Real-time Motion Generating Method for Artificial Fish

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Summary
In interactive 3D cyber space systems including computer games and virtual reality applications, we have increased need for real-time interactive control of articulated body motions for more realistic expression of characters. Animation methods that based on articulated body motions are used for produce real-time control of artificial life character's motion. But these methods are not adequate to complex systems, like virtual marine world, that transact many interactive actions. In this paper, we present the real-time animation method that can be applied to control of artificial fish character for constructing the virtual marine world.

Key words:
Real-Time Character Animation, Procedural Approach, Artificial Fish, Virtual Marine World.

1. Introduction

In computer games and virtual reality fields, it is frequent to generate the character's movement at real-time through various interactions with the surrounding in order to increase the reality of the characters. Especially, it is crucial for virtual marine world system, which tries to express the marine life more realistic, to generate the movement of artificial life at real-time of its constant interactions with the marine environment elements [1,2,3,4,5].

The various researches was done for the animation techniques for the real-time motion control and detailed techniques are used to endow DOF(degree of freedom) to complex structured character through control and deformations of various joints and complex meshes. Especially, skeletal animation technique is well known as it generates very similar movements of the real bone structure by building-in the simplified skeletal structure from real bone frame in the modeling data to the characters in order to express human and animals movement[5,6,7].

In general, the technique of kinematics and dynamics of physic-based technique are used to generate the skeletal movements. These techniques can generate more realistic and accurate movements of its one character, but if the use of joint DOF is great then a lot of calculation quantity will be needed. Especially, when simulating the movement of artificial life of the complex virtual reality system will increase the complexity of the animation thus the occurrence of the overall rendering performance loss[9,10]. In order to solve these problems, the efficient method to solve the change of appearance and skeletal structure of artificial life character that depends on the quality of virtual reality system and appropriate animation techniques should be presented.

In this research it introduces the method of generating the movement of the real-time artificial fish through the use of procedural approach. The method proposes the skeletal fish model to control movement and the architecture of artificial fish animation. Furthermore, it proposes the method of generating the movement of artificial fish and simulates it.

2. Related Works

The common method to generate the movement of articulated body such as humans and animals can be method relied on kinematics and dynamic[6,7,8]. Kinematics method generate the sequence of movements for articulated body animation by calculating the position of each segments by time, or gain the angle of each segment joints through the inverse-kinematics[6,7]. As majority of these methods need the optimization process to generate the new movements, it is hard to have instantaneous process for frequent interaction processing[9,10].

Dynamic method has skeletal physic-based modeling and produces the data of each segment positions by time by making the object move based on the dynamic rule[7,8]. The most representative researches for the generating the physically-based animation are Terzopolos and Tu method and these method uses the dynamic muscle model, which applied dynamic rule to make the artificial fish to create various actions depend on the situation[1,3]. However, these methods will not be easy to apply to the virtual reality system that has frequent interaction as it uses the calculation of the complicated linear system to solve the movement of the segments dynamically, which will make it fastidious to compose the calculation simultaneously for complicated articulated body.

Recently, there are various researches on procedural approach to generate the animation of the articulated body and real world object through the system that has the limited calculation ability such as PC[5,8,11,12]. In this

Manuscript received October 5, 2007
Manuscript revised October 20, 2007

method, it used the technique of imitating through the use of simple numerical formula rather than producing the exact calculation of each phenomenon based on the physics rule for the simultaneous processing of the motion. The procedural approach includes modeling the natural phenomena such as water and trees by using the simple numerical formula and generates the similar scenes to the real world by using it[11,13]. This kind of concept can be the most realistic method to generate the simultaneous movement in the virtual world that has frequent interactions.

3. Real-Time Motion Control of Artificial Fish with Procedural Approach

The behavior or movements of fish has rather simple and repetitive formation than humans and land animals[12,13]. Therefore, it is possible to create the similar movement from the real fish if modeling the pattern of the movement of the fish through the use of kinematical analysis is possible[1,3,15,19]. To have this, the movement of fish should be modeled by rather simple numerical formula and the algorithms execution structure that can create the similar movement from reality simultaneously is crucial. In this kind of execution structure, it is possible to create the procedural motion scene by calculating the geometrical model from time to time by the procedural of each frame through the use of small number of parameter set that defines the artificial fish in general.

In this chapter it proposes the architecture for hierarchical animation that supports the procedural technique for generating the simultaneous animation of the artificial fish and explains the method of creating the movement of the artificial fish and the skeletal model that defines the form of the artificial model.

3.1 Architecture for Artificial Fish Animation

The movement of a live fish is spontaneous, pursue various goals at the same time, and handle unexpected exceptional situation flexibly[16,17]. The movement of a live fish is spontaneous, pursue various goals at the same time, and handle unexpected exceptional situation flexibly[16,17]. It should be considered that the important element to endow reality in the artificial fish is the intelligent control that can create the similar movement to the living subject and the feature of the movement. This research proposes the intelligent control part, kinematics control part and architecture for hierarchical animation. The proposed structure manage the perception, condition and behavior through logical data that is the level of the intelligent control and through these data set, it can control various physical motions.

The Figure 1 illustrates the architecture for hierarchical animation that is for generating the real-time animation of the artificial fish. The proposed structure is composed of total of 7 layers and the features of each stage are as follows.

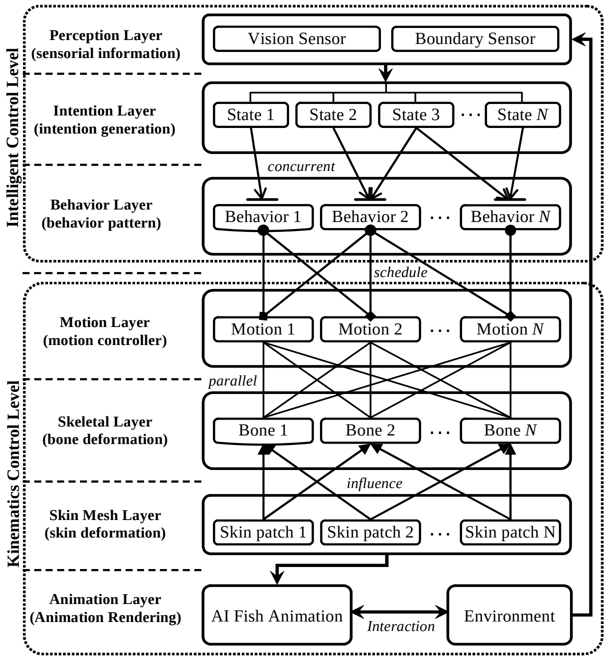

Fig. 1 Architecture of artificial animation

- Perception Layer: It creates the result of controlling the recognition of the environment and objects through the use of the vision sensor and the body sensor. The result data will be used as an input data for decision making.
- Intention Layer: It defines the condition for the decision making and induces the certain actions depending on these combinations
- Behavior Layer: The behavior to achieve the certain goal through the various set of movements. It works as amount of *N* state has one behavior correspondence. It includes the behavior pattern, such as feed-hunting and crowding.
- Motion Layer: It represents the control unit of the physical motion of the real conformation. In this class, it defines the unit of movement as swim, accelerate, stop, and turn, ascent and descent.
- Skeletal Layer: It is the skeletal structure to control the physical motion and is composed of joints that connect the segments, which represent the unit of each bone structure.

- Skin Mesh Layer: It is the set of meshes that means the composition of the surface and handle the natural skin deformation through the link with its bone frame.
- Animation Layer: It signifies the final animation scene, which can confirm the movement of the user's artificial fishes directly through CG rendering.

In the use of procedural approach, the architecture for hierarchical animation means the generating the movement part through the use of the intelligent control part and algorithm, and can create the animation scene flexibly by separating the appearance part that change by the movement in class. In this research, it aims at the physical motion simulation of the artificial fish that is from the proposed class architecture for hierarchical animations. Furthermore the research propose the detailed method of the generating the real-time movement by using the procedural approach.

3.2 Skeletal Fish Model

The animation that uses the articulated body is easy to generate the real-time animation than the use of single object as it can produce the animation of each joints individually. However, it can be a main cause of rendering performance loss if it tries to generate the movement by using many joint's DOF.

Therefore, it should generate the skeletal structure at the level of pertinent through analyzed data of the real movement of the artificial life and simplified to the utmost and should go through the process of the utmost simplification. In this research, the skeletal model of the artificial fish was designed on the basis of the analyzed data of the existing research on anatomy of fishes and kinematics. Figure 2 illustrate the skeletal structure of the artificial fish and the each bone segment and joint and the form of its surface.

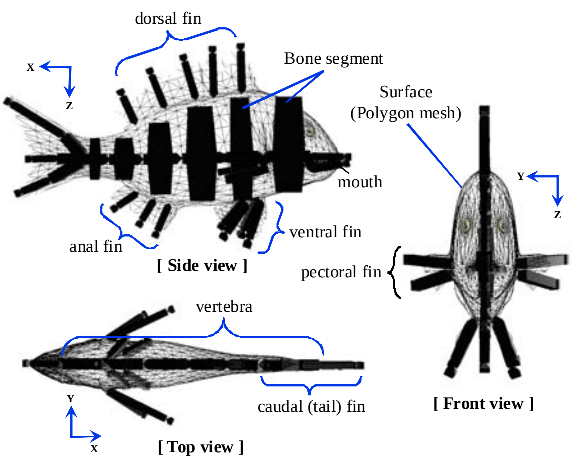

Fig. 2 Skeletal fish model view

The skeletal model of the artificial fish has hierarchical structure where the segment is connected to the joint depend on its hierarchic and generate movement by controlling the basic skeletal structure. Also, it is composed to process the natural binding of skin and deformation relying on the movement of frame.

The movement of artificial fish depends on the position of the vertebral column's joints and the change of each joint's angles. The surface of the artificial fish is composed of the little polygons and in order to express the movement these polygon's positions should be updated. To control the joint, the bone frame should be generated and arrange the bone frame so its ends meet. For the renewal of the each vertices' positions, the decision to how much influence it will get due to the movement of the each joints will be made and the worth of each joint's influence dependence will be decided as 0 to 1.

All bone frames will have individual transformation and each bone frame, positions and direction in the time base in the hierarchical structure will be defined as follow.

$$j_b^k(t) = \begin{cases} \{p_b^k(t), o_b^k(t)\}, & \text{if } \mathrm{k} = \text{root joint} \\ \{NIL, NIL) & \text{if } \mathrm{k} = \text{leaf joint} \\ \{NIL, o_b^k(t)\}, & \text{otherwise} \end{cases}$$

- $l_b^k = p_b^{parent}(t) - p_b^k(t), (k \neq parent \neq 0)$

$j_b^k(t)$ includes the worth of the kth joint position (p) and direction from time t, and $l_b^k(t)$ means the distance between kth joint and parents joint.

3.3 Skin Deformation

For the natural appearance of the character in the animation that used the articulated body method, it generates the skin of the character through the use of 3D polygonal mesh or the mathematical surface model. The skin model can express the natural appearance even to the skeletal change through binding of the skeletal model of the character.

- Skin Authoring: the process of creating the form of skin geometry depending on skeleton movement and uses the commonly well known toolset to create the complex form of skin geometry.
- Skin Computation: the mesh geometry calculation stage that is changed from the hierarchical skeletal structure. It applies the appropriate skinning algorithm.

In this research, it generates the skin model of the 3D polygon mesh form through the use of commercialized toolset. Allocated the influencing joints and blending weight in each vertex and is the applied combination that has the local coordinate system weight of the skin joints. Also, it is decided by the change of each vertex. Skinning model used the linear blend skinning method[19] and the V_c , that is the change of vertex from the hierarchal skeletal configuration c .

$$V_c = \sum_{n=0}^{b-1} \omega_n M_{n,c} M_{n,d}^{-1} V_d \tag{1}$$

Here, b is the number of the bone frame, ω_n is the weight of the n bone frame, vertex V_d is the initial vertex position that represent the dress pose of the character, $M_{n,c}$ is the change procession that is related from the skeletal configuration c to nth joints, $M_{n,d}^{-1}$ represent the inverse matrix of the dress pose that is related to the weight of n bone frame. Figure 3 illustrate the change of the vertex position and skin geometry depending on the movement of the hierarchical skeleton.

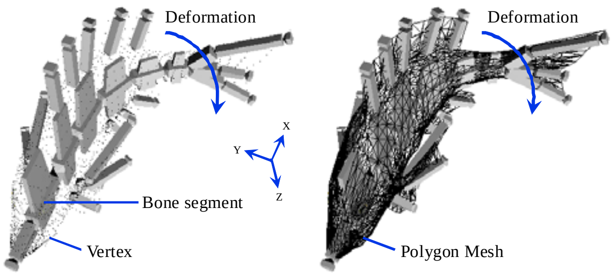

Fig. 3 Schematic bone / skin view

3.4 Analysis of Realistic Fish Motion

The motion pattern of the real fish is analyzed in the ethologic field through various research method and through the approach of the anatomy and kinematics the movement and the motion of the fish is analyzed[15,16,17]. The movement of the real fish is different by the type and the structure of the fish. In can be classified by the swim pattern, there are BCF(Body and/or Caudal Fin) that gains the propulsive force by curve in the backward-moving propulsive way from body to tail and MPF(Median and/or Paired Fin) swim pattern that have propulsive force from the exercise of middle or pectoral fin[17,18]. Out of these types 75% of whole fish occupy the BCF form. In this research, we analyzed the motion pattern based on the common swim pattern BCF form's fish and divided the basic motion pattern as swim motion and turn motion. With this division, in order to generate the motion that is similar to the reality we modeled motions with rather simple by numerical formula. In the figure 4, it shows the result of kinematical analysis of stable swimming condition of BCF-type fish.

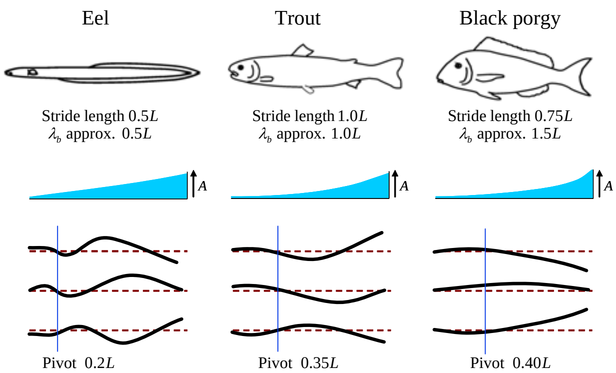

Fig. 4 Kinematical analysis of BCF-type fish swimming

λ_b means the wavelength of the body curve lone from the body length L and amplitude graph represent the distribution of reciprocation motion's maximum amplitude of side's scope from head to tail. The diagram indicated by curve shows the bends of body based on the central line during forward swim. The curved form is the fish's motion pattern and is the basic data for modeling the regular motion. The vertical line indicates the central point position for motion and can confirm the change of wave form when BCF form of fishes swim following this central point.

The shape of artificial movement can be defined through these fish's kinematical analysis data and can generate the similar movement of the real fish through the sine function deformation depending on the movement shape.

Figure 5 is the curve graph to indicate the output of power by the position of A, B and C in the body about the black porgy's two cycle of body wave period. By allocating each body part's output value of power is to the position of each bone segment of the artificial fish's skeletal structure and the weight value applied to the change of joint angle, the movement could be created more realistic.

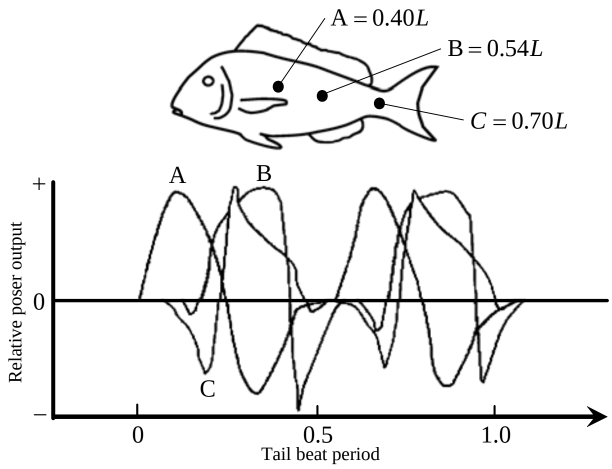

Fig. 5 Instantaneous power curves over two tail beats for the black porgy

3.5 Artificial Fish Motion

In this chapter, we divide the analyzed motion pattern of fish from chapter 3.4 to swim motion and turn motion. We will explain the method to generate the similar movement from reality by focusing on this. Furthermore, we will explain the process of modeling exercising structure and motion algorithm, which is crucial to generate the movement of fish, by using the simple numerical formula.

3.5.1 Fish Swimming Motion

By generating the swimming motion and turn motion body shape of the artificial fish to sine curve form we can generate the similar movement of the real fish's motion pattern. To be precise, the procedural motion of the artificial fish's swim motion and turn motion can be the function to control the position of the skeletal structure and the angle. The creation of the swimming motion of fish's basic sine basic traveling wave was adopted from the proposed function from Tu and Gates research and the equation is same as (2).

$$F(x,t) = A(x)\sin(2\pi/\lambda(x-\omega t)) \qquad (2)$$

Here, F represent the side displacement of the fish body's horizontal line, x is the joint position of the principal axis, t is time, $A(x)$ is amplitude, λ is the wavelength, ω is the frequency of the body.

The equation (2) didn't consider the change of wave depending on the swim pattern and the speed of the fish so there is the limit to create the realistic swimming motion. In order to complement this, we made it possible to generate the appropriate the sine traveling wave according to the swim pattern and the speed of the fish.

In the proposed method, in order to manage the central point of the change of motion depending on the swim pattern that varies by the type of the fish effectively the pivot was used. Due to the change of frequency and wavelength of the wave by the difference of swim pattern such as eel that have central point of motion comparatively in the front and the black porgy that has central point of motion comparatively at the back. Therefore, if we can regulate the central point through pivot the various type of motion can be generated. Furthermore, because the central point of motion changes by the swim and turn motion of the fish, the use of pivot at each motion creation and regulate the central point then more natural motion can be expressed. The Figure 6 illustrates the wave-domain to control the swim structure and swim motion in the proposed method.

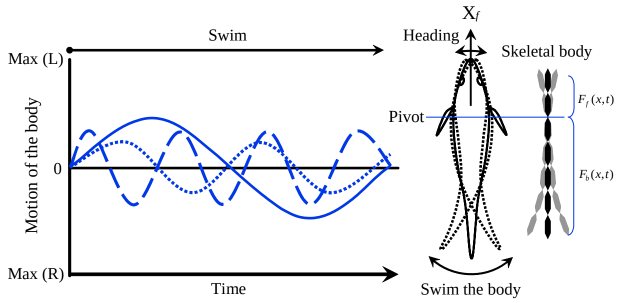

Fig. 6 Swim motion

Here, we used two sine functions to generate the swim motion depending on the position of the central point and the fish's speed change. These two sine functions define the F_b, that generate the backward motion of the pivot and F_f function that generate the forward motion of the pivot by based on the pivot that initiate the wave. Each calculation of the basic functions F_f and F_b is same as (3), (4).

$$F_f(x',t) = \sin(2\pi/\lambda'(x'-\varpi' t)) \qquad (3)$$

$$F_b(x',t) = A(x)\sin(2\pi/\lambda(x'-\varpi' t)) \qquad (4)$$

- $x' = x - pl$
- $\lambda' = (132 \times p - 18.8)\lambda$
- $\varpi' = s \times p \times \varpi$
- $A(x) = ((x - pl)/l) \times maxAmp$

Here, s is the speed of the fish, p is the position of the pivot where the wave is started, l is the length of the fish, *maxAmp* represent the maximum amplitude. The swim motion of the fish is decided by the change of the amplitude and frequency that is modified according to the progress speed *s* and the position of the pivot *p*. Here, as the progress speed *s* increases the frequency ω need to increase so we defined new frequency ϖ'. In equation (3), in order to prevent the pivot's amplitude of the fron motion wave big, we defined the λ' that will stretch the amplitude and produced the new function F_f to control the wave that depends on the position of the pivot. In equation (4), we sued the existing functin (2) to produce the function F_b to naturally generate the back-part motion of the pivot depending on the length of the fish.

3.5.2 Fish Turning Motion

The real fish uses tail, pectoral fins and ventral fins to turn motion skillfully[15,16]. However, the shape of the turn motion is determined directly by the motion of the tail part so pectoral fins and ventral fins can be excluded from the main element that influence the turn motion[1,20]. The research proposes the method to generating the turn motion by using the curve motion of the fish's tail section and controlling the motion. There are three form of turn motions basing the skeletal fish model that was proposed in chapter 3.2 and adapting the method of Koichi[20].

The first 'Normal Turning Motion' is the turning motion of the artificial fish by moving the tail to only one direction depending on the angle of the turn. Figure 7 illustrate the turning structure of the 'Normal Turning Motion' and the wave-domain that controls the turning motion.

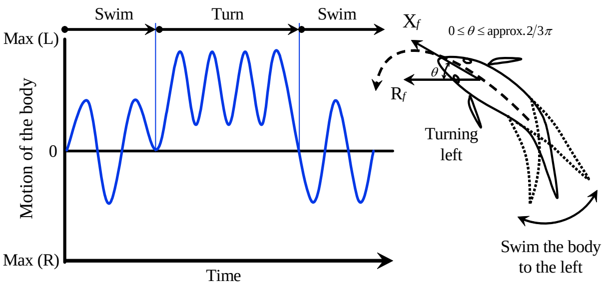

Fig. 7 Normal turning motion

The second 'Quick Turning Motion' is the form of fast turning to one direction of artificial fish depending on the turning angle while halting. This form is the slide turning on the basis of the body's turning axis during the moment of turning. This motion gives the ability to turn while halting and can minimize the turning radius. Figure 8 illustrate the turning structure of the 'Quick Turning Motion' and the wave-domain that controls the turning motion.

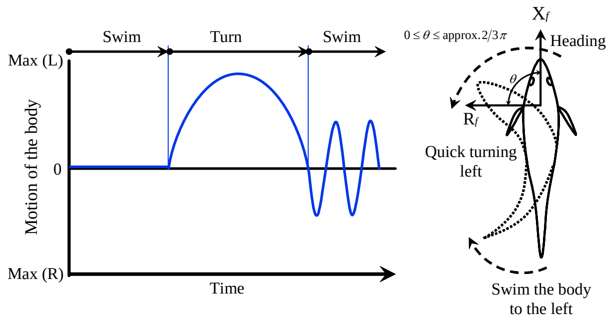

Fig. 8 Quick turning motion

The third 'Serial Turning Motion' is the form of turning of artificial fish to one direction serially while swimming. This form is turning fast to one direction while halting depending on the turning angle that is based on the turning axis of the body. Figure 9 illustrate the turning structure of the 'Serial Turning Motion' and the wave-domain that controls the turning motion.

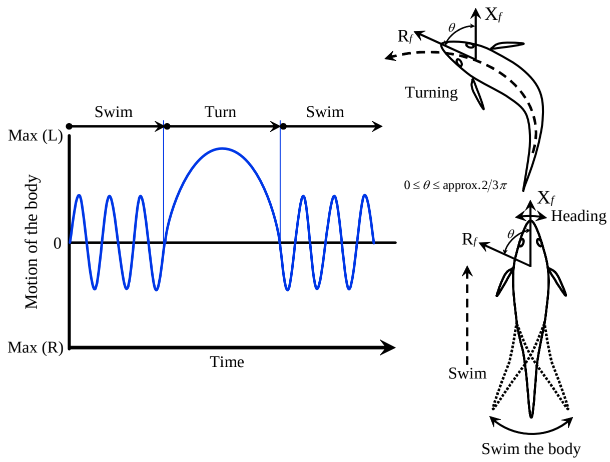

Fig. 9 Quick turning motion

These three turning motion methods employ the sine function of equation (2) and (3), which is used for the swimming motion and can apply differently depending on the turning form of the pivot's back-section movement change due to the turning direction of the fish. Each swim motion that is included in each turn motion use the swim motion sine equation (3) and (4) and the basic turning function F_{nt} for the 'Normal Turning Motion' can be defined as equation (5).

$$F_{nt}(x',t) = A(x)(\sin(2\pi/\lambda(x - w't)) + d)f \quad (5)$$

- $d \in \{-1,1,0\}$, $f \in [1,2]$

Here, d has the worth of -1(left), 1(right), 0(front), which is the variable for the basic turning direction and f shows the worth that regulate the worth of the amplitude that differs by the direction.

'Quick Turning Motion' and 'Serial turning Motion' has same form of turning wave so can use same turning function. 'Quick Turning Motion' and 'Serial Turning Motion' wave form has to end in one direction at once and should be able to generate the wave, which will help the worth to change depending on the direction. Therefore, the basic turning function F_{st} is defined as equation (6).

$$F_{st}(x',t) = A(x)\, fabs(\sin(2\pi/\lambda''(x - sw''t)) + d))) \quad (6)$$

- Tt : Turning Time
- $\lambda'' = 2 \times Tt$
- $\varpi'' = 0.5/Tt$

As there has to be smooth transfer between the swimming wave segments and turning wave segment in the turning motion, it needs the separate interpolate work. We assumed swimming wave and turning wave as *S(x,t)*, *T(x,t)* and used interpolation function $I_p(t)$ for the interpolation of the two waves. The interpolation function $I_p(t)$ is based on the sine wave such as *S(x,t)* or *T(x,t)* and uses $I_p(t)$ to create final turn motion $T_{locomotion}$ by combining the swim wave and turn wave, which the equation (7) can be defined as follow.

$$T_{locomotion} = S(x,t)(1.0 - I_p(t)) + T(x,t)I_p(t) \quad (7)$$

- $I_p(t) = fabs(\sin(PI \times t/t_p)$

3.5.3 Generation of Artificial Fish Motion

This research employed the procedural approach to generate the movement of the artificial fish and Figure 10 illustrates the process.

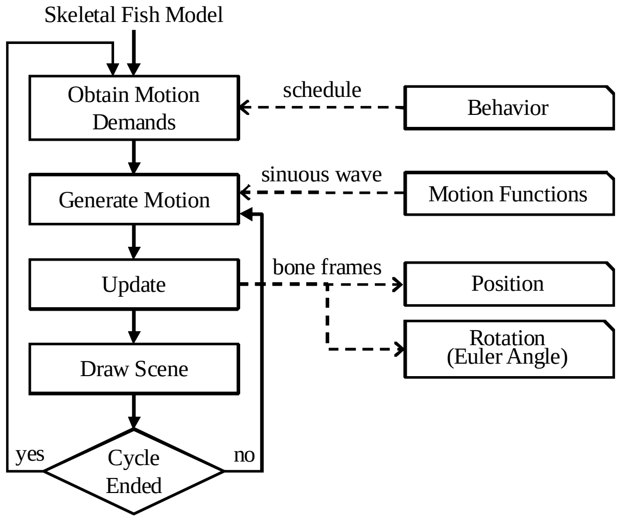

Fig. 10 Flowchart of motion generation

The motions of the artificial fish are composed of the behavioral unit and demand the motion by the schedule of behaviors. Each motion has vertebral bone structure and angle renewal through the worth of sine wave and weight from the motion generation function that was proposed in this research. Here, we set the orientation of the vertebral joints by using the Euler angles, which is the direction set of *x*, *y*, *z* from the coordinate system of vertebral column principal axis. Then the animation is being generated through the rendering process and executes the existing motion repeatedly until each motion has played for a week.

4. Experiments and Results

This chapter will show the method of generating the motion of the artificial fish by using the procedural approach and show result of real-time motion generation of the articulated bodies from PC environment. Black porgy was used for the research as the type of artificial fish that has articulated body and is composed of total of 30 bone segments. Furthermore, we generated the motion by using the 7 vertebra bone segment that has the direct responsibility of the swimming and 6 joints. From Figure 11 to Figure 14 is the result scene of the generated animation through procedural approach that used the each motion function from the proposed methods. The computer that was used to create this example was Pentium Ⅳ 2.7GHz leveled PC that has RAM of 512MByte and rendered through the use of DirectX library. The black porgy character model is composed of total 5,695 polygons and generated the movement of black porgy character model by having the motion speed of 50-60 frames (FPS) per second.

We simulated the each movement by setting the variable *f* for the position of pivot *p*, fish speed *s*, the fish length *l*, the turning direction *d*, turning time *Tt* and the amplitude weight *f* and these are shown in Table 1.

Table 1: Motion function parameter

	p	*s*	*l*	*d*	*Tt(ms)*	*f*
Ex1	0.40	50	50	N/A	N/A	N/A
Ex2	0.45	20	50	-1	N/A	2.0
Ex3	0.20	40	50	-1	2000	N/A
Ex4	0.40	35	50	-1	2400	N/A

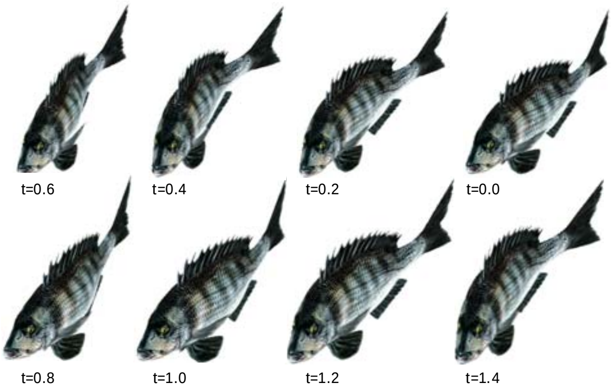

Fig. 11 Example1 : Swimming motion

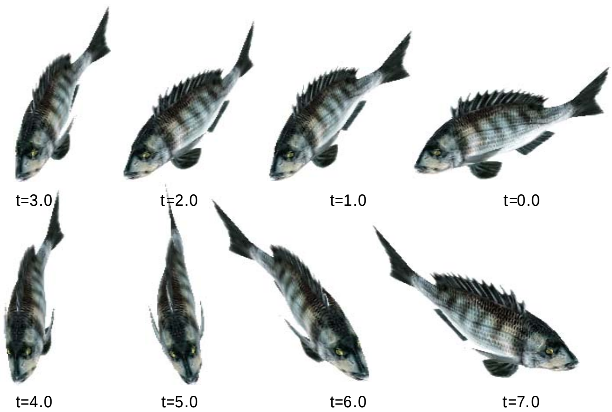

Fig. 12 Example2 : Normal turning motion

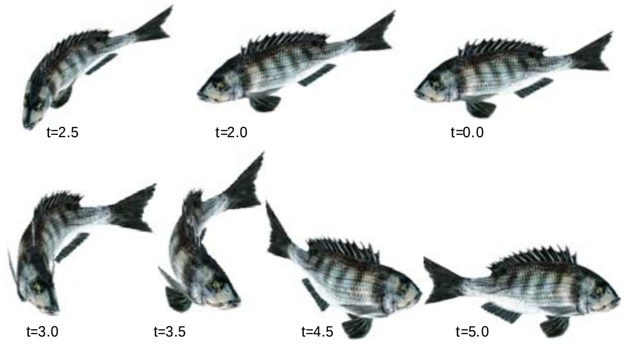

Fig. 13 Example3 : Quick turning motion

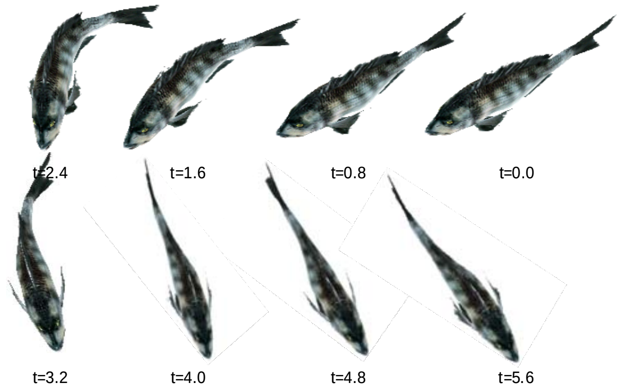

Fig. 14 Example4 : Serial turning motion

As shown in the figures, we have demonstrated the swimming motion and turning motion of the artificial fish through rather simple numerical formula and the union of small number of parametric variable. This experiment based the procedural approach to simultaneously generate the movement of the articulated bodied artificial fish and by applying the skeletal model and motion generating method we could create the similar scene to reality effectively. These methods showed experimental result that the animation data of the artificial fish is relatively easy and quick to create the similar movement of the character from reality with little effort and variety of environment.

5. Conclusion and Future Works

Purpose of this research was to simultaneously and quickly generate the movement of the artificial fish that is similar to reality in the cyber system, such as virtual marine world. To achieve this, we proposed the architecture of artificial fish animation to use the procedural approach. Also, we proposed the skeletal model and motion generating method for real-time motion control of the artificial fish. The method proposed in this research was to avoid complex calculations while generating the movement of artificial fish through the procedural approach and to help quickly generate the similar movement from the reality by analyzing the motion pattern of the real fish.

The method proposed in this research can be useful for the 3D educational applications that contain the subject about fish or cyber aquarium or marine simulation game. Also, we believe that it can be useful for developing aesthetic style content that has consensus with the user as can express various motions through the interactions with users. In future, the expanded research on motion generation is crucial such as the motion form of BCF and MPF and motion control on the collision of the articulated bodied fish and fish crowding.

Acknowledgments

This research was supported by Ministry of Information and Communication (MCT), Korea, under the CRC (Culture Research Center) support program supervised by Korea Culture & Contents Agency (KOCCA) and DCRC (Digital Contents Cooperative Research Center).

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