# Behavior Analysis Method for Fishes in a Water Tank Using Image Processing Technology

**Hwan-Seong Kim, Hak-Kyeong Kim, Nam Soo Jeong, and Sang-Bong Kim**

**Abstract:** This paper proposes a two dimensional behavior analysis method for fish in a water tank based on the ARX method and the Kalman filter algorithm using image processing technology. In modeling the behavior of fish, the input is denoted as the environmental change and uses M-sequence. The output is expressed by the partnership between fish. The behavior model of individual fish is identified by the ARX method. It is then estimated by the Kalman filter algorithm. Finally, the fish behavior is analyzed by FFT. To prove the effectiveness of the proposed algorithm, it is applied to two tilapias in a water tank with dimensions of 100cm × 100cm × 50cm. The effectiveness of the proposed method is demonstrated through ARX identification, estimation of Kalman filter, and FFT analysis.

**Keywords**: Fish behavior, Kalman filter, image processing, ARX(autoregressive exogenous), M-sequence.

## 1. INTRODUCTION

From the viewpoint of animal social behavior, the schooling behavior of fish is an interesting phenomenon[1-3]. In general, fish swim in a three-dimensional space. However traveling within two dimensions is more important than the motion in the direction of depth. So, for simplicity, the motion of fish is assumed to be restricted within a two-dimensional space.

Takagi et al.[4] suggested modeling the schooling of fish in a water tank using squares of various side lengths and/or circles of various diameters. Huth and Wissel[5] suggested a behavior model based on four types of patterns by interaction force that control self-motion depending on neighborhoods without environmental stimulus through experimental and simulation data. Niwa[6] proposed a self-organizing dynamic model of fish schooling based on a nonlinear equation using experimental data identifying individual fish as a gas molecule having locomotion, psychological response and motion fluctuation, using the Markov process model and H-theorem. Satou et al.[7] modeled fish behavior in a fish trap, taking into account the velocity of the fish trap and making use of experimental and simulation data of rainbow trout in a water tank. Sannomiya and Naito[8] suggested a fish schooling behavior model related to environmental force using a dynamical behavior model and the non-cooperative, non-zero-sum-game theory.

In the Sannomiya and Naito model, an interaction force in partnership is divided into 3 parts in order to keep a proper distance between neighboring individual fish. Since the interaction force in partnership depended on a number of parameters in the model, its calculation was very complicated.

Therefore, in this paper, assuming that the interaction force in partnership is inversely proportional to the distance between neighboring individual fish for simplification of the Sannomiya and Naito model[8], we proposed a behavior analysis method of fish using image processing technology within a two-dimensional space. That is, we consider that the depth direction of fish can be estimated by using the CCD camera under the assumption that the threshold value is proportional to the depth direction. We consider only environmental change taken by M-sequence signal as an input and the partnership of fish as an output in modeling fish behavior such as velocity and partnership, etc. The data of a fish behavior derived using the ARX method are estimated using the Kalman filter

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algorithm. We also analyze the fish behavior based on the FFT method using the partnership of fish in frequency domain. To prove the effectiveness of the proposed method, we apply our method to two tilapias. It is shown that the proposed method stably tracks the experimental data obtained from a CCD camera very well with a margin of error of approximately $\pm 0.77$g mm/sec$^2$ when M-sequence input as environmental change is stimulated in a fish tank. The fish data vary widely. Average partnership is larger at a static state than under environmental change. As a result of the FFT method, it is shown that the fish behavior is distinguished around 0.02 rad/sec in frequency domain when the fish is stimulated by inserting an object into the center of the water tank.

## 2. FISH BEHAVIOR MODEL

In order to obtain the modeling of the fish behavior, we use the ARX identification method that is employed in the field of automatic control. We use M-sequence, a white noise input sequence, as a control input for obtaining the action of the system. To realize the fish behavior identification, we assume that the output of the model is the partnership of fish and the input is environmental change. Since we cannot surmise how to change fish behavior, the motion or the velocity of a fish is not useful in a fish behavior model. A static state means a state with no change of temperature, sound or external motion. Environmental change state means a state with external force.

We now consider the stimulation of water surface as an external environmental change. When the environment is changed, the partnership of the fish will be changed. If the partnership of the fish is changed, it can be seen that the environment or swimming ability of individual fish is altered. This means that the fish behavior can be estimated by the partnership of fish.

### 2.1. Proposed mathematical model of fish behavior

Let $x_i$ and $v_i$ be the position and the velocity of individual fish $i(i=1, 2)$, respectively, where $x_i \in R^2$ and $v_i \in R^2$. The motions of two fish are described by the following[8]:

$$\dot{x}_i = v_i \tag{1}$$

$$m\dot{v}_i = F_i = F_{i1} + F_{i2} + F_{i3} + \zeta_i \tag{2}$$

where $m$ is the mass of individual $i$. $F_i$ is the force that causes the motion of individual $i$ and consists of four components-$F_{i1}$, $F_{i2}$, $F_{i3}$ and $\zeta_i$, which are given as the above (2). We call the first term $F_{i1}$ a propulsive force that expresses force related to swimming characteristics. An individual fish has the ability to determine a forward speed that it finds comfortable (called the characteristic velocity) in the absence of other forces that act on the motion of the fish. The second term $F_{i2}$ is described as a partnership interaction force. That is, $F_{i2}$ expresses the partnership of fish. An individual fish regulates the position and velocity of the partner by exchanging necessary information with the partner. It is the sum of schooling force that makes the individual uniform velocity and interaction force that keeps proper distance between two fish. The interaction force is assumed to be inversely proportional to the distance between neighboring individual fish for simplification of the Sannomiya and Naito model[8]. Thus, the partnership interaction force is proposed as follows:

$$F_{i2} = \alpha_1 v_1 + \alpha_2 v_2 + \alpha_3 \frac{1}{x_1 - x_2} \tag{3}$$

where $\alpha_1$, $\alpha_2$ and $\alpha_3$ are constants that depend on the size and sex of each fish. The third term $F_{i3}$ denotes interaction force with the environment. An individual fish encounters certain stimuli from the environment. For example, in our case, the wall of the water tank is considered to be a stimulus or environmental force. It includes the repulsive and attractive forces brought from the wall. In this paper, it is given by M-sequence with 1g mm/sec$^2$. The last term $\zeta_i$ is a disturbance force that denotes the other to cause motion. We assume that $F_{i1}$ and $\zeta_i$ are zero.

### 2.2. Identification of fish behavior model

The resulting behavior of fish after a change to the environment indicates that the motion of fish is dependent on the psychological state of individual fish. We cannot predict the action of fish. In some cases, when the object is inserted into the tank, fish will cease all motion and focus on that object. At other times, fish will entirely ignore the object with no change in their own motion. Thus, in this section, we can express a variation of fish motion as a change to the environment If the sampling time is sufficiently short, we can assume that the environment is changed by step state. By using the ARX identification method, we can obtain the following fish behavior model with one input $u$ denoted as the environmental change and one output $y$ expressed by the partnership between fish.

$$A(q)y(k) = q^{-n_k}\ B(q)\, u(k) \tag{4}$$

where

$$A(q) = 1 + a_1 q^{-1} + \cdots + a_{n_a} q^{-n_a} \tag{5}$$

$$B(q) = b_1 q^{-1} + \cdots + b_{n_b} q^{-n_b} \tag{6}$$

where $n_a$ and $n_b$ are the orders of the ARX model, $n_k$ is time delay, $a_i$ and $b_i$ are coefficients and $q$ is the shift operator.

Using the result obtained by the ARX model, the model is now expressed as the discrete equations as follows:

$$x(k+1) = Ax(k) + Bu(k) \quad (7)$$

$$y(k) = Cx(k) \quad (8)$$

where $A \in R^{n\times n}$, $B \in R^{n\times p}$ and $C \in R^{m\times n}$ are the system matrix, the input-driving matrix and the output-driving matrix, respectively. $x \in R^n$, $y \in R^m$ and $u \in R^p$ are the state variable vector, the output vector and the input vector. $n$ is the order of state variable.

2.3. Estimation of fish behavior

In this section, we will demonstrate a method for estimating fish behavior by using identified behavior model Eqs. 7 and 8. Since the model obtained includes noise, the model equations are redefined as the following continuous equations:

$$\dot{x}(t) = Ax(t) + Bu(t) + \omega(t) \quad (9)$$

$$y(t) = Cx(t) + v(t) \quad (10)$$

where $\omega(t) \in R^n$ and $v(t) \in R^m$ are disturbance and sensor noise given as white noise with the following expectations:

$$E\{\omega(t)\} = 0, \; E\{v(t)\} = 0. \quad (11)$$

A Kalman filter algorithm may now be introduced as follows:

$$\dot{\hat{x}}(t) = A\hat{x}(t) + Bu(t) + F(y(t) - C\hat{x}(t)) \quad (12)$$

where $\hat{x}$ is an estimated variable of a state variable $x$ and Kalman filter gain $F(t)$ is given as

$$F(t) = P(t)C^T R^{-1} \quad (13)$$

where $P(t)$ is a solution of the following Riccati equation:

$$\dot{P}(t) = AP(t) + P(t)A^T - P(t)C^T R^{-1} CP(t) + Q \quad (14)$$

where $R$ and $Q$ are covariances of sensor noise $v(t)$ and disturbance $\omega(t)$, respectively. The Suberscript $T$ represents the transpose matrix.

To design the Kalman estimator, we consider the partnership as an output of the model. When the environment is changed, the behavior of fish is influenced. At the same time, the partnership of fish will be changed. Thus, using the obtained partnership of fish, we can estimate fish behavior during environmental change.

## 3. EXPERIMENTAL METHOD AND APPARATUS

3.1. Experimental apparatus

Fig. 1 shows the experimental apparatus used for this paper. The apparatus consists of a water tank, a CCD camera and a data analysis system using an image processing method. The dimensions of the water tank are 100cm × 100cm × 50cm. The CCD camera is installed over the center of the water tank at an angle of 90° to accurately capture the motion of fish. The water depth is 20 cm. The fish used in the experiment are two tilapias; the first weighting 480g with a length of 21cm, and the second weighting 520g with a length of 25cm. The temperature of the water is 22℃.

3.2. Experimental method

Two experiments are conducted to analyze fish behavior. The first allows no stimuli, while the second introduces a change to the environment. As shown in Fig. 2(a), a stimulus or environmental change denoted as $F_{i3}$ is an M-sequence data, a type of white noise signal that can be produced by inserting an object into the center of the water tank. By using an image processing technique, data representing the position of the fish is obtained. Using this data, the absolute velocity of the fish is obtained; after that, the partnership between the two fish is also obtained. Fig. 2 is a block diagram of the system. Input is represented by $F_{i3}$, stimulus or environmental change, and output is represented by $F_{i2}$ partnership obtained using (3). Finally, the FFT data of velocities and partnerships of the two fish are obtained.

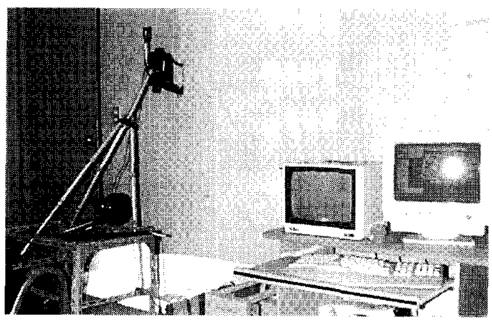

Fig. 1. Experimental apparatus.

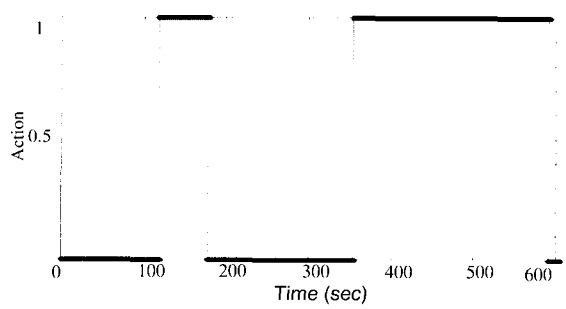


Fig. 2(a). M-sequence input data.

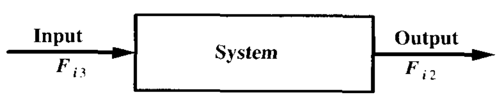


Fig. 2(b). The block diagram of system.

## 4. RESULTS AND DISCUSSION

### 4.1. Position, absolute velocity and partnership for two fish

Figs. 3-5 show movement, absolute velocity and partnership of two fish at the time a change to their environment is forced on the fish. Figs. 6-8 show movement, absolute velocity and partnership of two fish during a static state where no change to their environment occurs. In Figs. 3 and 6, two fish swim toward the walls as their environment is changed by the insertion of an object into the center of the water tank, whereas they swim freely during the static state. In Figs. 4 and 7, it may be seen that two fish swim at a greater distance from each other after their environment has been changed by the insertion of the object into the center of the water tank. During the static state, the distance is much less. In addition, the velocity of fish varies from 1mm/sec to 51mm/sec between the two states. In Figs. 5 and 8, partnerships with above 2g mm/sec$^2$ at the static state appear more often than at the environmental change produced by the insertion of an object into the center of the water tank. This demonstrates that partnership at the static state is stronger than at the environmental change state. Taship and velocities of two fish are larger at a static bles 1 and 2 show the statistical data of the fish at a static state and at an environmental change state, obtained from Figs. 3-8, respectively. The data vary widely. Of special interest, the averages of partnerstate than at an environmental change state, whereas maximum partnership and the standard errors of velocities of two fish are greater at an environmental change state than at a static state. This shows that instantaneous partnership is greater at an environmental change state than at a static state. Therefore, by comparing the result at a static state to the result at an environmental change state, we can say with certainly that two fish are moved by an extraneous force, in this case, a change to the environment.

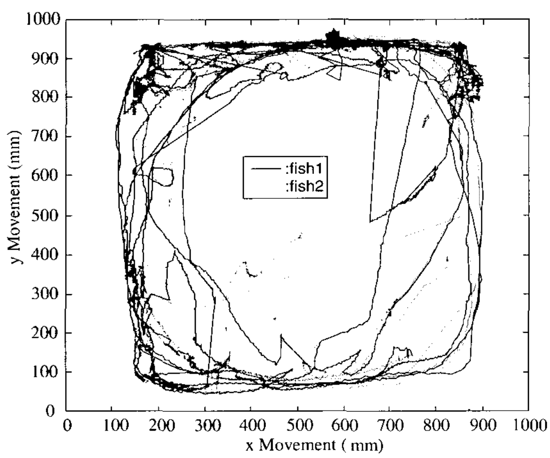


Fig. 3. The movement of two fish on x-y axis at an environmental change state.

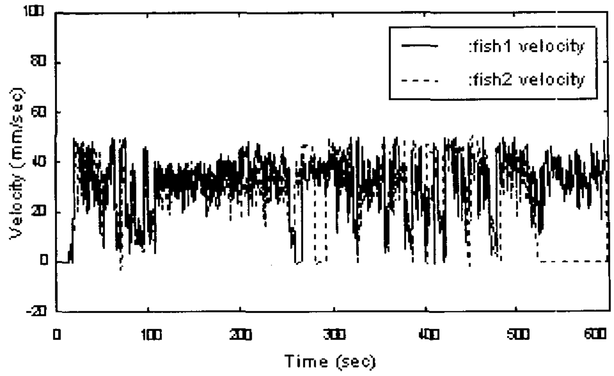


Fig. 4. The absolute velocities of two fish at an environmental change state.

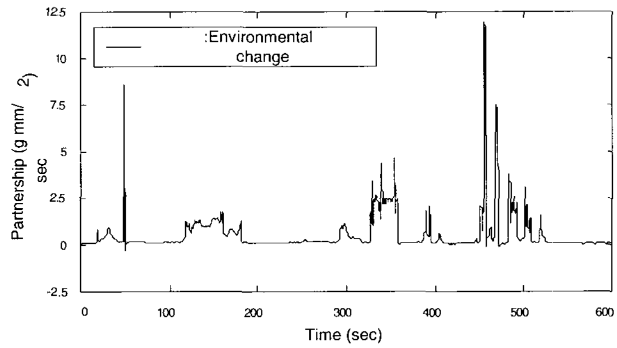


Fig. 5. Partnership of two fish at an environmental change state.

Table 1. Fish statistical data at an environmental change state.

| Environ-mental change | Average | Maxi-mum | Mini-mum | Stan-dard error |
|---|---|---|---|---|
| $v_1$ (mm/sec) | 31.17 | 50.41 | -0.37 | 11.25 |
| $v_2$ (mm/sec) | 21.97 | 50.41 | -2.16 | 13.51 |
| Partnership (g mm/sec$^2$) | 0.92 | 11.94 | -0.26 | 1.42 |

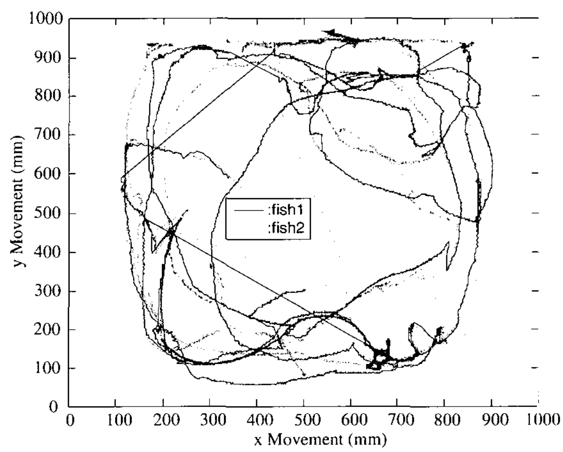


Fig. 6. The movement of two fish on x-y axis at a static state.

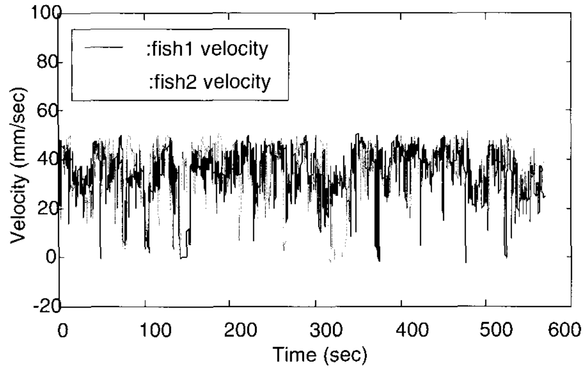


Fig. 7. The absolute velocities of two fish at a static state.

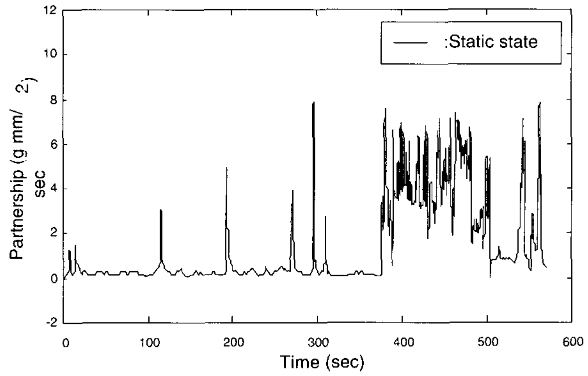


Fig. 8. Partnership of two fish at a static state.

Table 2. Fish statistical data at a static state.

| Environmental change | Average | Maximum | Minimum | Standard error |
|---|---|---|---|---|
| $v_1$ (mm/sec) | 34.14 | 51.01 | -2.11 | 10.60 |
| $v_2$ (mm/sec) | 34.60 | 51.01 | -2.00 | 11.60 |
| Partnership (g mm/sec$^2$) | 1.33 | 7.90 | 0 | 1.85 |

4.2. Identification of fish behavior model

The result of using the ARX identification method on the sampled data between 100 sec and 200 sec in Fig. 5 is that $n_a$ equals 21 and $n_b$ equals 8. In Fig. 9, $n_k$ may be taken as 3 since coefficients of autocorrelation of output $y$ have little change until delay time is 3. Fig. 10 shows the distribution of poles and zeros in the identified system. All poles and all zeros exist in the circle of radius with the size of one. The eigen values and zeros of the identified system are shown in Table 3 and Table 4, respectively. $n$, $m$ and $p$ are 21, 1 and 1, respectively. Fig. 11 shows identified partnership obtained by model Eqs. (4)-(8) and real partnership of fish calculated by Eq. (3) using experimental data such as position data and velocity data (Figs. 3 and 4) obtained by M-sequence input as environmental change. Sampling time is 0.05sec and model parameters are as shown in Table 5.

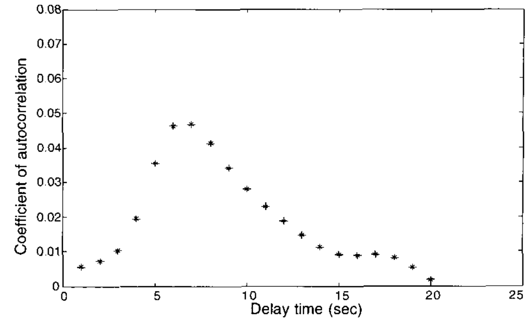


Fig. 9. The autocorrelation of output ($y$).

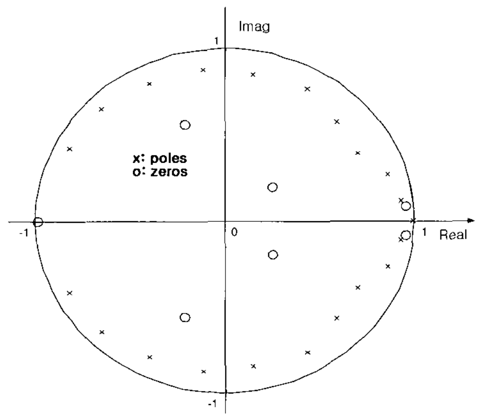


Fig. 10. Distribution of poles and zeros in identified system.

Table 3. Eigenvalues of identified system.

| Eigenvalues |
|---|
| -0.8169±0.4196i, -0.6503±0.6504i, -0.3969±0.7973i, -0.1115±0.8770i, 0.1516±0.8474i, 0.4348±0.7670i, 0.5910±0.5740i, 0.7024±0.3928i, 0.8572±0.2672i, 0.9315±0.1134i, 0.9945 |

Table 4. Zeros of identified system.

| Zeros |
|---|
| -0.9873, -0.2119±0.5615i, 0.2517±0.1971i, 0.9515±0.0831i |

Table 5. Model parameters.

| Parameters | $\alpha_1$(g/sec) | $\alpha_2$(g/sec) | $\alpha_3$ (g mm$^2$/sec$^2$) |
|---|---|---|---|
| Value | 0.001 | 0.001 | 18 |

Table 6. Statistical data of partnership (g mm/sec$^2$) at a static state.

| Parameter | Experimental data | Observed data | Error |
|---|---|---|---|
| Maximum | 7.90 | 7.92 | 0.47 |
| Minimum | 0 | 0 | -0.59 |
| Average | 1.33 | 1.33 | 0 |
| Standard Error | 1.85 | 1.85 | |

Table 7. Statistical data of partnership (g mm/sec$^2$) at an environmental change state.

| Parameter | Experimental data | Observed data | Error |
|---|---|---|---|
| Maximum | 11.94 | 11.94 | 0.77 |
| Minimum | -0.26 | -0.26 | -0.68 |
| Average | 0.59 | 0.59 | 0 |
| Standard Error | 1.18 | 1.18 | |

4.3. Estimation of fish behavior

Fig. 12 shows that the observed data estimated by the Kalman filter algorithm of (9)-(14) track the experimental data obtained by M-sequence input as environmental change very well. The error between the experimental data and the observed data is shown in Fig. 13. Statistical data of the partnership are shown in Table 6 and Table 7. Though the experimental data vary widely, it is shown that the data observed using the method we proposed track the experimental data with a margin of error of approximately $\pm 0.77$ g mm/sec$^2$. The average partnership is smaller but the variation range between maximum value and minimum value is greater during a state of environmental change than at a static state. This shows that the variation of the velocities and the distance between two fish are greater during an environmental change state than at a static state. We may therefore see that this model is very effective in analyzing partnerships of fish during an environmental change.

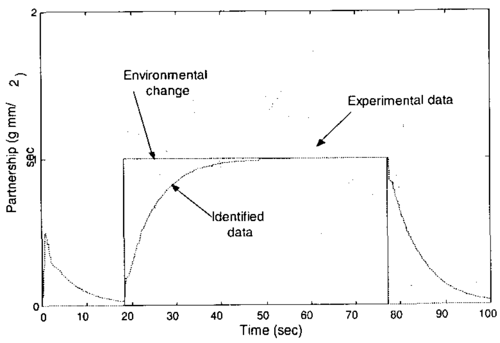


Fig. 11. Partnership model of fish at an environmental change state.

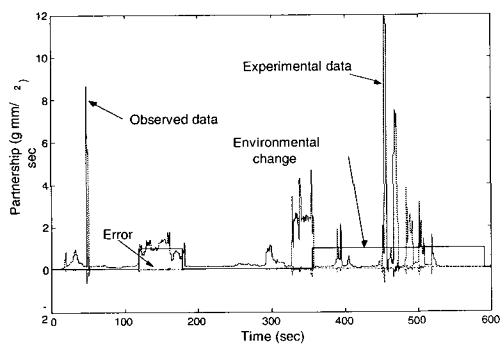


Fig. 12. Experimental, observed, input and error data of the partnership of fish.

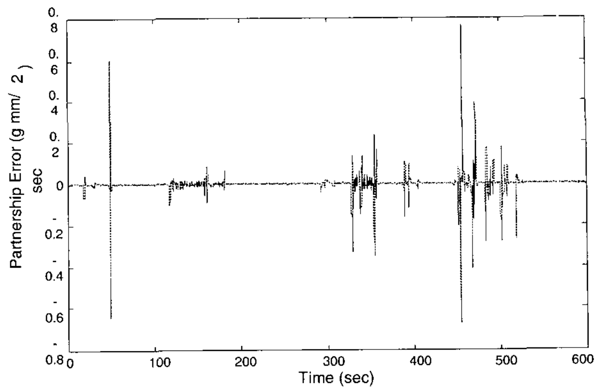


Fig. 13. Error between experimental and observed data of the partnership of fish.

4.4 Behavior analysis by FFT method.

In this section, we analyze the fish behavior using the FFT(Fast Fourier Transformation) method. By comparing the magnitude of each data, we see that the environment or psychological state of fish is changed. The FFT results of fish behavior are shown in Figs. 14 - 17. From the figures, at a static state, we also see that velocity and partnership have the highest value in frequency domain around 0.02rad/sec and 0.015rad/sec, respectively. When the environment is changed, we see that both velocity and partnership have the highest value in frequency domain around 0.02rad/sec, although we cannot identify the type of force that acted on the environment.

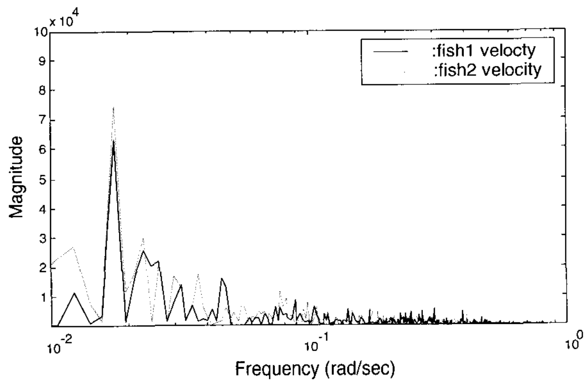


Fig. 14. FFT analysis the absolute velocity of fish at a static state.

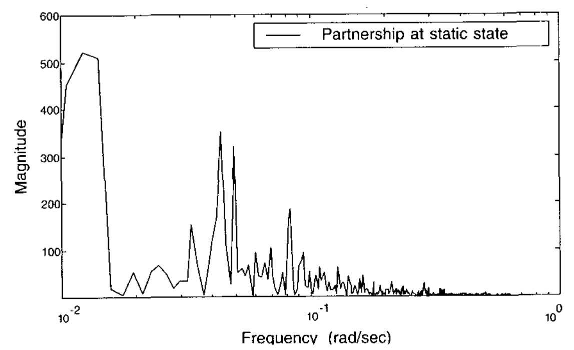


Fig. 15. FFT analysis the partnership of fish at a static state.

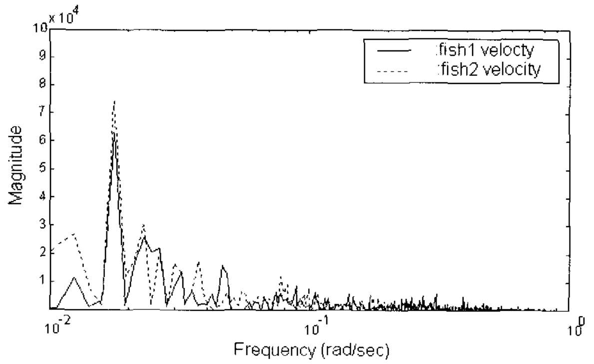

Fig. 16. FFT analysis the absolute velocity of fish at an environmental change state.

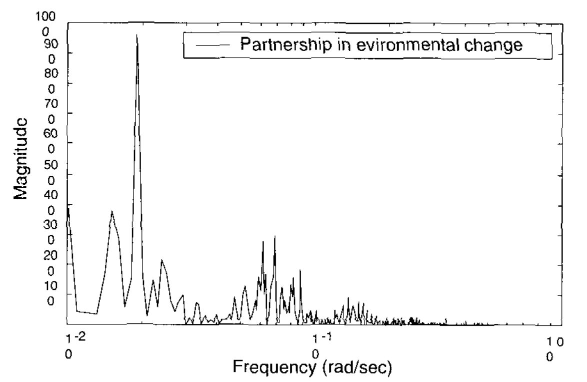

Fig. 17. FFT analysis the partnership of fish at an environmental change state.

## 5. CONCLUSIONS

In this paper, we proposed a two-dimensional behavior analysis method for fish using image processing technology. By considering the relationship between partnership of fish and environmental change, a fish behavior model was derived using the ARX method and estimated using the Kalman filter algo rithm. This method effectively analyzes fish behavior because the data observed estimated using the Kalman filter algorithm stably track the experimental data obtained from M-sequence input as environmental change with a margin of error of $\pm 0.77$ g mm/sec$^2$. As a result of FFT of velocities and partnerships, we verified that the fish behavior is distinguished around 0.02 rad/sec in frequency domain when the fish is stimulated by inserting an object into the center of the water tank.

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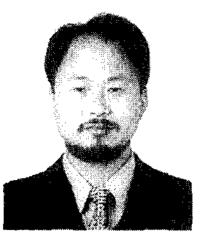

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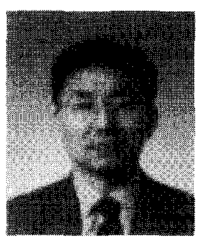

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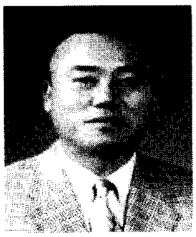

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