Animation Synthesis of Virtual Fish by Motion Extraction from Video

(実写画像からの動き抽出によるバーチャルフィッシュのアニメーション合成)

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Abstract In this paper, estimation method of fish position and posture from video using object matching technique is proposed. In the object matching, 3D reference model is divided into three parts, head, body and fins to accelerate the object matching process. NURBS(Non-Uniform Rational B-Spline) is employed for body model in order to represent flexible fish body postures using a small number of control points. The control points of the model is obtained by nine motion parameters, i.e. the center of gravity, the inclination of a fish's head and the angles between skeletons which represent the posture of the body. Some basic behaviors are segmented from the obtained 3D positions and postures by using the characteristics of the motion of fish. Finally, a novel locomotion is generated using the segmented basic behaviors according to the segment connection rule.

Key words: Animation, Motion extraction, Object matching, Virtual creature

1. Introduction

It has become possible to generate CG(Computer Graphics) images with reality by the improvement of CG techniques, especially modeling and rendering techniques. In commercials or weather reports, many CG images have been utilized frequently. Not only in movies but also in VR(Virtual Reality), CG techniques have become important ones to make virtual world. As regards the technique to represent a static creature at present, it is possible to generate a highly realistic image. If motions are tried to be represented, however, it is difficult to generate visually natural motions. Many trials for generating natural movements of creatures by using CG techniques have been studied. Each of which, however, remains some problems.

In this paper, a method to estimate 3D position of a fish and its flexible posture from video using object matching is discussed. Moreover, the time sequence of the obtained position and postures in 3D world is segmented into basic movements based on the changes of angle and speed. As a conclusion, a method to generate a novel locomotion and behavior of a virtual fish is

shown by synthesizing stored segments.

In the following section, related works of animation of artificial creatures is reviewed. In section3, a method to estimate motion parameters of a fish from video using object matching is explained. In the 4th, 5th sections, motion parameters obtained in section3 are divided into motion segments that denote a fundamental unit of motions and a method to generate automatic motion and a method to control trajectory by assigning control points are explained, respectively. Finally, a conclusion and future work are discussed in the last section.

2. Related works

In 3DCG, in order to generate animations, many researches using kinematics, inverse-kinematics, dynamics have been proposed. Methods to represent a motion by using a physical model¹⁾ or researches using artificial life²⁾³⁾ are proposed to generate a motion of artificial creatures. Especially in researches regarding a motion generation of an artificial creature, the following researches try to represent a motion of fish.

A framework for animation with minimal input from the animator is proposed by Tu et. al.⁴⁾. They define a physics-based virtual marine world in which artificial fishes inhabit. These motion patterns are decided by using a few mental state variables. In addition, a method to learn a fish's motion automatically is proposed⁵⁾. Moreover, Manabe et. al.⁶⁾ try to represent a

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motion of fish by applying a fan movement of caudal fin based on vibration wing theory. It makes a virtual colored carp swim by vibrating the fin with a constant frequency. It, however, has a problem that the algorithm has to set the angle of bend in the body against the fin by comparing with the swimming of a real carp heuristically.

On the one hand, some researches aim to realize a real time generation of fish motion⁷⁾. Though this method enables a school of fish to locomote in real time, a motion to vibrate the body is given heuristically. Moreover, researches in regard to motion generation of an artificial creature which aim at interaction with users⁸⁾⁹⁾ are proposed. Yamaguchi et. al.⁸⁾ propose a method to interact with a fish in a virtual water tank. It extracts a motion of a fish which swims in a water tank on a real world and makes a virtual fish swim in a virtual water tank using extracted motion parameters. The virtual fish itself, however, is not deformed, and only motion vector is obtained by a real image. Kurihara⁹⁾ proposes a system in which user interacts with a dolphin and generates a motion of it in real time. It employs task-oriented approach and path planning to obtain motion primitives such as "swim" or "turn". Then an autonomous motion is generated using these motion primitives. Schödl et. al.¹⁰⁾ proposes a method to generate a non-periodic video sequence which is called "video texture" by using several parts of consecutive video images. In this paper, an image of several fish's swimming in the water tank is generated for one of applications. Since a 2D video image is used, however, the view point cannot be changed. It is also difficult to represent 3D motion with depth.

Moreover, many researches aim to obtain 3D human motions from video images. Real-time approaches for estimating human body postures are reported^{11), 12)}. The method estimates significant points such as the top of the head and the end of the hands and feet from the boundary of the silhouette. It is, however, difficult to apply a simple object for extracting some significant points. For instance, since the method extracts only two or three feature points from fish silhouette, it is difficult to present a flexible shape of the fish. Yamamoto et. al.¹³⁾ propose tracking method of human posture based on a robot arm model. The method estimates the motion parameters using spatio-temporal gradient. Since the method has to calculate velocity field, it is hard to apply to non-textured object.

The authors, therefore, propose a method that 3D

fish locomotion and a flexible posture of the fish are extracted from video in which a fish is swimming by using object matching. NURBS(Non-Uniform Rational B-Spline) is employed in order to represent flexible fish postures using a small number of control points. Then, an animation of a virtual fish is reproduced using the extracted motion parameters. It is not necessary to analyze the motion of fish itself. It needs just only a simple object as a model. Moreover, motion segments are generated from the obtained consecutive motion parameters. By synthesizing the motion segments, a novel locomotion is also generated.

3. Motion extraction from video

3.1 A 3D virtual fish model

Motion parameters of a fish are obtained from a real motion of a fish. A carp is employed as target fish for the reason of its body size and habit. The swimming fashion of a carp belongs to the horse mackerel type. In this swimming fashion, a caudal fin moves as a fan and then it gains driving force by repellent force of momentum against the water. It is, therefore, necessary for fish to vibrate its body and gain the driving force in order to advance. From a skeletal structure point of view, head is composed of bone and head length of a fish is almost one-third of its total length. Furthermore, it has a backbone composed of a great many of spines. The head, therefore, cannot deform, but the rear part of the body deforms smoothly. As a result of preliminary observation, the head hardly deforms, and only inclination and direction in the water tank coordinate system change. On the other hand, the body deforms smoothly along the backbone. The observed fish forms are shown in Fig.1.

Therefore, 3D model of a virtual fish employed here is configured in which a body structure of a fish is divided into the following three parts.

Head: Because the head hardly deforms and it can be regarded as rigid body, it is synthesized by simple polygons.

Body: Body has a backbone composed of a great many of spines, and it deforms smoothly. In order to realize

Fig. 1 Forms of a fish in preliminary observation.

a smooth deformation, NURBS is employed⁷⁾. As illustrated in **Fig.2**, a model is configured by some groups of control points.

Fin: A pectoral or caudal fin doesn't have muscles itself and it is just attached with the body. Since fins are very transparent, it is difficult to extract accurate boundary of fins. It is, moreover, hard to represent their elastic motions easily. They are configured by connecting a polygon as a plate with the body.

In this paper, fins are not extracted in the process, but models of fins are created in order that the same model should be used in generating animation based on the obtained motion parameters. The body part of 3D model of a virtual fish is drawn in **Fig.3**. A center of gravity of the fish is set to the base of the fish's head which locates at about one-third from the head, and it is set to the origin of local coordinate system. The number of parameters obtained here is 9. These are a center of gravity $\{G_x, G_y, G_z\}$, the inclination of a fish's head $\{R_y, R_z\}$ and the angles $\{A_0, A_1, A_2, A_3\}$ between skeletons which determines the posture of the body. These 9 parameters are enough to represent the control points shown in **Fig.2**. A group of control points is located on axial slice of the fish. An assumption that there is no twist motion around the skelton is employed.

3.2 Calibration of a 3D model

In order to create an appropriate 3D model which is used for object matching, a fish is captured under restricted conditions in which the posture of fish is ideal

Fig. 2 Control points.

Fig. 3 3D model for object matching.

straight. Then, difference images against a background image and edge images of the upper side and the front side are generated. Next, a small size model is used as an initial model, and matching is performed varying the width and height of the 3D model for each image. The most appropriate model which has the highest evaluation value is employed as a 3D model for object matching.

3.3 Acquisition of motion parameters using object matching

In order to obtain the motion parameters of a fish, object matching is employed for each frame of consecutive input images and the posture of fish is estimated. As initial values of posture in estimation process of each frame, the posture of a previous frame is used. Moreover, a reduction of matching process is realized by hierarchical matching.

(1) Motion parameters for the first frame

In the first frame, a procedure to extract motion parameters is different from that on and after the second frame. First, a subtraction image between the first frame and a background image in which a fish doesn't exist is generated and then the image is binarized. Next, the region in which a fish exists is extracted by performing dilation and erosion. A skeleton is extracted for the image captured from the upper side of the water tank, in order to estimate the inclination of the head. In the same way, a skeleton is extracted in the second frame. Center points of two obtained skeletons are obtained, and then a translation vector of a fish is calculated. The progress direction of the fish is estimated from the translation vector, and it assumes that the fish's head is in the same direction of the progress direction. Then, the skeleton is divided into seven equal parts in order to obtain approximate values of motion parameters as initial ones for the 2nd frame. Segments formed by the second, third, fourth, fifth of points and the end points make a skeleton of a virtual fish. Finally, initial motion parameters for $\{A_0, A_1, A_2, A_3\}$ are obtained from the skeleton of the fish of the first frame. These are used for initial parameters to estimate motion parameters after 2nd frame.

(2) Evaluation function

The motion parameters of the first frame obtained in the previous section are utilized as the initial values of the next frame, the motion parameters of each frame are obtained in turn. In extraction of the motion parameters, object matching is employed by using a subtraction image obtained from the upper side and

the front images and using the edge image detected by using canny edge detector¹⁴⁾.

Define the parameters which determine the posture of 3D model as $X = \{x_i \mid 0 < i \leq n\}$. Where, n denotes the total number of parameters. S denotes the area of a fish in the subtraction image and $P(X)$ denotes the area by projecting 3D model onto the image plane. $f(A)$ is defined as a mapping function which calculates the area of region A on the image plane. An evaluation function with regard to area is defined by

$$J[X] = \frac{f(P(X) \cap S) - f(P(X) \oplus S)}{f(P(X))}. \quad (1)$$

where, $\oplus$ is XOR operator of both regions and $\cap$ is AND operator of them. In the same way, suppose that E denotes the edge region obtained from canny edge detector and $Q(X)$ denotes the edge region in which the model is projected onto image plane, and an evaluation function with regard to edge is defined as follows;

$$K[X] = \frac{f(Q(X) \cap E) - f(Q(X) \oplus E)}{f(Q(X))}. \quad (2)$$

The weighted sum of the formula(1) and (2) is employed as the evaluation function of the object matching. The function $V[X]$ is shown in equation(3).

$$V[X] = J[X] + W \times K[X] \quad (3)$$

where W is weight. In this paper, W is set to 4 based on preliminary experiments. The magnitude of $J[X]$ is about two or three times larger than that of $K[X]$ in average. $J[X]$ detects the global location of the fish and $K[X]$ fits the detail of the fish posture.

(3) Posture estimation from the upper image

First, matching of the head region is performed by using the image captured from the upper side of the water tank and x, z coordinate values of a center of gravity of a fish $\{G_x, G_z\}$ and inclination around y axis $\{R_y\}$ are estimated. In the estimation of the head region, the region is searched within 100×100 pixels centered on the center of gravity of previous frame. Fish usually swims toward the head direction at a certain speed, because of its body structure and the swimming fashion. Therefore, suppose that the head region on the current frame exists around the prolongation of the inclination of the head on the previous frame. The search of the head region is beginning around the direction of the head position on the previous frame. Because a fish goes forward without changing its direction in most cases, the

matching can perform effectively. In the case it does not satisfy this assumption such that a fish twists its body to accelerate or twists the body to change direction, that is to say, in the case the maximum value of $V[X]$ is smaller than a certain threshold, region restriction is not employed, but matching is performed around the head region of previous frame. Based on empirical observations, 2.1 is employed as the threshold. If 70% of area and 35% of edge of the fish are matched, the value of $V[X]$ exceeds the threshold and parameters are estimated in detail. The matching procedure is explained as follows;

1. The position and angle are predicted roughly, as the value of $\{G_x, G_z\}$ are changed 3 pixels and that of $\{R_y\}$ is changed 3 degree, respectively. The search range is limited in the restricted region. In this prediction, the matching ratio with regard to edge which is denoted in formula(2) is used for an evaluation function.
2. If the matching ratio mentioned above is larger than a certain value, $\{G_x, G_z\}$ and $\{R_y\}$ are changed 1 pixel and 1 degree within ± 3 , respectively. The most optimal parameters which make it the largest that the value of evaluation function shown in equation(3) is searched.
3. In the case matching ratio of step1 is always smaller than a certain value, it is judged that the region prediction is failed. Then, process 1 is performed without any region restriction.

The upper input image and the result of estimated head region are shown in Fig.4(a) and (b), respectively. In the posture estimation process of the body, the optimal parameters are searched by changing the value $\{A_0, A_1, A_2, A_3\}$ in turn. The result of the estimated body is drawn in Fig.4(c).

Fig. 4 Posture estimation from upper image.

Fig. 5 Posture estimation from front image.

Fig. 6 Transition of the obtained center of gravity.

(4) Posture estimation from front image

Based on the parameters $\{G_x, G_z, R_y, A_0, A_1, A_2, A_3\}$ obtained from the upper image, the y coordinate value of the center of gravity $\{G_y\}$ and $\{R_z\}$ which are the inclination around z axis are searched. Though the fish usually vibrates the body in order to gain the driving force, the body cannot be changed its direction upper and lower direction rapidly. In the matching process, G_y and R_z are, therefore, changed by 1 pixel and 1 degree, respectively, so that the optimal parameters which make evaluation value the largest are searched. Fig.5(a) and (b) illustrate the input image and the result of posture estimation from the front image.

Fig.6 shows transition of the center of gravity which obtained by the proposed method. The changes of x, y, z coordinate values are almost smooth. The algorithm, however, fails to extract y coordinate values in the case fish faces or turns its back to the front camera.

4. Motion generation of a virtual fish

4.1 Classification of the movements based on motion parameter

A fish gains driving force by repellent force of momentum against the water. In changing its course, it makes the direction of the head turn around by twisting the

whole body. In the movement of a fish, a behavior of the body itself and a locomotion in underwater have tightly relations in each other. Therefore, it is necessary that the behavior like a twisting and transition in the locomotion should be regarded as one movement. In this paper, a basic unit of the movement represented by the combination of such behavior and locomotion is called "segment".

(1) Classification of fish posture

Postures of a fish at each frame are classified into basic posture P and non-basic posture $\bar{P}$. Basic posture denotes that a fish stretches its body almost straight. In this paper, in the case that each value of parameters $\{A_0, A_1, A_2, A_3\}$ obtained at the previous section is within ± 4 degree, the posture of the fish is defined as basic posture. The rest of postures, in which the fish leans its body, denotes non-basic posture.

(2) Division into segments

There are many kinds of characteristic behaviours in fish locomotion. In this paper, the fish locomotion is, however, divided into the only two significant characteristic behaviours. One is vibrating motion in which a fish moves with its own internal power and the other is deceleration motion. The motions which have vibrating motion and deceleration motion are, therefore, extracted from the motion sequence. These two behaviours are the most fundamental ones. The vibrating motion denotes a motion from P to $\bar{P}$ and the returning to P again. The deceleration motion denotes the movement which keeps up the posture of P successively. The concept of the classification of the movement is shown in Fig.7. The movement as $F_1 \rightarrow F_2 \rightarrow F_3$ in Fig.7 is the one in which a fish makes the body vibrate only for a certain amplitude and returns to the basic posture. These changes of postures are regarded that the fish accelerates for moving forward or leans the body for turning. On the other hand, in the movement $F_0 \rightarrow F_1$ in Fig.7, a fish moves toward a certain direction without vibrating the body. In this movement, it is regarded that the fish advances just by inertial force and that the speed decelerates.

However, in the case that the direction of the fish hardly changes as $F_1 \rightarrow F_3$ and $F_3 \rightarrow F_5$ illustrated in Fig.7, that is, such a movement of vibrating the body to accelerate, it is also divided into segments. Therefore, the merge of vibration behavior is performed by the following procedure described in the next paragraph.

(3) Merge of segments

In the case that the amount changes of the head's in-

Fig. 7 Segmentation into basic behaviors.

Fig. 8 Segmentation into basic locomotion.

clination is smaller than a threshold T_h in consecutive vibrating motions, plural vibrating motions which were described in the former are merged into one segment. If the angle $\{R_y\}$ around y axis at the first basic posture and the angle at the last basic posture is smaller than T_h in the two consecutive vibrating motions, they are merged. The threshold T_h is defined as 10 degree in this paper. On the other hand, if the angle is larger than the threshold, segments are kept divided as different movements. Three motions, which are deceleration motion as $F_0 \rightarrow F_1$, acceleration motion as $F_1 \rightarrow F_5$, and right turn or left turn motion as $F_5 \rightarrow F_8$ are obtained as shown in Fig.8.

(4) Results of motion segments

A movement of virtual fish generated by obtained motion parameters is illustrated in Fig.9 and the results of the divided segments are shown in Fig.10(a)~(c). Fig.9 shows every 3 frames of the trajectory of the center of gravity of the fish in 150 frame generated by the motion parameters obtained in the previous section as black points. It also shows the posture of a fish at the beginning and ending of the segment. Fig.9 presents the same locomotion of a virtual fish which is obtained by a real fish taken from video. The obtained locomotion looks similar to the real fish locomotion. Fig.10(a) illustrates the extracted right turn segment from the obtained motion shown in Fig.9. The segment shows fish locomotion with vibrating its body in order to turn right direction. Fig.10(b) and (c) shows acceleration and deceleration locomotion, respectively. In acceleration locomotion, changes of the center of gravity of the

Fig. 9 Obtained locomotion.

Fig. 10 Segmented locomotion.

fish between neighbouring frames become larger according to the end of the segment. On the other hand, in deceleration locomotion, the changes becomes smaller. These results shows that the motion segmentation performs well.

4.2 Motion Synthesis of a Virtual Fish

A motion synthesis of virtual fish is realized by connecting the end points of each segment. In connecting segments, coordinate system is transformed in order that the new segment should be aligned with the final basic posture of the previous segment. As described in the previous section, the motion of a fish is connected smoothly because all postures of the fish in the ends of segments are basic postures. Also in a novel movement generated by connecting segments, unnatural motions by changing the body postures don't appear.

On the other hand, unnatural movements are generated in the case that the arbitrary two segments are connected because the speed of virtual fish is different from each segment. Therefore, the following restricted conditions are given in connecting two segments S_{i-1} and S_i . It is connected only in the case that the ending speed $V_{e_{i-1}}$ of segment S_{i-1} and the beginning speed

Fig. 11 Examples of jointed segments.

Fig. 12 Selection of segment based on control points.

Vb_i of segment S_i are almost the same. As a result of preliminary experiments, the beginning speed Vb_i and the ending speed Ve_i of each segment were within the range of 0 ~ 6 pixel/frame. Therefore, the speed is divided into 3 ranges and the connection should be permitted if the speed is within the same range.

The generated animations are shown in Fig. 11. In generating animation, segment which satisfies the possibility of connection is selected at random and then connected. In the case it doesn't satisfy the possibility, segment data is selected from a set of data at random until the one which satisfies is selected.

5. Motion synthesis of virtual fish by assigning control points

To control the trajectory of a virtual fish's movement, the connection conditions are more restricted than the one in previous section. As shown in Fig. 12, to generate a motion aiming to go towards control point C_i , a segment which makes the position to be closest to C_i is selected. Moreover, by virtual fish's center of gravity passing through the region of a certain distance from the control point C_i , the target control point is changed to the next control point C_{i+1} .

The result of virtual fish movement by assigning several control points is illustrated in Fig. 13. Fig. 13 shows the movement every 30 frames. Each control point is drawn by a small cube, and it shows a virtual fish is moving in specific order. The virtual fish moves

through or around the assigned control points, it also goes up or down to swim towards the control points. Some motions, however, don't perform well. For example, in the case of 90th frame, the fish goes through the left of a control point. In that case, it seems better to go around the right of the control point because the next control point locates on the left side of it. It is caused by the lack of suitable segments, rich segment sets, however, enable to resolve it.

6. Conclusions

In this paper, a method to obtain motion parameters of a fish is proposed by employing posture estimation of the fish. In posture estimation, object matching technique is performed to each frame of the video taken from a real fish in a water tank. Motion parameters denote a center of gravity, the inclination of a fish's head and the angles between skeletons which determines the posture of the body. These represent a transition of the movement of fish with the change of times. The method to divide the motion parameters into several segments by using the characteristics of the motion of fish is proposed. The method presents a novel locomotion of a virtual fish by synthesizing obtained segments from a real fish movement according to the segment connection rule.

We are planning to propose a more accurate and more high performance extraction method of motion parameters. Moreover, an objective criteria is necessary to evaluate how much natural or real the obtained locomotions are. It is also a charming theme to make a motion data base and its retrieval. Furthermore, we are trying to generate retargetting motion from the obtained motion parameters and compare with physical-based model technique quantitatively.

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Fig. 13 Control of virtual fish locomotion using control points.

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