fig. 4 Silhouettes of carp fast-starts (Numbers indicate time in ms.)

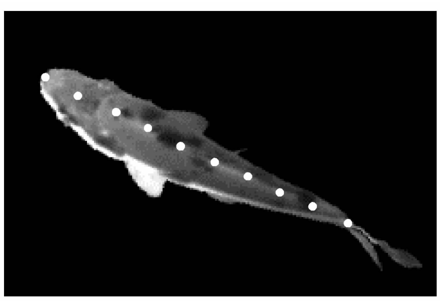


Fig. 5 Intersegment points on midline

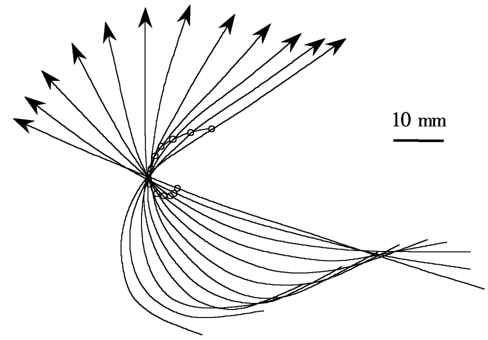


Fig. 6 Track of C-start

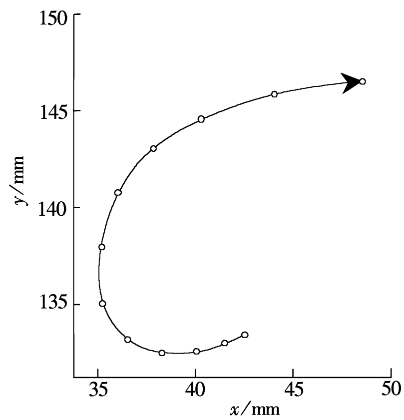


Fig. 7 Track of CM

2.2 The kinematics results

The C-start kinematics results are given in Tab. 1. The body length of the test fish is 95.5 mm.

The C-start duration is divided into two stages: stage 1 is defined as the formation of the C shape and stage 2 as the return flip of the tail associated with a forward acceleration. The total turn angle is defined as the sum of the turn angles of stage 1 and stage 2.

Tab. 1 *C*-start kinematics results

Stage 1 duration/ms	Stage 2 duration/ms	Stage 1 angle/(°)	Stage 2 angle/(°)	Mean stage 1 rate/((°)·s^{-1})	Maximum stage 1 rate/((°)·s^{-1})	Maximum stage 2 rate/((°)·s^{-1})	CM rate/ ((°)·s^{-1})	Turning radius
36	11	118	8	3 278	3 750	750	4 305	0.068*L*

The stage 1 angle for the anterior part of the body is determined by measuring the angle between the straight lines passing from the center of mass to the tip of the head at frame 0, and at the end of stage 1, the stage 2 angle is acquired in the same way.

The rate of turning, during stage 1, of the CM of the fish when stretched straight is calculated by measuring the arc of the turn of the CM divided by the duration of stage 1.

The radius of the path of the CM throughout stage 1 is calculated and defined as the turning radius.

3 Conclusion

This paper presents an automatic analysis system to analyze the kinematics of fish fast-start. Using this system with carp, we have obtained the parameters of the turning rate, the CM turning rate, the CM turning radius, etc. The results show that this system can obtain more accurate kinematics data.

References

[1] Webb P W. Fast-start performance and body form in seven species of teleost fish [J]. *The Journal of Experimental Biology*, 1978, **74**: 211 − 226.

[2] Domenici P, Blake R W. The kinematics and performance of fish fast-start swimming [J]. *The Journal of Experimental Biology*, 1997, **200**: 1165 − 1178.

[3] Domenici P, Standen E M, Levine R P. Escape maneuvers in the spiny dogfish [J]. *The Journal of Experimental Biology*, 2004, **207**: 2339 − 2349.

[4] Jing J, Yin X Z, Lu X Y. Observation and hydrodynamic analysis on fast-start of yellow catfish [J]. *Progress in Natural Science*, 2005, **15**(1): 34 − 40.

[5] Wu Y F, Jia L B, Yin X Z. The kinematic analysis of s-start of zebra danio [J]. *Journal of Experimental Mechanics*, 2007, **22**(5): 519 − 526. (in Chinese)

[6] Pan B, Xie H M, Wang Z Y, et al. Study on subset size selection in digital image correlation for speckle patterns [J]. *Optics Express*, 2008, **16**(10): 7037 − 7048.

[7] Pan B, Xie H M, Xu B Q, et al. Performance of sub-pixel registration algorithms in digital image correlation [J]. *Measurement Science and Technology*, 2006, **17**(6): 1615 − 1621.

基于序列图像的鱼类机动性分析系统

蒋　明[1,2]　　何小元[1]

([1] 东南大学土木工程学院, 南京 210096)
([2] 苏州科技学院土木工程学院, 苏州 215011)

摘要:为了建立一个研究鱼类机动性的自动化分析系统,使用高速摄像机(1 000 frame/s)记录了鱼的快速起动过程,并进行动力学分析. 首先确定并等分第 1 帧图中鱼的中轴线,保存等分点坐标;然后运用图像相关在下一帧图中找出第 1 帧图中的所有等分点,并用样条函数拟合这些等分点,得到鱼的中轴线,重复这一步骤,获得序列图像中鱼的中轴线;最后根据中轴线随时间的变化分析计算鱼在起动过程中的运动特性. 运用此系统,测试了鲤鱼的 C 形起动过程,鲤鱼 C 形起动分为 2 个阶段:第 1 阶段,整个身体弯曲成 C 形;第 2 阶段,尾鳍做大幅度反向摆动,然后鲤鱼做直线运动. 通过对各个阶段鱼体中轴线的跟踪,获得了鲤鱼 C 形起动的转动角速度、质心转速和质心转动半径等运动学参数.

关键词:鲤鱼;机动性;运动学;数字图像;相关

中图分类号:Q66