A Visual Measurement of Fish Locomotion Based on Deformable Models

Chunlei Xia[1,2], Yan Li[3], and Jang-Myung Lee[2]

[1] Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, P.R. China
[2] School of Electrical Engineering, Pusan National University, Busan (Pusan) 609-735, Republic of Korea
[3] Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang 110016, P.R. China
c.xia2009@gmail.com

Abstract. Measurement of fish locomotion is an essential issue not only for biological studies but also valuable for robotics researchers. In this study, an automatic marker less method was proposed for recording fish locomotion by using digital camera. A fish observation system was presented to capture fish motion from top view. And the active shape model was utilized to construct the deformable fish model for tracking fish locomotion and acquiring the precise fish posture. Subsequently, the fish model was applied to tracking the movement of a single fish. The skeleton of fish body was further calculated from the deformable fish model. The two-dimensional posture of fish body was described by the 20 points on the skeleton. Experimental results demonstrated that the proposed locomotion tracking method was efficient to measure the shape variation of the fish body.

Keywords: Fish Tracking, Model based Tracking, Active Shape Model, Posture Measurement, Swimming Modes.

1 Introduction

Through millions of years of evolution fish achieved remarkable swimming ability by natural selection, especially, in hovering, turning in intricate water currents and dexterous manipulation under floating conditions [1]. The perfect body mechanisms and swimming modes of fish could inspire innovative designs to improve the ability of locomotion of aquatic robots [2]. Biomimetic robotics has attracted an increasing number of attentions from the researchers. Recently, the fish-like propulsion mechanism, the fin material, and the mechanical structures have been focused on in research works.

Most of the previous works studied the fish locomotion patterns and swim modes by the mathematical models and computer simulations. The artificial fish model was studied for producing the animation of fish school for computer graphic [3]. As the demand of bio-inspired robotics the swimming pattern of fish was studied and a

X. Zhang et al. (Eds.): ICIRA 2014, Part I, LNAI 8917, pp. 110–116, 2014.

number of fish model has been proposed and applied to control locomotion of robotic fish [4, 5, 7].

In the last decade, modeling of fish swimming had a great progress and was successfully applied to robotic fish control. Fish locomotion should not only be studied by the mathematical models but also need to be verified by the actual fish locomotion data. The fish swimming modes were measured by video camera and colored markers attached to the fish body [6]. Five markers were manually attached to fish body from tail to head. The body motion data was obtained by the 5-point data. In order to track the body motion, markers should have high contrast with the fish body in gray scale. Attaching markers to fish body needs a lot of manual operations and it requires skilled operator to minimize the positioning error of markers. Consequently, the marker less automatic observation method is necessary to track and measure the fish locomotion, such as model based posture analysis [8].

In this paper, a deformable fish model is constructed based on the active shape model (ASM). Variation of fish body is modeled in two-dimension. Top view of fish body is modeled by using ASM for measuring precise fish posture. And the fish posture is simplified as a skeleton line for further analysis.

2 Structure of Fish Observation System

In this study, the fish motion data was captured and recorded by a digital camera. The structure of fish observation system is presented in Fig. 1. This observation system consisted of a small aquarium, a digital camera, a light source and a desktop computer. Top view observation was preferred to measure and analyze the fish locomotion. The digital camera was placed over the aquarium that capturing top view images of the aquarium. Since the shape of fish body would not change much in the top view image, it is stable and reliable to analyze the posture of fish and track fish movements. The field of view of the camera was required to cover the whole movement area of the fish. The field of view of the camera was optimized by adjusting the distance from camera to the water surface in the arena. According to the experimental conditions, the light source was placed below the aquarium in order to acquire the maximal contrast between the fish and the background. Locomotion of a single fish was observed in this study.

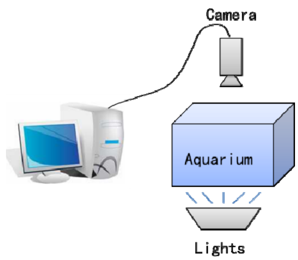

Fig. 1. Structure of fish measurement equipment

3 Visual Measurement of Fish Locomotion

3.1 Extraction of Individual Fish Image

Fig. 2 shows a captured image of a single Zebrafish (*Danio rerio*) moving in a round arena. Since the observation was conducted under stabilized light condition and background of aquarium was clean which providing the optimized contrast for extracting fish images. The fish showed a strong contrast to the white background which could be easily extracted by the thresholding method. Comparing with the widely used background subtraction method, adaptive thresholding is more robust for fish segmentation against the illumination changes. Usually, background subtraction requires calculating mean image of background, such as MOG (Mixture of Gaussians), to deal with the light changes. However, fish could not continuously move all the time when a fish stay for a certain period in the image it would be counted as the background in the process of calculating mean background over time. Therefore, the adaptive local thresholding method was utilized to extract the individual from the background for enhance the robustness of fish segmentation. The fish body was presented in a white shape in the binary image after segmentation. Further analysis was conducted based on the binary images which minimized the computational complexity and processing time.

Fig. 2. Top view of fish body and its segmented image

3.2 Construction of Deformable Fish Model

Since the fish body changes its shape and posture flexibly, a statistical deformable model, active shape model, was utilized to describe the two-dimensional fish body. Active shape model is built on a priori knowledge of the object which is robust to shape changes in the complicated background [9]. In active shape model, fish body is represented by a shape vector xi with n landmarks:

$$\mathbf{x}_i = (x_{i,0}, y_{i,0}, x_{i,1}, y_{i,1}, \cdots, x_{i,n-1}, y_{i,n-1})^T, i = 1, \cdots, N \quad (1)$$

where $(x_{i,j}, y_{i,j})$ are the coordinates of the jth landmark of the ith shape in the training sets, N is the number of images in the training set, and T is the transpose operator. The ASM learns a priori knowledge of the shape changes from a set of shape and image samples which is called training set.

To build a deformable fish model, the typical fish postures were manually selected from the video clips recorded by the observation system. And these fish images were manually marked with landmarks along their contours.

According to the authors' experiences and the image size of fish, 42 landmarks in total were determined to describe the fish shapes in this work. An example of fish shape is presented in Fig. 3, landmarks were linked by lines to show the overall shape of a fish. The starting point (0th) indicated the tip of fish head and the 20th point represented the fish tail. And the x and y axis described the fish size in pixels. The sequence and position of landmarks should be kept consistent throughout the training.

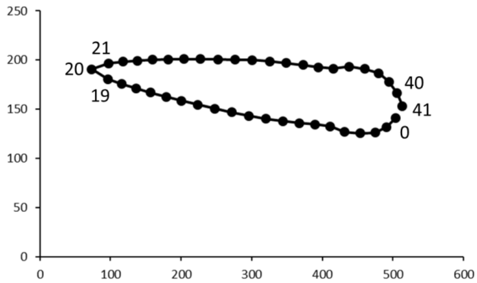

Fig. 3. A mean shape of fish calculated from training samples

In this work, 20 images of individual fish were selected as the training set. In the training phase of ASM, shape variations were obtained from the training samples. Any shape in the training set could be represented approximately by the mean shape and weighted modes of variations:

$$\mathbf{x}_i = \bar{\mathbf{x}} + \mathbf{Pb} \tag{2}$$

where $\boldsymbol{P}$=[$p_1,p_2,\ldots,p_t$] is the matrix of the first t eigenvectors and $\boldsymbol{b}$ is the vector for weights. The model could be deformed from the mean (i.e., $\bar{\mathbf{x}}$) shape to fit the new data by changing the weight vector $\boldsymbol{b}$. The detailed algorithm of modeling shape variation is given in [9].

3.3 Locomotion Measurement Using Fish Model

The constructed fish model was subsequently utilized to track the fish locomotion in a video clip. The fish model initially was manually placed in the arena and the fish model iteratively matching to the fish image by searching the optimized boundary of fish images. Consequently, the fish model continuously follows the fish movement. The detailed matching algorithm of ASM model is described in [9]. In this study, binary image of fish was obtained in advance to locomotion measurement and the matching process was conducted on the binary fish image (Fig. 2). Measuring fish posture from binary image could highly decrease the computational complexity and could improve the measurement speed. Fig. 4 shows a fish image fitted by the proposed fish model from the video clip.

Fig. 4. An actual fish image represented by fish model

3.4 Calculating Skeleton of Fish

Since the fish body showing a symmetric structure in shape the fish posture could be simplify represented by calculating the skeleton of fish for further analysis. In the previous steps, fish locomotion was modeled into 2D shape. The skeleton of fish could be easily obtained from the shape model. The skeleton is described as a series of points which calculated from the corresponding pair of landmarks on the left and right side of fish body. Each of the points of skeleton was the mean values of the corresponding pair landmarks.

4 Experiments and Results

The proposed locomotion tracking method was tested with a single Zebrafish in the laboratory condition. A round aquarium with diameter of 20cm was selected for the experiments, and the water depth was 5 cm. Five video clips of fish were recorded by using Logitech C905 webcam and each video clip recorded 2 minutes of fish movement. The resolution of video clips was 1280*720 pixels. The fish image was approximate 500*80 pixels. The proposed method was implemented by Microsoft Visual C++ 10.0 and an open source computer vision library, OpenCV, on a personal computer (Intel® Core™ 2 Duo CPU E4500@ 2.20GHz).

Fig. 5 shows various patterns of fish locomotion which described by the deformable fish model (yellow contour). In addition, the fish skeleton was presented in green points and lines. These results demonstrated that the proposed fish model could accurately fit the actual fish image and measure the fish posture. The measurement data could describe the precise body motion that could be used for studying the mathematical fish locomotion models or for behavioral fish from the biological aspects.

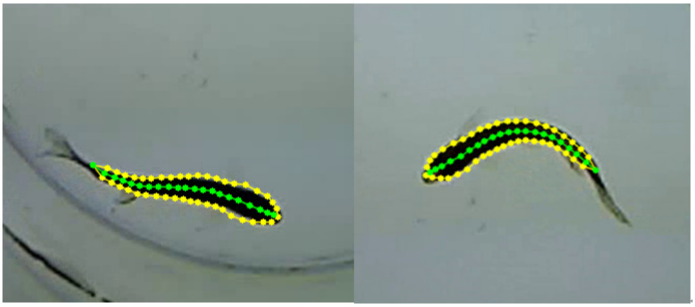

Fig. 5. Individual fishes represented by the fish model (yellow contour) and their skeletons (green line)

One of the advantages of the ASM is to segment objects from complicated background. Due to the background was rather simple in this study binary image of fish was adopted for shape analysis. However, in the case of long term observation, many unexpected objects would be occurred in bottom of the aquarium, such as discharges of fish, which would contribute severe noise to the background and increase the segmentation error in binary fish image. Computational function for describing the boundary feature of fish body, such as Mahalanobis distance [9] or neural network [10], would be an efficient way to segment the accurate fish body. Furthermore, since the ASM could identify the occluded objects by *a priori* knowledge of shapes the proposed model could be also utilized to recognize and segment multiple fishes from occlusions.

5 Conclusion

A model based fish tracking is presented for measuring fish posture in this study. The fish model was constructed based on the active shape model and shape variations were modeled from the sample data of fish images. The fish model represented precise fish posture and the skeleton of fish was further calculated from the model. The skeleton of fish described the posture and bending of fish body. The performance of the proposed method was demonstrated through experiments. The proposed method could provide accurate fish posture data for more depth studies, such as investigating hydrodynamics models for controlling robotic fish.

Acknowledgements. This project is supported by National Natural Science Foundation of China (Grant No.41406112).

References

1. Wu, T.Y.: Fish swimming and bird/insect flight. Annual Review of Fluid Mechanics 43, 25–58 (2011)

2. Sfakiotakis, M., Lane, D.M., Davies, J.B.C.: Review of fish swimming modes for aquatic locomotion. IEEE Journal of Oceanic Engineering 24(2), 237–252 (1999)
3. Tu, X.: Artificial Animals for Computer Animation. LNCS, vol. 1635. Springer, Heidelberg (1999)
4. Zhou, C., et al.: The design and implementation of a biomimetic robot fish. International Journal of Advanced Robotic Systems 5(2), 185–192 (2008)
5. Hu, T., Low, K.H., Shen, L., Xu, X.: Effective Phase Tracking for Bioinspired Undulations of Robotic Fish Models: A Learning Control Approach. IEEE/ASME Transactions on Mechatronics 19(1), 191–200 (2014)
6. Yan, H., Su, Y.-M., Yang, L.: Experimentation of fish swimming based on tracking locomotion locus. Journal of Bionic Engineering 5(3), 258–263 (2008)
7. Hu, H., et al.: Design of 3D swim patterns for autonomous robotic fish. In: IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE (2006)
8. Lai, C.-L., Tsai, S.-T., Chiu, Y.-T.: Analysis and comparison of fish posture by image processing. In: 2010 International Conference on Machine Learning and Cybernetics (ICMLC), vol. 5. IEEE (2010)
9. Cootes, T.F., Taylor, C.J., Cooper, D.H., Graham, J.: Active shape models-their training and application. Computer Vision and Image Understanding 61(1), 38–59 (1995)
10. Xia, C., Lee, J.M., Li, Y., Song, Y.H., Chung, B.K., Chon, T.S.: Plant leaf detection using modified active shape models. Biosystems Engineering 116(1), 23–35 (2013)