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Developing a Simulator of the Capture Process in Towed Fishing Gears by Chaotic Fish Behavior Model and Parallel Computing

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A fishing simulator for towed fishing gear was investigated in order to mimic the fish behavior in capture process and investigate fishing selectivity. A fish behavior model using a psycho-hydraulic wheel activated by stimuli is established to introduce Lorenz chaos equations and a neural network system and to generate the components of realistic fish capture processes. The fish positions within the specified gear geometry are calculated from normalized intensities of the stimuli of the fishing gear components or neighboring fish and then these are related to the sensitivities and the abilities of the fish. This study is applied to four different towed gears i.e. a bottom trawl, a midwater trawl, a two-boat seine, and an anchovy boat seine and for 17 fish species as mainly caught. The Alpha cluster computer system and Fortran MPI (Message-Passing Interface) parallel programming were used for rapid calculation and mass data processing in this chaotic behavior model. The results of the simulation can be represented as animation of fish movements in relation to fishing gear using Open-GL and C graphic programming and catch data as well as selectivity analysis. The results of this simulator mimicked closely the field studies of the same gears and can therefore be used in further study of fishing gear design, predicting selectivity and indoor training systems.

Key words: Towed fishing gear, Capture process, Fish behavior model, Simulator

Introduction

There is an international need to be sure that commercial capture is highly selective and responsible in order to maximize utilization of the stock (Charles, 2001). This means precisely catching those fish that may be marketed as food while avoiding danger to those that form the future stock or food for those stocks. Reasonable and high efficiency of fishing operation were highly recommended by means of fishing gear design and automatic operation as well as geometry of the gear and reaction of fish for the above-mentioned purpose. The non-linear simulation method in the form of chaos theory maybe used for the reduction of the difference between the simulation result and the complex field observations and related theory and for mimicking and prediction of fish capture and selectivity control.

Modeling of fish behavior in a towed fishing gear based on chaos decision-making was developed to mimic the fish response and capture process (Kim and Wardle, 2003) as firstly applied in the North Sea 4 panel bottom trawl using haddock as an example. In this study, that model and it's simulation techniques are extended and established to form a simulator using a high performance cluster computer system and parallel programming. The purposes of the present study are to test a sensitivity of the model by chaotic fish behavior and to develop a simulator in comparison with the field fishing operation. It included development of an underwater animation display and was applied to simulate 4 kinds of towed gear for 17 fish species. The results of the simulation fitted very well to the field observation and catch suggesting it could be used for selectivity and management of fisheries g(Lane and Stephenson, 1998) and reduce the number of field experiments and the trial and error involved in dangerous and non-economic methods.

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Meterials and Methods

A simulator for towed fisheries was developed and established using a cluster computing system, capable of modeling the chaotic fish behavior (Kim, 1996) and create the underwater visualization of fish movements and 3-D gear geometry as outlined and shown in Fig. 1. The selected towed fishing gears were the North Sea 4-panel bottom trawl for haddock, midwater trawl in the North Pacific Ocean for walleye pollock, two boat bottom seine in the East China Sea for yellow croaker and two boat surface seine for anchovy. The main sub-models of the grand model of the simulator for the capture process were those generating sea bed and sand cloud, generating random fish, fishing gear geometry, stimuli of the gear, chaotic response model, capture process model etc.

The cluster computing system

To develop a simulator using chaotic behavior model for capture process in a towed fishing gear, it is important to have an economical system that can process enormous amounts of data with high speed and parallel computation. A Linux cluster system (Buyya, 1999; Sterling et al., 1999) has been built on Compaq Alpha processors connected through Ethernet and an environment for programming in MPI (Message Passing Interface) (Snir et al., 1996) and for managing the whole system.

Each node in the cluster system is equipped with UP1000 mother-board specifically designed for an Alpha-21264 processor shown high performance in floating-point computation and a low ratio of cost-performance. The communication system for connecting these nodes is based on 100 Mbps Fast Ethernet which was originally developed for LAN. The communication system using a 24-port Intel Express switching hub connected to each node through an Ethernet Network Interface Card (NIC) in order to utilize the bandwidth without bottleneck.

The system consists of sixteen computing nodes and a communication system that consists of a switching hub, NICs in each node, and a set of private IP addresses. The cluster system has a specific node as the bridge node to have two NICs: one is to provide a internal interface to the private network, and the other is to provide a public interface to the Internet through one public IP address. An operating system for cluster systems is Linux, Red Hat V6.2 because Linux is freely available and possible to achieve high performance with low-cost.

The computer system has been established as an unique environment for programming the simulator for the capture process in a towed fishing gear in Fortran and MPI, and for managing the whole system and jobs in the cluster system. Regarding the expenses and compatibility for the cluster system, installed MPI libraries are MPICH V.1.2.3 (Gropp and Lusk, 1996) which is strong in the aspects of portability and high performance with MPI F90 Compaq Fortran compiler. The computing time of the simulator was linearly proportional to the number of the communication patterns in each process. This implies that the

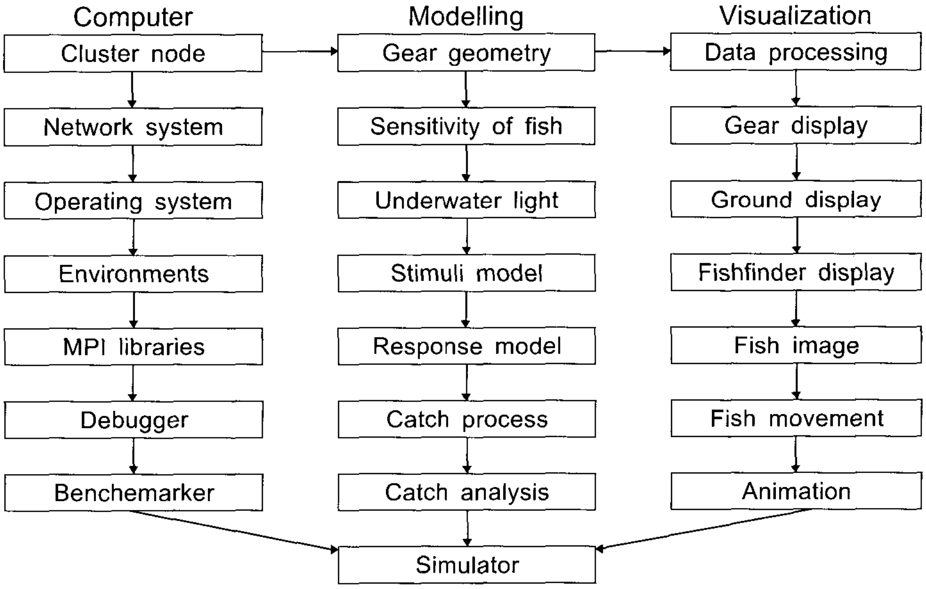

Fig. 1. Block diagram of simulator for capture process of towed fishing gears.

simulator will show the performance as high as the number of computation nodes whose loads are balanced automatically.

Generating random fish

The selected fish species are squid (*Todarodes pacificus*), hairtail (*Trichiurus lepturus*), Reduling searobin (*Lepidotrigla microptera*), Spanish mackerel (*Scomberomorus niphonius*) yellow croaker (*Pseudosciaena polyactis*), filefish (*Navodon modestus*), brown croaker (*Miichthys miiuy*), Belanger's croaker (*Johnius grypotus*), roundnose flounder (*Eopsetta grigorjewi*), anchovy (*Engraulis japonca*), and walleye pollock (*Theragra chalcogramma*). The body length (B_L) and weight (W_F) were reformulated as power equation or exponential equation with year from the data (Coull et al., 1989; Jin and Tang, 1996; NFRDI, 1998).

The size of fish can be generated by random distribution, normal distribution or Gamma distribution etc. (Press et al., 1996) as mean and deviation for the specific frequency of fish school. Once fish size as body length is decided, sensitivity of vision (Kim, 1998) and swimming ability (Kim and Wardle, 1997) could be decided. The sensitivity of vision in each fish species was represented by a contrast threshold (C_T) with a intercept (C_0) and a minimum resolvable angle (A_M) with an intercept (A_0) in relation to body length (B_L) and background luminance (L_b) as follows:

$$C_T = C_0 \exp(-H_b L_b - H_L B_L) \tag{1}$$

$$A_M = A_0 \exp(-K_b L_b - K_L B_L) \tag{2}$$

Two coefficient (H_b, K_b) and intercepts (C_0, A_0) in the equations (1, 2) for several species in addition to fishes reported by Kim (1998) were estimated by visual index V_I (Schellart and Prins, 1993) and ecological and physiological similarity as shown in the following equations and Table 1. The other coefficients (H_L, K_L) are set as constant value 1.5.

$$C_0 = 17.32 \exp(-0.544\, B_I) \tag{3}$$

$$A_0 = 22.98 \exp(-0.389\, V_I) \tag{4}$$

The swimming energy (Q_0) and maximum burst swimming speed (V_B) as fish swimming performance were represented as body length (B_L) and water temperature (T_W) as follows:

Table 1. The relevant coefficients for visual sensitivity of 11 species of fish

Species	V_I	C_0	A_0	H_b	K_b
Squid (*Todarodes pacificus*)	2.9	3.6	7.4	0.65	0.50
Hairtail (*Trichiurus lepturus*)	2.8	3.8	8.0	0.65	0.50
Reduling searobin (*Lepidotrigla microptera*)	2.0	5.8	10.6	0.60	0.45
Spanish mackerel (*Scomberomorus niphonius*)	3.0	3.0	6.0	0.65	0.50
Yellow croaker (*Pseudosciaena polyactis*)	1.9	6.2	11.0	0.60	0.45
Filefish (*Navodon modestus*)	1.8	6.5	11.4	0.60	0.45
Roundnose flounder (*Eopsetta grigorjewi*)	1.1	9.5	15.0	0.45	0.40
Walleye pollock (*Theragra chalcogramma*)	2.4	4.7	9.0	0.60	0.45
Brown croaker (*Miichthys miiuy*)	2.2	5.2	9.8	0.60	0.45
Belanger's croaker (*Johnius grypotus*)	2.1	5.5	10.2	0.60	0.45
Anchovy (*Engraulis japonca*)	2.3	5.0	9.4	0.60	0.45

Table 2. Relevant coefficients in equations (5, 6) for swimming ability of 9 species fish

Species	E_0	E_1	n	H_0	H_1	m
Squid (*Todarodes pacificus*)	80	50	0.90	1.0	0.20	0.50
Hairtail (*Trichiurus lepturus*)	110	60	0.80	1.3	0.20	0.45
Reduling searobin (*Lepidotrigla microptera*)	100	50	0.85	1.6	0.26	0.45
Spanish mackerel (*Scomberomorus niphonius*)	162	81	0.80	2.1	0.40	0.30
Yellow croaker (*Pseudosciaena polyactis*)	110	55	0.85	1.7	0.26	0.45
Filefish (*Navodon modestus*)	90	50	0.85	1.5	0.26	0.40
Roundnose flounder (*Eopsetta grigorjewi*)	123	62	0.99	1.5	0.23	0.40
Walleye pollock (*Theragra chalcogramma*)	145	73	0.80	1.9	0.26	0.30
Brown croaker (*Miichthys miiuy*)	145	73	0.80	1.9	0.26	0.40
Belanger's croaker (*Johnius grypotus*)	140	70	0.80	1.8	0.25	0.40
Anchovy (*Engraulis japonca*)	5	11	0.80	3.1	0.28	0.86

$$Q_0=(E_0+E_1\,TW)\,B_L^{\,n} \tag{5}$$

$$V_B=(H_0+H_1\,TW)\,B_L^{\,m} \tag{6}$$

The coefficient (E_0, E_1, H_0, H_1) and power (n, m) in the equations (5,6) for several species in addition to the species by Kim and Wardle (1997) was estimated considering ecological and physiological similarity as shown in Table 2.

Stimuli of the gear

The specification and geometry of the four selected towed gears (Ferro, 1989) when towed underwater were abstracted in Table 3. The main visual stimuli of the towed fishing gear components or the sand cloud can be represented as contrast and visibility as shown by Kim and Wardle (1998) and the other stimulus of water flow as shown by Kim (1997).

Chaotic response of fish behavior model

The fish behavior model (Kim, 1996) involved chaos activated by the so-called psycho-hydraulic wheel in order to generate realistic responses to fishing gear stimuli. The characteristics of these responses were investigated by experimental substitution of the coefficients in relevant equations. For example in the parameter $m=\alpha+\beta m_1$ in the equation of chaotic behavior, let α vary from 8 to 10 and β vary from 2 to 4 when m_1 is a coefficients relating stimuli. The possible angular range (A_R, rad) of response movement in a fish behavior can be represented as $A_R=\pi\exp(-CS)$ when angular coefficient C varied from 0.2 to 3 when stimulus was S. The limit of individual distance (D, m) between fishes can be represented with body length (B_L, m) and direction of neighboring fish (A_N, rad) as $D=P\ B_L \cos(A_N)$ when coefficient P varied from 0.7 to 1.0.

The number of knots of the netting K_N needed to stimulate a fish for minimum response was varied from 2 to 4 knots in a horizontal plane. The angular coefficient C was the main factor affecting the catch ratio to total number of encountered fish and the next was the stimulus coefficient β while interval coefficient P and number of knots K_N were less effective from the results of 23 simulations using the 4 panel North Sea bottom trawl towing for 3 min and encountering 200 haddocks. The overall range of the catch ratio was from 20% to 95% for all variations of the coefficients and from 60% to 95% when only the angular coefficient C was changed. Therefore if the above coefficients can be decided by the response behavior of fish in relation to fishing gear, catch ratio of the fish can be predicted by fishing simulation using the chaotic behavior model by Kim (1996).

Results and Discussion

Simulation of the capture process

The catch ratios from simulations for the four towed gears in accordance with angular coefficient C of the chaotic behavior model are shown in Fig. 2. The catch ratio by simulation in the North Sea 4 panel bottom trawl for haddock was varied from 7% to 100% when C=0.7-2.0, the midwater trawl in the North Pacific Ocean for walleye pollock was 48-90% when C=0.2-2.4, the bottom two boat seine in the East China Sea for yellow croaker was 20-90% when C=0.3-1.5 and the surface two boat seine for anchovy was 80-90% when C=0.1-1.5. The catch ratio in the

Table 3. Major specifications and shape of the four fishing gears towed underwater

Items	North Sea bottom trawl	Midwater trawl	Two boat seine	Anchovy boat seine
Engine power (HP)	600	3,800	1,500×2	180×2
Length of head rope (m)	28	226	114	1,144
Length of ground rope (m)	21	224	126	1,156
Length of hand rope (m)	55	100	38	80
Twine diameter (mm)	3.4, 2.8, 2.1	9.0, 7.7, 3.9, 3.3	3.7, 3.3, 2.7, 2.2	4.9, 3.6, 0.5
Mesh size (m)	0.14, 0.11, 0.09	8, 4, 2, 1, 0.6, 0.4	0.15, 0.09, 0.07	3.6, 1.5, 0.72
Color of nets	Yellow, Green	White	Black, Green	Red, White
Towing speed (ms-1)	1.5	1.0	1.3	0.5
O.B spread (m)	3.0	210	90	200
Net height (m)	5	81	13	33
Net spread (m)	25	142	80	196
Net length (m)	34	240	79	793
Number of net nodes	2,531	1,761	1,825	2,330

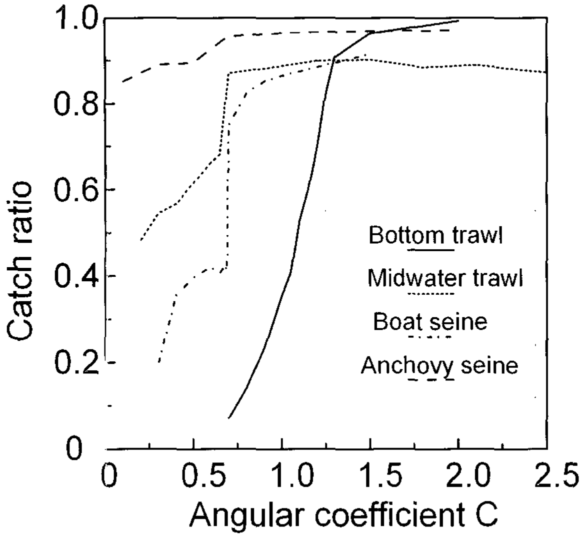

Fig. 2. The variation of catch ratio from the results of simulations for the four towed gears in accordance with the angular coefficient C of the chaotic behavior model.

North Sea bottom trawl was lineally increased with angular coefficient while the catch ratios of the other towed gears were varied irregularly (Suuronen et al., 1997; Hjellvik et al., 2002).

The frequency distribution of the body length of 2,000 walleye pollock (Erickson et al., 1996) encountered during the first 100 s in the North Pacific Ocean midwater trawl is shown in Fig. 3, 48.2% were caught and 51.8% escaped when angular coefficient C=0.2. The frequency ratio in relation to position of escape along the length of the fishing gear is shown in Fig. 4 showing the maximum escapes at the end of the belly, i.e. the front part of the codend.

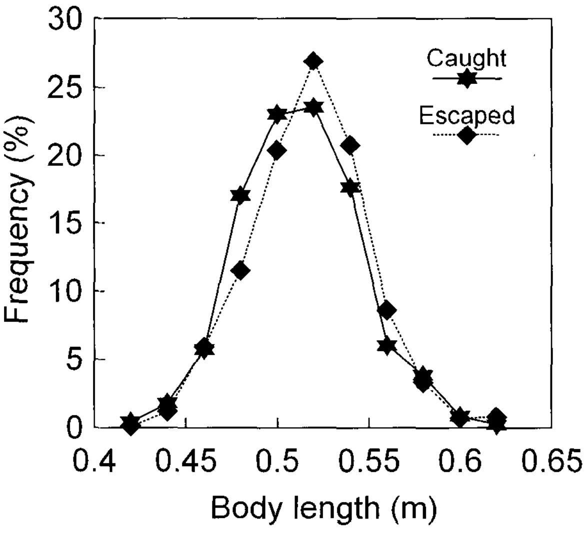

Fig. 3. The frequency of the body length of walleye pollock when caught and escaped.

The distribution of catch ratio from the data of field studies of the commercial fisheries for the four selected towed fishing gears is shown in Fig. 5. The North Sea bottom trawl for haddock shows a mean and standard deviation of 1,130±530 kg per day for 15 days, the midwater trawl in the North Pacific Ocean for walleye pollock shows 8,400±5,100 kg per hour for 521 hauls, the two boat seine in the East China Sea shows 2,890±1,670 kg per day for 481 days and the two boat seine for anchovy shows 4,794±4,347 kg per day for 147 days.

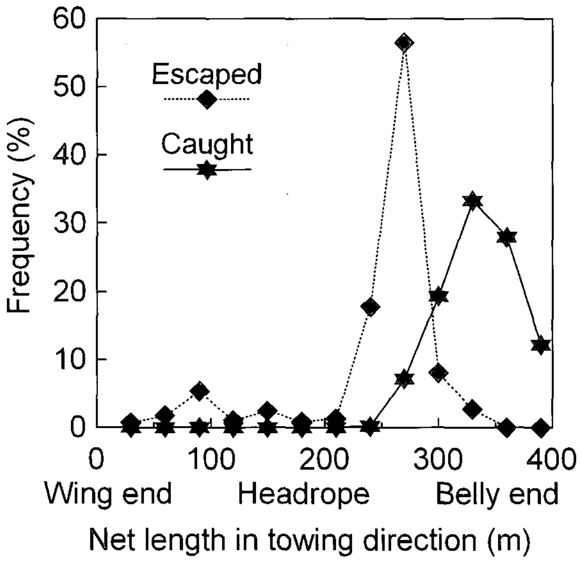

Fig. 4. The frequency of capture and escape of walleye pollock related to position along the net.

The catch (W_T) as weight in a haul is an integration of each fish weight (W_F) for number (N_C) of caught fishes. Then the number of caught fish which is mainly related to the angular coefficient C in this chaotic behavior model can be derived from the catch ratio (R_C) to total number of encountered fish (N_F) as follows:

$$N_C=N_F\times R_C, \quad W_T=W_F\times N_C \qquad (7)$$

Therefore if optimum angular coefficient C and total encountered number (N_F) are selected properly from Fig. 2, a more realistic simulation could be obtained by using this behavior model when compared with the field studies of fishing operation shown in Fig. 5. For example the catch ratio in the simulated

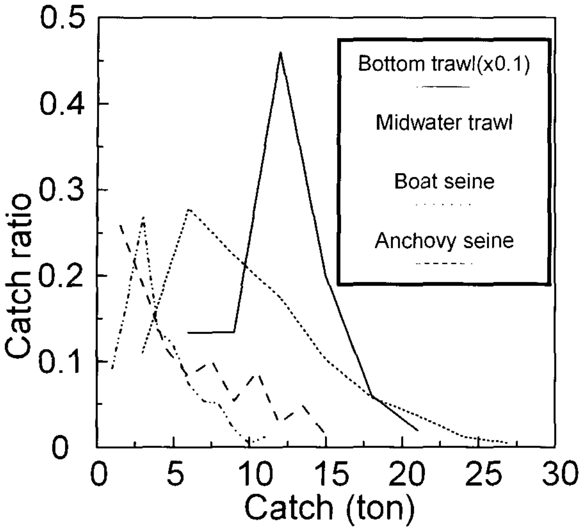

Fig. 5. The distribution of catch ratio from field studies of commercial fisheries for the four selected towed fishing gears.

walleye pollock midwater trawl during 5 min towing was 80% when the total encountered number of fish was 2,000 for the first 50 s with an angular coefficient C=0.7 as shown in Fig. 2. Therefore the catch number for one hour towing can be calculated as 2,000 fish ×0.8×60/5 min=19,200 fish. Then catch weight could be 19,200 fish×300 g (mean body weight)≅5.76 ton which is similar to maximum frequency of 6 ton as shown in Fig. 5. Accordingly, these results derived from this chaotic behavior model do appear to closely mimic the real capture process (Johannes et al., 2000; Gudmundsdottir and Vilhjalmsson, 2002) if the optimum angular coefficient was selected for realistic fishery management (Schnute and Richards, 2001).

Animation of the capture process

Visualization as virtual reality of the underwater scenes was derived from the 3-D geometry of the fishing gear, the fishing vessel cruising and fish finding, and the simulated 3-D movements of fish in real time animation.

The data for fishing gear geometry can be calculated from Alpha cluster system as length values of 3-D coordinates in relation to net nodes including net opening and tension information by porting to Linux Fortran for Alpha cluster system modified from Ferro (1989). Underwater 3-D image of the fishing gear can be visualized by firstly making still images using C language graphic programming connecting them into Open-GL programming as represented an example of still image in the web-site (mirbada.gsnu.ac.kr).

The fishing vessel cruising can be simulated by the bridge monitor as ship handling by engine control and steering wheel control based on the data of wind, wave, water temperature, salinity etc. The fish finding by color fish finder (Simrad ES60) can be changed depth, gain, shift speed by the data of fish distribution based on fish migration (NFRDI, 1998). An example of still image as an integration of fishing vessel cruising and fish finding which could run real time was shown in Fig. 6.

The data for fish movements from the simulation using the chaotic behavior model (Kim, 1996) by Alpha cluster system were also represented as length values of 3-D coordinates for fish position in relation to time including heading of fish. The above massive data were buffered in the RAM of the computer system. Animation of fish movements was achieved by Open-GL and C-language programming as controlled time steps, frame by frame, after inputting fish images from still photos. An example of the resultant animation of the two boats seine for yellow croaker in the East China Sea is represented as 3-D geometry in Fig. 7.

Accordingly, fishing simulation in a selected fishing ground can be achieved as 3-D geometry of the fishing gear, the fishing vessel cruising and fish finding, and the simulated 3-D movements of fish in real time animation by relevant selection and operation of four kind of fishing gear.

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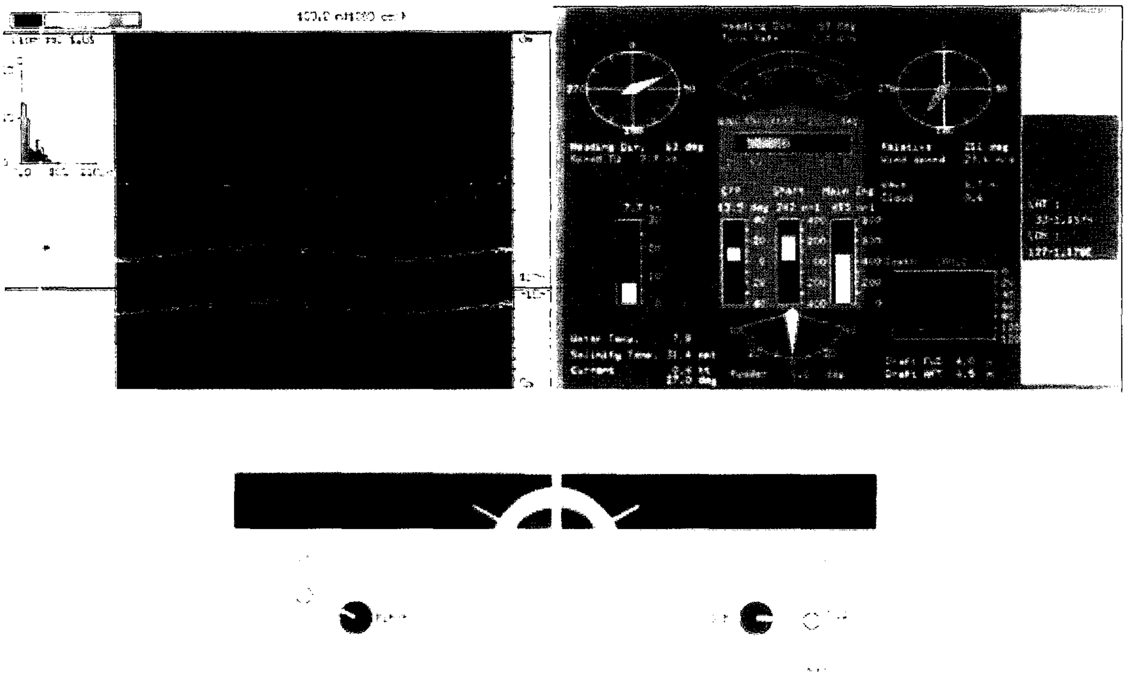

Fig. 6. An example of a still image of animation by fishing vessel cruising and fish finder operation.

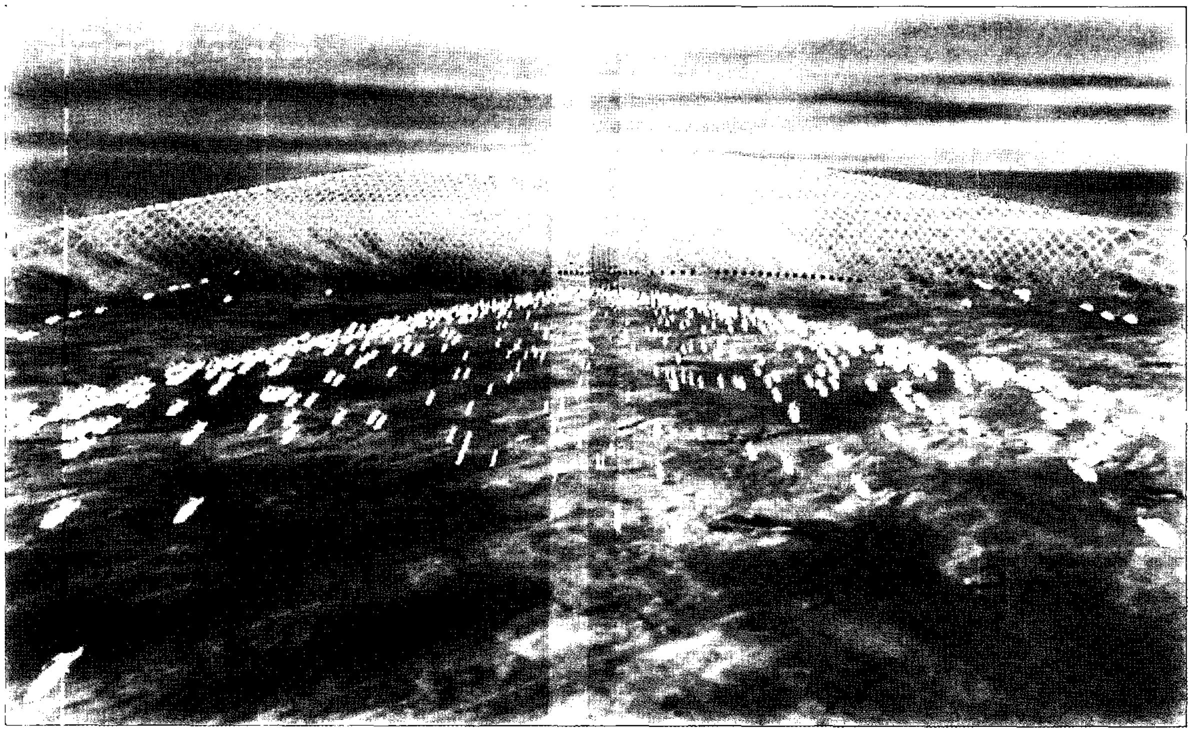

Fig. 7. An example of a still image during the animation of the two boat seine fishing for yellow croaker in the East China Sea.

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