A Study on the Generation of Artificial Fish's Behavior Using Elasticity Force

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Abstract. Objects can interact with each other in accordance with the events considering certain conditions. However, to express the interactive behaviors, the event conditions and behavioral patterns need to correspond with each other almost on a one-to-one basis. Thus, if the number of patterns which have been already defined is insufficient, the realistic actions cannot be accomplished and the event conditions to be considered increase for the expression of diverse behavioral patterns, which will in turn increase the complexity of the whole system. Thus, this study suggests a new method which will facilitate more realistic expression of artificial fishes and the creation of diverse behavioral patterns for one evasion event by applying a physical approach utilizing elastic momentum and using variable multi-sensors.

Keywords: Virtual Space, Artificial Fish, Elasticity, Sensory System.

1 Introduction

Digital creatures refer to the digitally restored characters of the animals and plants in a real world or of the imaginary creatures and are used as the contents library such as videos or games.

An artificial fish is a type of digital creature which transforms to an automatic agent form which is used in interactive media such as computer animations or computer games. Those behaviors are controlled by the data generated by definite logic rules and generate dynamic mutual communication rules and algorithms. The complexity of the automatic behaviors generated in this manner is regulated by the degree of the expression of correlation with the environmental variables on the basis of the artificial variables acting given to the early artificial fishes and the force acting under the sea. Tu expressed the behaviors according to an event by combining motion mechanisms and also expressed the behaviors, combining motions according to Fear, Hunger, and Libido by giving intention attributes to artificial fishes. When each attribute is given fishes, the behaviors matching the situations are generated by using muscular system for realistic motion. However, the same motions tend to repeat due to the insufficient consideration of the variables determined by environmental factors.

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Fishes behave according to sensors and the state of fishes without considering the variables such as the distance between predator fishes and prey fishes, the weight of fishes, and the approaching velocity, which results in the same behavioral patterns under the same conditions. Thus, to express more realistic behaviors, this study suggests a behavior generation method based on physics by considering environmental factors. This method leads to another behavior of artificial fishes by the given environmental factors even under the same input conditions and state attributes. To do this, the initial momentum and direction is defined, the direction vector and evasion direction of predator fishes and prey fishes are determined by applying force as an environmental variable, and then the distance between them and the evasion velocity are determined.

2 Basic Elements of the Existing Artificial Fishes

2.1 Modeling

Tu, having designed the early artificial fishes, suggested the fishes based on a spring-mass model with elasticity. This fish model based on this force was composed of 23 point masses and 91 springs and these springs were named “Muscles”. These fishes generate the motion by changing the rest length of these springs.

2.2 Sensory System

Artificial fishes need sensor systems to detect other dynamic or stationary objects in a virtual undersea space. A sensor system detects the objects reacting in a certain distance and generates events depending on the objects. Reynolds detects other fishes or obstacles using a ray tracing method using a ray from the fish heads. This method is the most primitive method which can detect the object in the direction of the fish heads only. To compensate this, Tu suggested a sensor system with 300 degree viewing angle by using the vision of above 3 typical sensing. Fig. 1 is a ray tracing sensor system suggested by Tu.

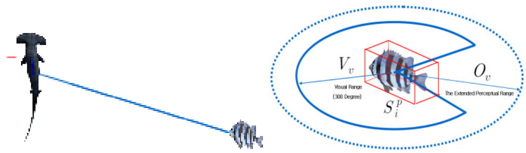

Fig. 1. A method suggested by Reynolds, A sensory system suggested by Tu

2.3 Artificial Fish-Motion Generation and Behavioral Pattern Algorithms

Grey provides a formula to indicate the velocity of fishes through the vertical velocity of fish tails by a central axis in the water. Equation (1) shows the travel speed according to the velocity of the fish tails.

$$(V_{fish} / V_{tail}) = (2\pi a^2 / \lambda^2)[1/((1+[4\pi a^2 / \lambda^2])] \tag{1}$$

In equation (1), a is the amplitude of the tails, λ is the wave length, and V_{fish} and V_{tail} indicate the travel speed and the propagation velocity of fishes. Artificial fishes are divided into predators, preys, and pacifists. Predators hunt preys and preys escape from predators. Predators and preys act in response to sensors. In case there is no input value to detection sensors, individual object wanders. Predators pursue preys when preys are detected within the radius of a sensor. Preys with relatively small radius flee when predators appear within a certain distance. Table 1 describes each behavior.

2.4 Problems of the Previous Studies and Solutions

The early artificial fishes were designed in the order of sensing, choosing the behavior defined to match each object, and fleeing when preys detected predators in terms of the relationship between predators and preys. Thus, each object could express only monotonous behaviors because the same event (sensing) could generated the same behavior. As solutions to this problem, the previous studies were conducted on a method triggering behavioral patterns by considering the state of preys and predators such as the weight and the velocity and the environmental condition such as the velocity of fluid, frictional force, and buoyance when preys detected predators. However, this also has the disadvantages in the sense that it increases the complexity in design and implementation of system because the output value matching each input value needs to be generated in advance for triggering behaviors. Fig. 2 is the comparison between the behavior inducing algorithms considering the previous simple behaviors inducing algorithms and all the input variables and the algorithms suggested in this study. The simple behavioral patters are pointed out as a problem in respect of the evasion after the early detection. In respect of the input parameter analysis after the detection and the generation of output values according to the input values, a measure that brings each fish's approaching velocity, approaching distance, and early evasion velocity which has been defined earlier is taken according to the combination of input values. The elastic momentum method suggested in this study can immediately determine the above approaching velocity, approaching distance, and early evasion velocity by utilizing the output values numerically after simplifying the correlation between these input values and output values.

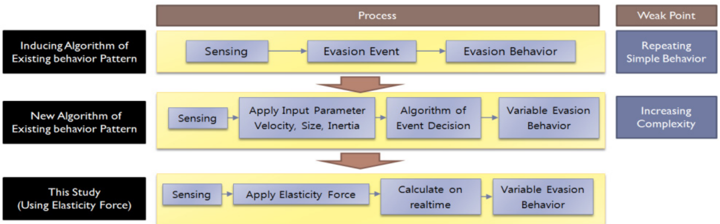

Fig. 2. Comparison between the previous behavior inducing algorithms and the improved algorithms

3 Improvement of an Artificial Fish Sensor System and Design of a Free Behavior Inducing System

To build a realistic virtual undersea space, preys and predators have variable sensors. More realistic behaviors can be induced by changing the size of sensors according to the size of objects and the degree of hunger. Furthermore, the forces acting on the dynamic objects in a 3D virtual space include the propulsion, buoyancy, gravity, and friction force due to the water viscosity. These are the important parameters in expressing natural behaviors when preys are found by predators. The distance between two objects approaching at rapid rate decreases sharply immediately before fleeing and an object which moves slowly flees in the distance equivalent to the size of the sensor. This study generates elastic momentum to this basic force for natural behavior. Elastic moment is generated by a virtual spring between preys and predators. A spring contracted by the inertia resulted from the momentum of a dynamic object reacts beyond the critical point, which will give the different elastic force to the objects approaching at rapid rate or a slow rate and generates evasion velocity according to the size and weight of fishes. Furthermore, the adjustment of the elastic modulus facilitates realistic fish behavior.

3.1 Variable Sensor and Evasion Direction Deciding System

Variable Multi-sensor

Real fishes control their ability to detect preys. Thus, this study has designed variable sensors and set the early pursuit velocity and evasion velocity differently. The predators which feel more hunger over time expand the sensor size and increase the velocity of early pursuit. Furthermore the predators have separate sensors which detect preys or the ordinary obstacles such as rocks and seaweed. Fig.3 shows the sensors of artificial fishes.L_f, a prey detection sensor or predator detection sensor, varies depending on the state of objects and L_o, an obstacles detection sensor, detects the floor conditions or surrounding rocks depending in the state of Wander, Flee, and Pursuit.

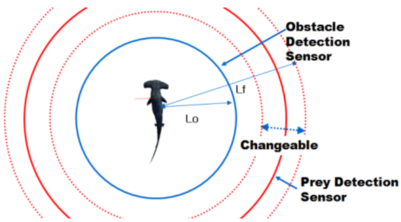

Fig. 3. Variable multi-sensor

Evasion Direction Determination Algorithm

When the sensors of prey and predators react to each other, preys flee at the velocity of $V_{evasion}$ and the evasion direction $D_{evasion}$ is determined by considering predators and surrounding obstacles. In case there is no obstacle within the sensing rage of prey, preys have the same direction as that of predators. In case there are obstacles or other predators within the sensing range, the direction of preys is determined in the following manner. $P_{predator}$ is the location of Predator 1 and $P_{Obstacle}$ is the location of Predator 2(or obstacle).

$$P_{predator} = (x_{predator}, y_{predator}, z_{predator}),\ P_{obstacle} = (x_{obstacle}, y_{obstacle}, z_{obstacle}),\ P_{prey} = (x_{prey}, y_{prey}, z_{prey})$$

At this time, if the location of a prey is P_{prey}, $P_{predator}$ - P_{prey} is the direction of an predator for an prey and the direction of an obstacle for a prey is $\overrightarrow{P_{Obstacle} - P_{Prey}}$. The evasion direction of a prey is $D_{evasion}$, which is the opposite direction of the total of the vectors of these two directions.

$$\vec{D}_{evasion} = -((x_{predator} + x_{obstacle} - 2x_{prey}), (y_{predator} + y_{obstacle} - 2y_{prey}), (z_{predator} + z_{obstacle} - 2z_{prey}))$$

Fig. 4 shows the evasion direction of prey and predators against obstacles.

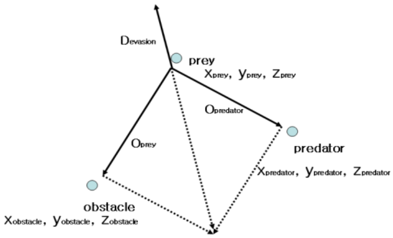

Fig. 4. Evasion direction vector

Virtual Spring Generation for the Application of Elastic Force

Preys which respond to a sensor immediately evade upon the receipt of an event, yet a sensor incurs an event generating a elastic spring and moves a certain distance x to achieve the equilibrium between the inertia forces and the elastic forces, and then shows evasion event when having maximum x value. At this time, the elastic force is reflected in the velocity after converting elastic force into kinetic energy. Fig 5 shows a virtual spring generated between two objects.

Fig. 5. Generation of a virtual elastic spring

When the location of an predator is $P_{predator}$ and the location of a prey is P_{prey}, the distance between a predator and a prey becomes *l*.

$$l=\sqrt{(x_{predator}-x_{prey})^2+(y_{predator}-y_{prey})^2+(z_{predator}-z_{prey})^2} \tag{2}$$

When the reciprocal detection state of a prey and a predator becomes True, a spring with length *l* and the modulus of elasticity *k* is generated between the two. The potential energy of this spring V_e is shown in Equation 3.

$$V_e = \int_0^x F dx = \int_0^x kx dx \tag{3}$$

The reason why the sensor length of a prey is not equal to the length is because the length of a spring which is shorter than the length of a sensor can be generated at some point of time because of obstacles. F is the momentum by a fish, *k* is spring constant, and constant *x* is the modulus of strain. At this time, when assuming the size of predators is infinitely larger than that of preys, the compression by predators is not achieved and only the whole location is changed, so it is set as a partition. Thus, the relative momentum to predators is not considered. The modulus of stain *x* for predators' momentum $F_{positive}$ is generated. At this time, as $\int_0^x kxdx = \frac{1}{2}kx^2$, the energy of a fish on a spring *W* has been changed into potential energy. Thus, the maximum of modulus of strain *x* becomes $x_{\max}$.

In other words, when *x* becomes $x_{\max}$, evasion event will be given and then the evasion direction obtained from a sensor system becomes ($x_{Predator}$ + $x_{Obstacle}$ - $2x_{Prey}$), - ($yx_{Predator}$ + $y_{Obstacle}$ - $2y_{Prey}$), - ($z_{Predator}$ + $z_{Obstacle}$ - $2z_{Prey}$).

$$\frac{1}{2}mv^2 = \frac{1}{2}kx^2 \tag{4}$$

As the initial evasion velocity v_{escape} is the velocity after the elastic energy restored as the kinetic energy, v_{escape} can be calculated by Equation 5.

$$v_{escape} = \frac{\sqrt{m_{prey}k}(Cv_{p/p}-m_{prey}a_{prey})}{m_{prey}k} \tag{5}$$

4 Experiments and Result

In this paper, the relationship between fishes is limited to the relationship between preys and predators. Predators have the attribute of Pursuit and Wander and preys have the attribute of Flee and Wander. These behaviors are generated and become extinct by the interaction between preys and predators. To implement the behaviors of an artificial fish, this study has modeled a prey after a back porgy and a predator after a hammerhead. As for the behaviors, to express the behavior of Flee, Wander, and Pursuit, animations in units such as Swimming, Turning, Rapid Swimming were produced and set according to the given situations. Table 2 indicates the event of individual object in accordance with the reaction of sensors.

O and X indicating the occurrence of sensor detection were set for the case where one party detected the other party first because the detection sensor sizes of preys and predators were different. As for the behaviors of preys and predators, the following 3 behaviors are defined: 1) a case where both do not detect the other, 2) a case where a predator detects a prey because it has a larger detection sensor than a prey, 3) a case where a pry detects a predator after the predator pursues the prey. For the target object, a black porgy and a hammerhead were produced by 3Ds Max 8.0 and their behaviors were expressed by this animation. VR environment was implemented by Virtools 4.0.

Table 1. Events according to the sensor response

Condition		Predator	Prey	Object’s reaction		Object Behavior
Sensor Detection	1	X	X	Predator	Wander	Random Move(Wander)
				Prey	Wander	
	2	O	X	Predator	Pursuit	Variation of a predator ’ s orientation value (target : prey)
				Prey	Wander	
	3	O	O	Predator	Pursuit	Application of elasticity momentum through the calculation of the distance between a predator and a prey.
				Prey	Flee	Application of flee determination direction of a rey

Fig.6(a) shows the detection sensor of a black porgy. The detection sensor was made as a globe with consistent radius and was designed to be proportional to the size of objects. As mentioned earlier, the detection sensor for preys and predators were designed to be larger than the evasion sensors for obstacles. Fig.6(b) shows the behaviors that a prey determines the evasion direction after detecting a predator.

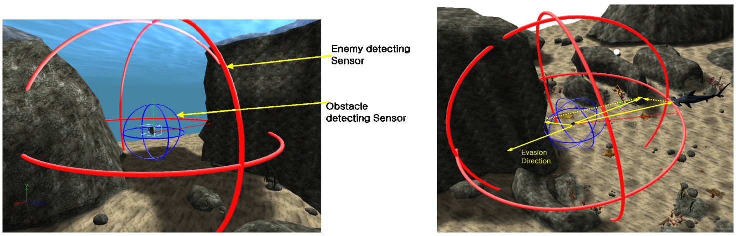

Fig. 6. (a)Variable multi-detection sensors, (b) Evasion behavior of a prey

Fig.7 shows the changes in velocity and direction of a fish applied with and without the existing elastic moment. The graph Fig.7(a) indicates the change of the velocity of a prey in respect of time t. A prey changes the direction or shifts to the evasion velocity at t_6. At this time, the animation is not naturally connected. In Fig.7(b), a prey detects a predator at $t_{4,5}$and then reduces its velocity due to the elastic force against the inertial force and approaches a predator closer by x than the existing fish. When x has the maximum value, the velocity becomes 0, the minimum value, and the opposite evasion direction is taken. At this time, the elastic force has maximum value.

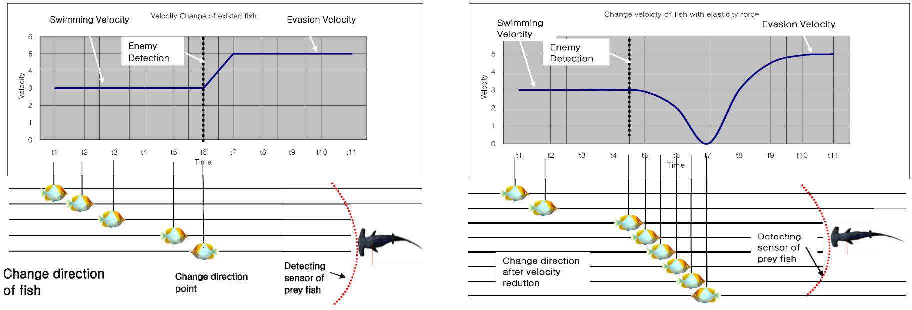

Fig. 7. (a)Velocity and directional change of a prey which is not applied with elastic momentum, (b) Velocity and directional change of a prey applied with elastic momentum

5 Conclusion

This study has suggested a method to generate a natural behaviors of artificial fishes in a 3D virtual space rendered on a real-time basis. These behaviors are different from each other because the response time by the environmental variables such as the size and weight of target objects are calculated on a real-time beyond the limitation of one-to-one correspondence rules. Furthermore the study designed the similar phenomena to a real world by applying variable multi-sensors. To do this, the study has suggested a method for evasion direction determination, calculation of approaching distance of preys and predators, and evasion velocity determination. The expression of realistic behaviors of digital creatures is controlled by precision motion control. This study has suggested a method to process behaviors followed in accordance with a formal framework calculated on a real-time basis. Thus, for the generation of less artificial fishes, the improved intelligence through objects' learning as well as the environmental variables such as the changes in water's viscosity due to velocity of fluid and temperature will be needed.

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