Life-like Animation System Based on Intermittency and Diversity of Motion

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Abstract: Creation of lifelike characters is critical to movie, animation, and game development. To achieve the required levels of sensibility and experience, animators must master essential skills and knowledge in a variety of productions. Because media art games and applications must react to situational changes or user interventions, the software must generate a computational model behavior. In this study, we propose a lifelike animation system that captures the intermittency and diversity of motion found in living organisms based on tropical fishes . Referring to fish physiology and ecology, we constructed a virtual fish model incorporating the relationship between speed and frequency of the caudal fin and the biological and structural characteristics of real fish. Stochastic control is performed in two stages;: sudden motion generation in the selection process and creation of diversified movements in the parameter selection process. An evaluation experiment confirmed that the sense of life is enhanced by combining the two attributes of intermittency and diversity.

Key words: Animation, Animacy Procedural Animation, Generative Art & Entertainment, Animacy Perception, Artificial Life

1. Introduction

Effective digital film content, animation, and gaming relies on the creation of lifelike characters.
Thus, the animation industry largely relies largely on the experience and sensibility of well-trained, highly skilled animators.
Dynamic animation that changes over time can be achieved by using various techniques. However, in interactive contents such as games and media art, the software must sense and respond to user input. this Therefore, creation of a model that generates lifelike response behavior is imperative.
As a trial for building animate objects, an integrative study has been performed by various researchers. Animacy attributes "a quality of creature" to an object, while animacy perception denotes that an object "feels alive" and displays a movement expected from a living thing.
Animacy can be imparted even to simple geometry figures. Motions such as "moving together" and "pushing away" can be generated by simply changing the timing of the collision between two objects, as reported in Michotte [1]. Heider & Simmel observed social relations and intention-related perceptions occurring among animated figures [2], while Tremoulet & Feldman reported a perception of motion other than the shape effect . .Thus, animacy perception appears to involve various levels of cognitive functioning. Thought processing from instinctive perception to reasoning has been extensively researched. By combining physical simulation with concepts of perception, Tu & Terzerpolous suggested that an artificial fish can evoke the movements of a real fish [7], while. Boids is another well-known program for simulating a large number of objects[8]. Sims used a genetic algorithm (GA) to evolve the control and morphology of virtual creatures [9], yielding various forms and locomotion strategies.
Travers has developed a prototype-based programming environment called LiveWorld that imparts lifelike behavior to objects [10]. However, LiveWorld does not account for differences in the movements of individual objects, nor does it account for diversity among objects of the same type. In this study, we propose a method for generating lifelike motion that focuses on sudden and varying movements. The model is based on tropical fishes,

which displays relatively simple but diverse behavioral patterns. The success of the scheme depends on fundamental researches into fish anatomy and biology. The swimming properties of the fish must also be clearly understood.

The proposed lifelike animation system mimics the intermittency and diversity of motion found in real tropical fishes. The virtual fish model incorporates the relationship between speed and frequency of the caudal fin and the biological and structural characteristics of the fish gleaned from fish physiology and ecology [11,12]. Stochastic control is performed in two stages. The selection stage generates sudden motion, while the parameter selection stage creates motion diversity under parameter control. In an evaluation experiment, we confirmed that the sense of life is enhanced by combining the two attributes of intermittency and diversity.

2. Element analysis of a life motion

Movement is conventionally simulated as a continuous, smooth motion element. However, real organisms frequently display sudden motion elements that satisfy commands such as “move suddenly” and “repeat movement or halt.”

Fish actively swim within schools, and a single fish species undertakes various types of movements. In this section, we discuss the basic movement elements that evoke a sense of vitality, based onon the basis of the knowledge of fish physiology and ecology gained from video analysis.

2.1 Preliminary experiments to extract the life-element

To extract the basic elements of lifelike behavior, we supplemented video- recordings with visual observations of *Chrysiptera cyanea* (sapphire devil) swimming in a water tank, and statistically analyzed the results. Figure 1 tracks the horizontal and vertical trajectory of the moving fish, and a spectral analysis of the movement trajectory is shown in Fig. 2. At this stage of the project, we seek only a rough description of the dynamics. Thus, while fish movement is accurately captured in three dimensions, it is not yet elucidated in two dimensions. Figure 1 shows that the selected fish samples travel with less range in the depth direction than in the horizontal direction. In the power spectrum of Fig. 2, the overall amplitude is inversely proportional to the frequency. This relationship, called pink noise, typifies nerve activity and also respiratory and heart rhythms [13,14]. We consider that introducing pink noise to robot movements imbues the robot with biological properties, as reported by Fukuda et al [15]. Figure 3 plots the distribution of the acceleration change. Rather than smooth swimming, fish show frequent acceleration and deceleration. The acceleration peaks at a small positive amplitude but the distribution is slightly left-skewed (skewness = −0.0548, calculated from Equation (1)). Not only is deceleration imposed by the resistance of the water but fish tend to intentionally halt their motion as well.

$$\frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}\left(\frac{x_i-\bar{x}}{s}\right)^3 \qquad (1)$$

2.2 Consideration based on the physiology of fish ecology

Many fish propel forward by vibrating their caudal fins. Swimming speed is proportional to the frequency of caudal fin vibrations, and is given by

$$U = k \times F \times L \qquad (2)$$

where k is the coefficient of swimming (which defines the forward distance moved in a single round trip of the caudal fin), F is the frequency of caudal vibration (Hz), and L is the length of the fish. To eliminate artifacts arising from the mismatch of shape and behavior in the fish models covered in this study, we assume that swimming speed is proportional to the frequency of caudal fin vibration.

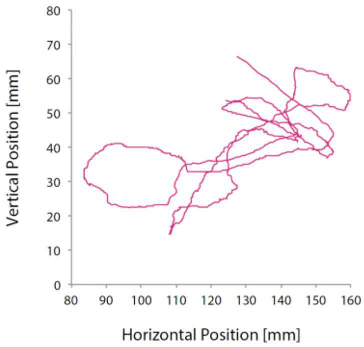

Figure 1 Movement trace of sapphire devil swimming in an aquarium.

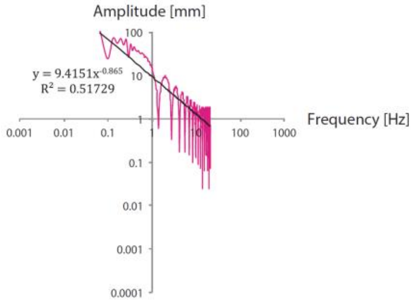

Figure 2 Spectral analysis of the movement trace of sapphire devil..

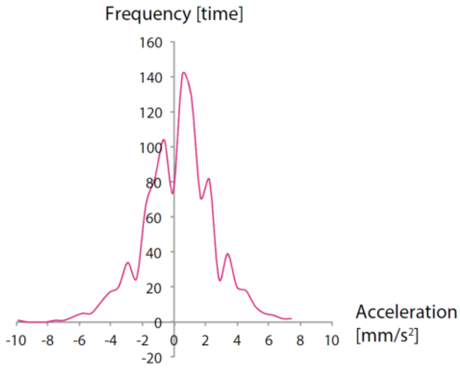

Figure 3 Distribution of acceleration of sapphire devil swimming motions.

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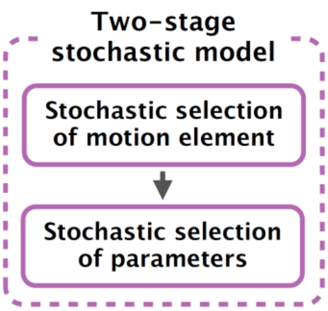

Figure 4 Two-stage stochastic model for generating fish motions.

Table 1 List of Motion Modules.

(1) **Acceleration**	Sudden linear acceleration or change in direction while accelerating
(2) **Natural slowdown**	No intentional behavioral changes; natural deceleration by the drag force of the water
(3) **Cruising**	Continual forward motion at constant speed
(4) **Slowdown**	Sudden stop or intentional speed reduction

3. Method for Generating Movement Bursts and Diversity

In this paper, we propose a method for generating motion includes burstiness and diversity mentioned in Section 2. This method consists of two-stage stochastic model (Fig.4). First stage is the process of selecting behavior elements such as acceleration and deceleration stochastically. Second stage is the process of selecting parameters of the motion stochastically. Thus, however components of motion are relatively simple, our method allows the motion generation with burstiness and diversity.

3.1 Motion Modules

The proposed method combines the four behavioral elements listed in Table 1. These behaviors were derived from the acceleration distribution and visual observations of the fish. From the preliminary experiments described in Section 2.1, we extracted and linked the basic elements of fish motion, as depicted in Fig. 5.
We refer to these four elements of behavior as “motion modules.” A motion module is the basic unit of motion generation. At each interval, the algorithm performs a selected operation on a motion module..

3.2 Selection of Motion Module

The motion module selection process is modeled as a state transition in discrete time. The state space of motion modules $\Omega = \{S_1, S_2, S_3, S_4\}$ is modified by a simple Markov Chain as follows (see also Fig. [Please insert]).

$$p(x_0, x_1, \dots, x_r) = p(x_0)p(x_1|x_0)p(x_2|x_1)\dots p(x_r|x_{r-1})$$

$$\Omega = \{S_1, S_2, S_3, S_4\}$$

where $S_1 S_1$ is the acceleration, $S_2 S_2$ is the natural slowdown due to drag, and $S_3 S_3$ and $S_4 S_4$ denote intentional cruising and slowdown behaviors, respectively.
In other words, the probability of selecting a motion module at time step *n* depends on the motion module selected at time step *n*-1.

3.3 Generation of Motion

Motion diversity is achieved by stochastic control of the parameters determining the acceleration and speed of the selected motion module..

3.3.1 Acceleration motion module

In the acceleration motion module, the fish is considered as a single rigid body. The force is calculated by adding the angular and linear accelerations, and incorporating random noise.

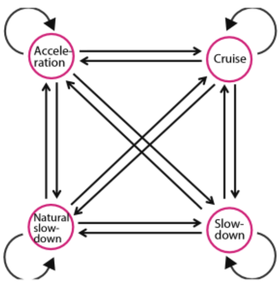

Figure 5 Model for Selecting Motion Modules..

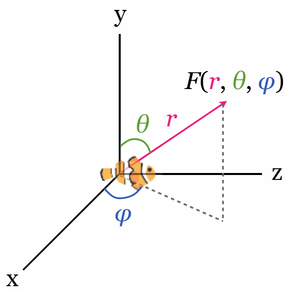

Figure 6 Fish Coordinates and Force Vector.

As shown in Figure 6, the force F acting on the fish is constructed as a vector in local spherical coordinates with the fish placed at the origin. The world coordinate system is the left-handed Cartesian coordinate system. The reference frame of the fish is the positive direction of the z axis. The magnitude of F (i.e. r) is assumed constant. The deflection angles θ and φ are calculated as

$$\theta = 90 + R(a_\theta) \qquad (3)$$

$$\varphi = 90 + R(a_\varphi) \qquad (4)$$

The function R (a) returns a pseudorandom number within the range −a to a. Because the linear refractive movement is randomly selected, we adopted the approach of Onitsuka et al [18], who investigated the swimming behaviors of Ayu fishes. When R(a_φ) = R(a_θ) = 0, fish swim straight ahead with no rotation, and the a_φ and a_θ parameters are assigned as constants. The higher the a_θ and a_φ, the larger the average pitch and roll angle, respectively. The local spherical coordinate system is converted to the local orthogonal (left-handed) coordinate system by the following expressions:

$$x = r\sin\theta\cos\varphi \qquad (5)$$

$$y = r\cos\theta \qquad (6)$$

$$z = r\sin\theta\sin\varphi \qquad (7)$$

while the acceleration a and angular acceleration α are respectively given by

$$\boldsymbol{a} = \frac{1}{m}\begin{pmatrix} 0 \\ 0 \\ z \end{pmatrix} \qquad (8)$$

$$\boldsymbol{\alpha} = \frac{1}{I}\begin{pmatrix} -y \\ x \\ 0 \end{pmatrix} = \frac{1}{mr^2}\begin{pmatrix} -y \\ x \\ 0 \end{pmatrix} \qquad (9)$$

In Equations (8) and (9), the mass m and radius r are assumed constant, and I is the moment of inertia. Finally, the changes in velocity v and angular velocity ω are obtained by integrating a and α, respectively. For simplicity, the integral is assumed as the product of the acceleration and the time step dt.

$$\boldsymbol{v}(t+\Delta t) = \boldsymbol{v}(t) + \boldsymbol{a}\cdot\Delta t \qquad (10)$$

$$\boldsymbol{\omega}(t+\Delta t) = \boldsymbol{\omega}(t) + \boldsymbol{\alpha}\cdot\Delta t \qquad (11)$$

3.3.2 Natural slowdown motion module

In the natural slowdown motion module, deceleration is involuntary and is wholly imposed by the drag force of the water. The water resistance D is proportional to the square of the velocity:

$$D = C_D\frac{\rho u^2}{2}S \qquad (12)$$

Here, C_D and ρ are the drag coefficient and the density of water, respectively, u is the speed of the fish, and S is the representative area of the fish. In the absence of u, D is assigned a constant value. The translational and rotational components of D are independently calculated as D_v and D_ω, respectively. Finally, V and ω are updated as follows:

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$$\boldsymbol{v}(t+\Delta t) = \boldsymbol{v}(t) - \boldsymbol{v}(t)\cdot D_v\Delta t \quad (D_v \le 1) \qquad (13)$$

$$\boldsymbol{\omega}(t+\Delta t) = \boldsymbol{\omega}(t) - \boldsymbol{\omega}(t)\cdot D_\omega\Delta t \quad (D_\omega \le 1) \qquad (14)$$

3.3.3 Cruise motion module

During cruising, the fish maintains constant translational motion. Therefore, drag D_v = 0and D in the natural slowdown motion module comprises only the rotational component D_ω. Finally, this module updates v, ω, and the natural slowdown motion module.

3.3.4 Slowdown motion module

In this module, voluntary deceleration dominates over natural slowdown.
Also, drag components D_v and D_ω are calculated by the following equations:

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$$D_v = B_v\cdot C_D\frac{\rho u^2}{2}S \qquad (15)$$

$$D_\omega = B_\omega\cdot C_D\frac{\rho u^2}{2}S \qquad (16)$$

where B_v and B_ω are constants denoting the magnification of voluntary deceleration in the translational and rotational directions, respectively.

4 Configuration of the virtual fish model

To allow autonomous fish movement, the motion generation method described in Chapter 3 must be augmented with basic functions that prevent fish from escaping the walls of the virtual aquarium. The basic configuration of the virtual fish model is depicted in Fig. 7. The system comprises five layers;: the input layer, three intermediate layers, and an output layer.

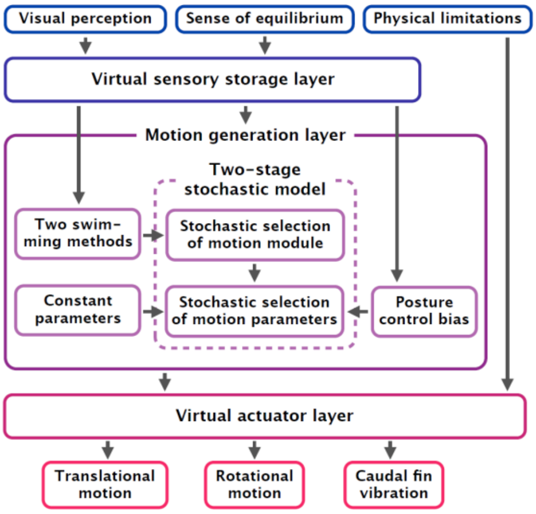


Figure 7 Basic Construct of the Virtual Fish Model.

4.1 Input layer

The input layer passes information perceived from the surrounding environment to the intermediate layer controlling the action. Visual sensory perception of other objects is performed through the field of view, while the equilibrium balance determines the slope of the world coordinate system of the body. The physical constraints define the maximum speed, maximum angular velocity,and the aquatic drag force.

4.2 Virtual sensory storage layer

The virtual sensory storage layer temporarily stores the input information. Visual perception of objects (in this case, the virtual aquarium walls and food particles) is stored as transient target information of the object.

4.3 Motion generation layer

As mentioned in the previous section, the motion generation layer selects and controls the motion module by using a two-stage stochastic model. Here we define two virtual swimming methods: “free-swimming” and “target-oriented swimming.” In the latter mode, fish avoid walls and swim toward food. Target-oriented swimming is selected if the target information exists in the virtual sensory storage layer; otherwise, free-swimming mode is selected. The selected swimming method changes the transition probability in the stochastic selection process of the motion modules. The aquatic drag force D and the vector force F are determined from multiple parameters, which the user can adjust to control the fish movement.
In this study, the posture of the fish should remain approximately horizontal; that is, the pitch angle should be retained near zero. Therefore, when calculating the deviation angle θ in the acceleration module, the “posture control bias” is activated based on the basis of the balance information.

4.4 Virtual actuator layer

The virtual actuator layer processes the fish kinematics. Specifically, it uses the laws of rigid body dynamics to update the angular and linear accelerations.

4.5 Output layer

The output layer controls the CG model of the fish. We prepared two versions of the model, one based on a simple shape, and the other assuming the shape of the fish, as shown in Fig. 6.
The output layer uses the linear and angular velocities (calculated in the virtual actuator layer) to perform translational and rotational motion, respectively. The caudal fin vibrates at a rate proportional to the velocity *v* of the body, as described in Section 2.2. The phase angle α_F and vibration angle Θ_F are calculated by Equations (17) and (18), respectively.

$$\alpha_F(t+\Delta t) = \alpha_F(t) + K_F \cdot v\Delta t \quad (17)$$

$$\theta_F = \theta_{Fmax} \sin \alpha_F \quad (18)$$

Here θ_Fmax is the maximum vibration angle of the caudal fin and K_F is the coefficient of the velocity of vibration. Figure 7 is a snapshot of the CG simulation, in which fish are swimming toward spherical food particles.

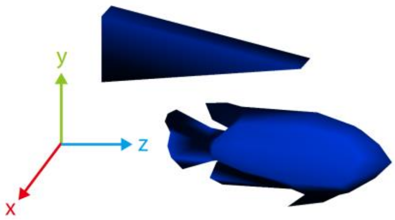


Figure 8 Shapes used in the CG model

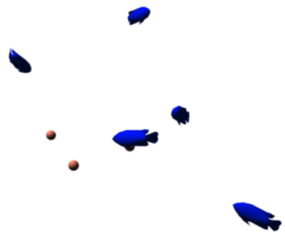


Figure 9 CG simulation of sapphire devils swimming toward food particles (brown spheres)..

5 Experimental apparatus

The effect of sudden movement and diversity on whether the simulated object was perceived as a living entity was investigated by a questionnaire. As an action element, diversity is defined as a complex change of direction; —a series of spontaneous elements such as speed changes. The other element of lifelike motion, i.e., sudden movement, is accomplished by adjusting the parameters described in Section 4. Each element is independently considered in the three stages of the animation process.
The animation patterns are summarized in Table 2. All videos of the executing CG model were presented for 60 s. The model behavior was also evaluated in terms of perception, allowing the simple shape in Figure 8 to perform fishlike movements without the viewer being aware of its intentions. Identical experiments were then conducted on a fish shaped object. In addition to the experiments, spectral analyses of the trajectories generated by each moving fish were undertaken.

5.1 Experimental apparatus

The animated video was played on a personal computer placed on the desk. The program that executes the video was created in a 3D game engine.
In each of the three videos (one for each pattern), the parameters were decided in advance. The software generated animation in real time, while the video presentation was manually operated manually. The behaviors imposed in each video are given in Table 2. The questionnaire asked participants to assess the lifelike quality of the video, and whether it conveyed sudden and/or diverse movements (Table 3). In a separate column, participants were invited to rate their impressions of the video and discuss the types of perceived movement
. The questionnaire responses were evaluated at five levels: 1. not at all; 2. scarcely; 3. neutral; 4.somewhat; 5.definitely.

Table 2 Property of each generated animation.

Pattern 1（P1）	No sudden accelerations or decelerations, No complex changes in direction, Outside turn made to avoid collisions with the wall of the virtual tank without changing direction, Traverses a virtual aquarium
Pattern 2（P2）	No sudden accelerations or decelerations, Complex change of direction, Change direction more frequently than avoid walls.
Pattern 13（P3）	Add “Intermittency” to pattern 2, Perform sudden accelerations or decelerations as well as complex changes in direction.

Table 3 Participant questionnaire

1.	Did you feel the movement of the creature?
2.	Did you feel intermittency in the motion of the object?
3.	Did you feel diversity in the motion of the object?

5.2 Experimental Procedure

Participants (24 people) were individually seated in front of the display to view the videos. The age of participants ranged from 15 to 23. Prior to viewing, participants were informed they would be shown three videos, and were expected to rate them on the question paper provided. The evaluation method and the playing operations for each video were explained to participants. The properties of the videos listed in Table 2 were not provided. Each video was played for 60 s, and could be viewed multiple times, as desired by the participants. The experiment terminated once each of the three videos had been evaluated.

5.3 Experimental Results

5.3.1 Rating scale (simple geometry)

The first experiments were conducted using a simple shape. Figure 11 (a, b, c) show the average scores and standard deviations of the rating scales (1), (2), and (3) in the questionnaire, respectively, for each test pattern. The senses of "living entity" "sudden movement" and "idiopathic" were evaluated by student's t test. The perception of "sudden movement" improved from P1 to P3, and from P2 to P3, at the 0.1% significance level (t = 7.508, p = ; t = 7.292, p = , respectively).The perception of "diverse movement" also differed between the patterns at 0.1% (between P1 and P3, t = 9.119, p = ; between P2 and P3, t = 3.854, p =).

These results indicate that, by imposing complex motions in the form of sudden accelerations or decelerations and directional changes, inanimate objects can acquire lifelike attributes of diversity and suddenness in their movements.

In addition, the object was progressively perceived as "feeling alive" as the complexity of the movement increased from P1 through P2 to P3 (all differences significant at the 0.1% level). Therefore, by enhancing the lifelike qualities of movement, we can impart a sense that a simple object is indeed alive.

5.3.2 free description (simple geometry)

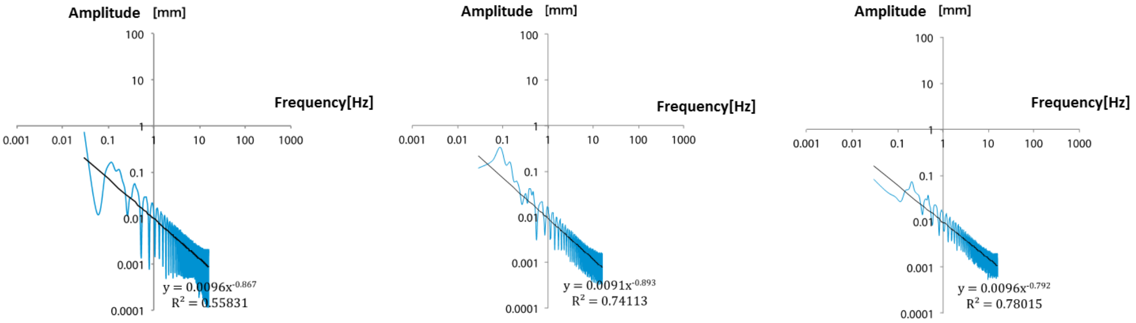
After watching animations of the simple shape, participants confirmed that they had seen motion. The movement patterns of P1 such as "simple movement" and "linear motion" provoked many answers about movement patterns and simple rules. Movements were regarded as mechanical in this scenario. P2 was characterized by features such as "movement in the depth direction" and "frequent change of direction." While participants reported a sense of three-dimensional movement, they felt that this motion was governed by a rule rather than natural "like a robot searching rather than a creature." P3 incorporated more complex movements such as "sudden acceleration and sudden stops," "turning acceleration," and "twisting motions" Participants were keenly aware of intentional velocity changes in this scenario. In addition, many respondents reported that the individual objects had acquired a personality. These responses suggest that participants routinely observe such motions in real life, and that simulated movement alone can evoke the behaviors of creatures such as fish and hamsters.

5.3.3 Rating Scale (fish shape)

Participants then viewed animations of a simulated fish and evaluated their quality. The average rating scale and standard deviation of rating scales (1), (2), and (3) are displayed in Fig. 11, panels (d, e, f), respectively. Similar to the simple shape, we analyzed the evaluations of "feeling alive," "sudden movement," and "idiopathic" by student's t-test. Between P1 and P3, and also between P2 and P3, "sudden movement " was enhanced at the 0.1% significance level (t = 5.754, p = and t = 3.646, p = , respectively). Similarly, "movement diversity" was enhanced between P1 and P3 at the 0.1% significance level (t = 5.598, p =), while between P2 and P3, significant difference was observed at the 5% level (t = 2.154, p =). PThe perceptions of the object as alive increased between P1 and P3, and between P2 and P3, at the0.1% significance level (t = 5.070, p = and t = 3.003, p = , respectively). In addition, the average score of the evaluation improved overall.

5.3.4 Free description (fish shape)

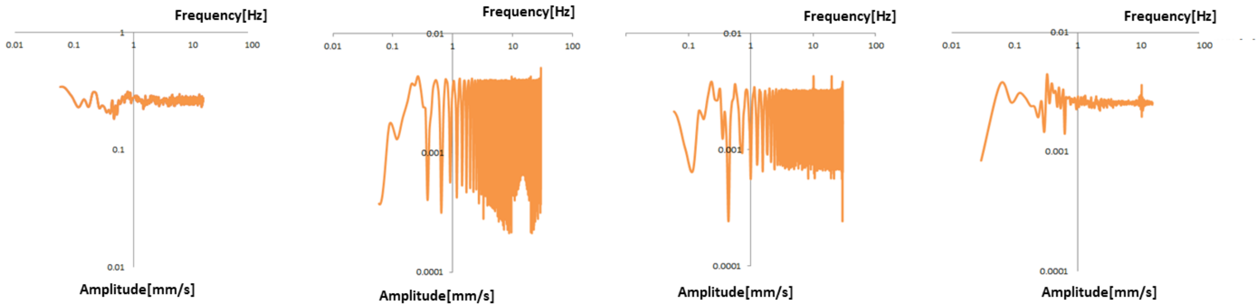
As in the previous experiment using a simple shape, participants provided free descriptions of their impressions. When viewing P1, the simplest and most regular behavior participants typically described the "spontaneously traversing the entire aquarium." Although the impression of three-dimensional movement increased in P2, participants reported a sense of artificial regularity, as they did for simple shapes. More realistic complex movements were captured in P3. Participants reported goal-oriented behaviors such as "Run away or chase other fish" and "swim to the food ." Other responses, such as "Evaluation is likely to depend on fish habitat," "Do real fish move so fast?" and "Similar to the movement of goldfish that I have kept," indicate that participants' individual impressions of fish have affected their evaluations when the object both looks and moves like a fish.



(a) Spectrum analysis of the movement trace of the Pattern 1.

(b) Spectrum analysis of the movement trace of the Pattern 2

(c) Spectrum analysis of the movement trace of the Pattern 3



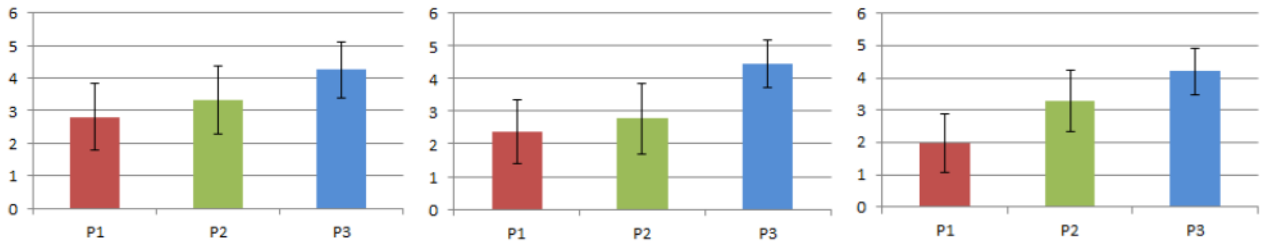
(d) Spectrum analysis of the velocity of the Sapphire devil.

(e) Spectrum analysis of the velocity in Pattern 1

(f) Spectrum analysis of the velocity in Pattern 2

(g) Spectrum analysis of the velocity in Pattern 3

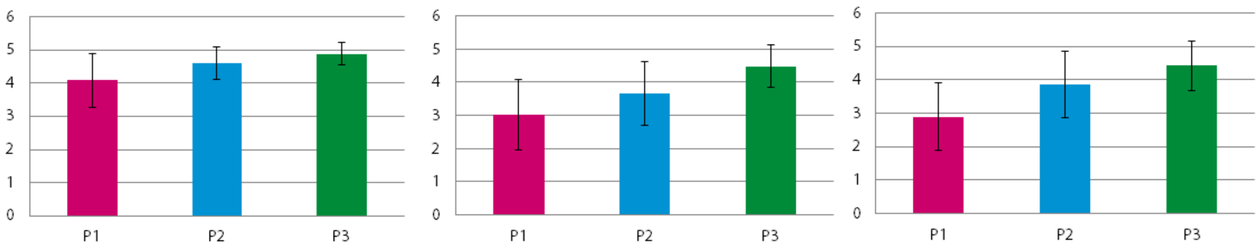
Figure 10 (top) Spectral analysis of movement traces in CG simulations and (bottom) spectral analysis of the velocity



(a) Feeling of vitality.

(b) Feeling of intermittency.

(c) Feeling of diversity.



(d) Feeling of vitality.

(e) Feeling of intermittency.

(f) Feeling of diversity.

Figure 11 Average scores and standard deviations of each rating scale for increasingly complex behavioral patterns.

5.4 Spectral Analysis

Spectral analysis of the movement trajectories acquired in each pattern are displayed in Fig. 10. The videos of all three patterns are characterized by pink noise

5.5 Consideration

The experimental results verify that imposing suddenness and diversity on animated movements can improve the sense of life. In the study by Aoyama, participants are asked to recall the nature of a particular organism given exercises on simple structures [19]. In our study, complex movement invoked a sense of life in simple shapes ; however, in each pattern, the lifelike quality was enhanced when the object was shaped like a fish. As discussed in Section 5.3.4, the fish body encouraged participants to visualize a fish, rather than a generic object. In biological simulations, realistic body and behavior that instill comfort in the participator are of paramount importance [20]. Even if the object looks like a fish, it must display proper behavior before it is intimately regarded as a fish. Thus, the effectiveness of the proposed motion generation method has been suggested. Pink noise, which characterizes lifelike behaviors [13-15], appears in the spectra of all three patterns. This result does not translate per se into participants' evaluation of the object as a living entity. However, in spectral analyses of the speed of the generated animations (Fig. 10 (d, e, f, g)), peak activity appears only in P3, the most complex movement pattern.

In addition to the peak amplitude, a late and an early period are found in Fig. 10 (g). Modulating the rhythm of motion generation appears to enhance the sense that an object is alive.

6 Conclusion.

Using tropical fish as a model, we demonstrated the utility of a proposed animation system that focuses on sudden and diverse movements. This method minimizes the visual components of fish and environment (the latter being a very simple virtual aquarium).

Future developments will incorporate bending movements of the fish body and vibrational motions of the pectoral fin in compliance with the virtual environment.

References

[1] A. Michotte.: The Perception of Causality, Basic Books (1946/ English transl. 1963).

[2] Heider and Simmel.: An experimental study of apparent behavior, Am. J. Psychology, vol.57, no.2, pp.67-70(1944).

[3] J.Feldman and P.D.Tremoulet.: Perception of animacy from the motion of a single object, Perception, vol.29, pp.943-951(2000)

[4] K.Nakamura and S.Sumi: Motion information contributing to the perception of animacy or inanimacy from the motion of a single object, IEICE Technical Report, Vol.101, pp.95-100, 2002

[5] K.Terada, R.Takeuchi, H.Fukai and A.Ito.: Effect of predictability of goldfish behavior on perception of animacy and intentionality, IPSJ SIG Technical Report, Vol.2012-HCI-148, No.10, pp.1-8, 2012

[6] J.Opfer.: Identifying living and sentient kinds from dynamic information: the case of goal-directed versus aimless autonomous movement in conceptual change, Cognition, vol.86, pp.97-122(2002)

[7] X.Tu and D.Terzopoulos.: "Artificial Fishes: Physics, Locomotion, Perception, Behavior", Computer Graphics, SIGGRAPH 94 Conference Proceedings, pp.43-50, July(1994)

[8] Craig W. Reynolds.: Flocks, Herds, and Schools: A Distributed Behavioral Model, Published in Computer Graphics, 21(4), (ACM SIGGRAPH '87 Conference Proceedings, Anaheim, California, July 1987.), pp. 25-34, July (1987)

[9] Karl Sims.: Evolving virtual creatures, Computer Graphics, Annual Conference Series, (SIGGRAPH '94 Proceedings), pp.15-22, July (1994)

[10] Michael David Travers .: Programming with agents: new metaphors for thinking about computation, Massachusetts Institute of Technology, Program in Media Arts & Sciences, 1996. Includes bibliographical references (pp.197-206).

[11] K.Aida.: Basis of fish physiology, Koseisha Koseikaku, 2011

[12] K.Tsukamoto.: Basis of fish ecology, Koseisha Koseikaku, 2010

[13] K.Kawahara.: Studies on control and fluctuation phenomena in biological rhythm, Electronic Science and Technology, No.4, pp.33-39, 1997

[14] Wataru Matsunaga, Eiji Watanabe.: Visual motion with pink noise induces predation behavior, Scientific Reports, (2012)

[15] Haruaki Fukuda and Kazuhiro Ueda.: Interaction with a Moving Object Affects One's Perception of Its Animacy, International Journal of Social Robotics, Volume 2, Issue 2, pp 187-193, June(2010)

[16] N.Kato and H.Suzuki.: Motion of Pectoral Fin of Fish and Its Application to Underwater Robots, Web Journal of Japan Society of Computational Fluid Dynamics, Vol.12, No.3, 2005

[17] A.Higashi and S.Ito.: Aero Aqua Biomechanics, Society of Aero Biomechanism, Morikita Shuppan, 2010

[18] K.Onitsuka, J.Akiyama, A.Yamamoto and T.waki.: Swimming behavior of isolated Ayu in statistic water, Journal of Hydraulic Engineering, Japan Society of Civil Engineers, Vol.52, pp.1195-1200, 2008

[19] N.Aono, T.Morita, and K.Ueda: Analysis of Animacy Perceived from Movement of a Two-Link Rigid Arm, Journal of IEICE, Vol.J95-D, No.5, pp.1268-1275, 2012

[20] H.Suzuki, K.Morisaki, K.Watanabe, Y.Hayashibara, H.Nishi: Gait generation and impression evaluation in the animal-type quadruped robot: Journal of Japan Society for Fuzzy Theory and Intelligent Informatics, Vol.24, No.5, pp.1012-1022, 2012

Figure 10 (top) Spectral analysis of movement traces in CG simulations and (bottom) sSpectral analysis of the velocity