光ファイバー視運動反応装置による魚群行動制御

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Fish Behaviour Control by the Optical Fiber Optomotor Reaction Device †

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Abstract : 'Optomotor Reaction' is defined as the movement of the eyes or the whole body that is induced by the image of a visual target kept on the retina of animals. Many kinds of fish also display this reaction. The optomotor reaction has been frequently studied in the aquarium as a measure of moment perception, visual acuity, sensitivity thresholds, fish behaviour to the trawl nets or seine nets, etc. However this peculiar characteristic of fish is not finding increasing use in research on controlling fish behaviour in the field, since it is difficult to make a visual target in the field. In this study a device was designed to produce a light band that is scattered by the muddiness of the water and becomes a visual target in the optomotor reaction. In this paper, the efficiency of this device is introduced with the results of some experiments, and some of the conditions which should be considered when using it in the field.

Keywords : *Fish behaviour control, Optomotor reaction*

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動物が視覚目標を網膜上の定位置に留め置こうとするために行う眼球または体全体の運動を視運動反応と称する。多くの魚種もまたこの反応を呈することが知られており，それを利用した魚類の運動知覚，視精度，視覚閾値あるいはトロールや旋網などを想定した対漁具行動等々の水槽実験例は数多く報告されている。しかし，フィールドでの魚群行動をコントロールする目的にこの反応を適用した研究例はほとんどない。それは視運動反応を解発させるための視覚目標をフィールドに作成することが困難なためである。そこで本研究では，光の水中での散乱現象を利用して作成した視覚目標の視運動反応装置を考案し，本装置の有効性を検証するとともに，実用化の際に考慮すべき諸条件について考察した。

Introduction

The motion of the whole body or the eyeball for retaining the image of a visual target reflected on the retina for its orientation is called an optomotor reaction. This reaction is mainly used in the research of measuring the performance of fish swimming, fish reaction to fishing gear, and the visual function of fish or other animals.

Brett et. al[1] described a black-and-white stripe pattern in the wall and basal plane of a water channel, and observed the

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optomotor reaction of Salmoniformes to its rotation. He also examined the cruise swimming velocity of the fish. Shaw et. al[2] examined the group formation of fish using equipment which described a stripe pattern in a drum which surrounds a cylindrical tank. Pavlov[3] and Parrish[4] discussed the relationship between the swimming behaviour and the optomotor reaction of fish to trawler fishing. Imamura[5] suggested that optomotor reaction was related to expulsion and the threat effect of fish to the swing rope. Inoue et. al[6),7] observed the difference in the reaction of fish to various patterns as a visual target. In addition, he devised the optomotor reaction equipment for a visual target in which a band of light moved by the flashing of an electric lamp arranged on a screen, set around the circumference of the tank[8]. Brockerhoff et. al[9] examined the usefulness in screening for recessive defects in the visual system of zebrafish *Danio rerio* mutants using optokinetic response equipment. They suggested that optokinetic response and optomotor reaction are the same.

The visual target of these optomotor reaction equipment used in these experiments were projected on a screen set at the circumference of the tank in which the fish live. So it is difficult to use this equipment in the field. Therefore, an optomotor reaction device using the light scattering phenomenon in the water was devised, and a verification experiment was carried out on the control effect of swimming behaviour of the fish using the device.

Materials and Methods

Device

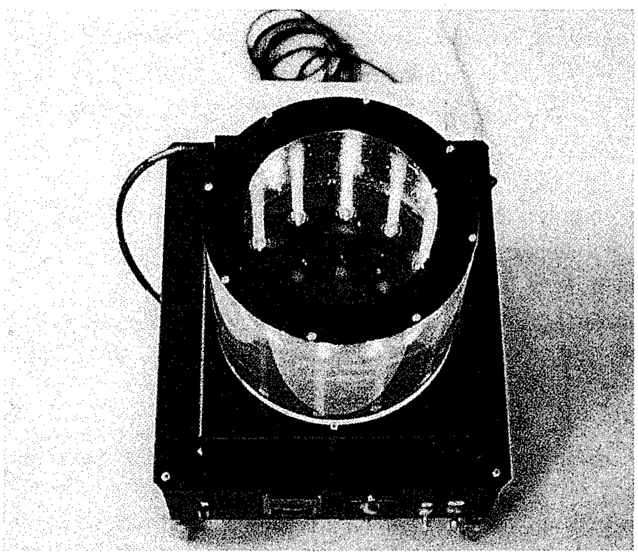
In the transverse direction in clear water with high transparency, the optic axis of the ray can not be observed. However, it is possible to observe the ray from the transverse direction, when there is slight aqueous suspension because the light scatters in the water.

The outline of the equipment devised in this study is shown in Fig. 1. In this experiment, a halogen lamp was used as a light source. It was divided into 12 equal parts using optical fiber, a convex lens was installed in the tip of each fiber, and these lights were irradiated in the direction of a parallel ray in the surface. It was installed in a rotating base with the lens division, and it is able to turn clock-wise and counterclockwise and can change the rotational transfer speed. A cylindrical acrylic tank satisfied the water with haze material a little was set on the rotating base. The optical fiber circles in the tank created a scattered light with a striped pattern.

Kaolin was used to create the aqueous suspension in this experiment, since it is considered a standard compornent of haze. The relationship between kaolin concentration and light absorptance became a linear relationship at each wavelength. The absorption spectrum was measured at the range of 400nm to 700nm, showing the tendency to absorb short -wavelength light.

It perpendicular turned the receiver sensor of light energy analytical equipment (Licor 1800C) to the basal plane central to the cylindrical tank of the device in Fig. 1 in the scattered light of stripe pattern, and we measured the spectral characteristics at various kaolin concentrations shown in Fig. 2. The

A



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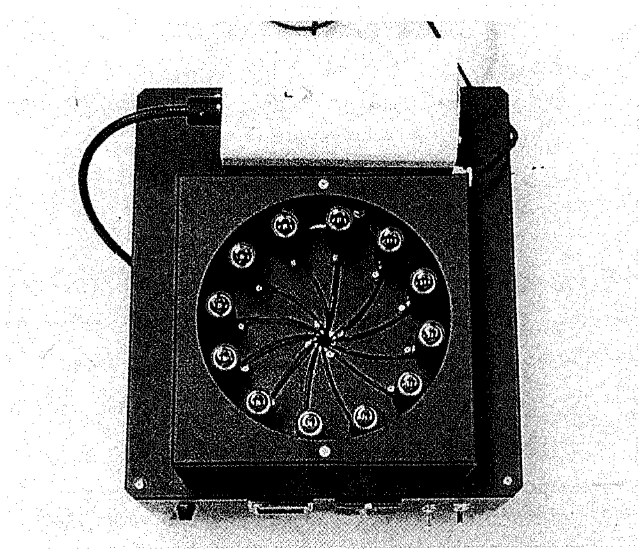

Fig. 1. A : Oblique view of the optomotor reaction device.
Some clear light stripe patterns which are the visual target for fish in the tank were taken in this photograph.
B : Upper view of the present device.
12 convex lenses with optical fiber and the box of halogen light source were taken in this photograph.

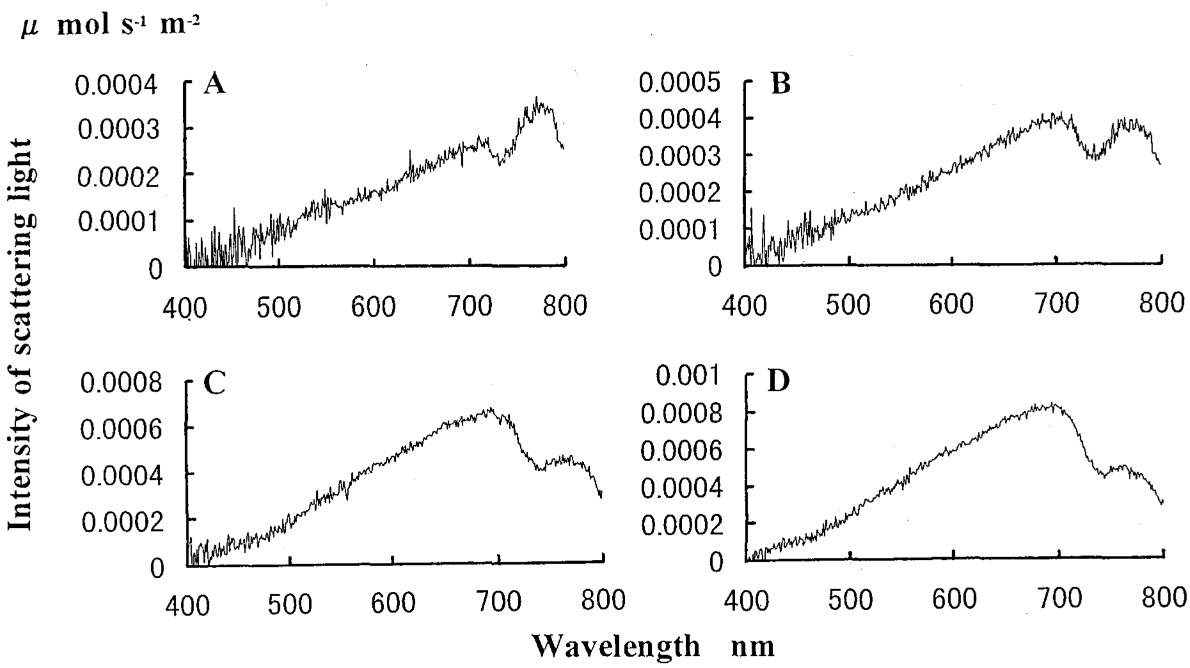

Fig. 2. Spectral diffraction energy characteristic of the light stripe pattern at various kaolin concentrations. A : 0ppm, B : 10ppm, C : 20ppm, D : 30ppm.

intensity of the scattered light increases in the long wavelength component since a halogen lamp was used as a light source, and that intensity strengthened as the kaolin concentration rises. In this study, each experiment was carried out at the 20ppm kaolin concentration level.

Fish

In the experiment to induce optomotor reaction and the experiment which examined the effect of the water surface illuminance from indoor fluorescence lighting, described in the next item, red sea bream *Pagrus Major* which were used produced at the Chiba Prefectural Sea Farming Center. The average length of the fish used in these experiment was about 30mm and about 60mm. And, the red sea bream of about 60mm total length done seedling production in Kinki Univ. Shirahama Regional Fisheries Research Laboratory was used for the experiment which examined the effect of background light and the experiment which examined retention and attractiveness. The trial fish for each experiment were properly transferred to the experiment tank from the breeding tank for every experiment. The water temperature was 22～25°C during the session.

Experiment of behaviour control

Inducement of optomotor reaction

In order to judge the behaviour control effect of the optomotor reaction device by using optical fiber, fish reaction was observed using the standard equipment with a screen. This was used as the control study. The experimental cylindrical tank is made of transparent acrylic 200mm in diameter. A visual target using black vinyl tape on a vinyl chloride white board set around the circumference of the tank was placed in the longitudinal direction at regular intervals. After a trial fish was transferred into the tank, and left to adapt for 5 minutes, the visual target was started in a clockwise direction. The fish behaviour was recorded for 5 minutes. Estimation hour of 5 minutes was measured in which the trial fish swam in the direction of the transfer direction of the visual target. Then the behaviour was evaluated by calculating the optomotor reaction rate. The tangential velocity of the visual target was made in 5 stages at $\pi/3$, $\pi/2$, $2\pi/3$, $5\pi/6$ and πrad/sec. Water surface illuminance in the controlled study was 250 lx, Red sea bream with an average length of 30 mm were used in this control experiment. While the fish reaction in which the water surface illuminance was 250 lx, whose value was equal to the controlled study, was compared with the case of 4.5 lx considering the effect of the water surface illuminance by fluorecent light for indoor lighting. Each experiment was repeated 5 times under the same conditions.

Effect of monochromatic background light

The color filter (Fuji film ; BPB60) was connected to the optical fiber division. Spectral diffraction energy distribution of the orange-colored light stripe pattern used in this experimental tank is shown in Fig. 3. The effect on the optomotor reaction was evaluated by the irradiation of a 600nm monochromatic light of the Okazaki Large Spectrograph of the National Institute for Basic Biology as a background light. The relative intensity of background light is 0 in the case of a visual target without the monochromatic background light, and is 1.0 when the intensity of the visual target is the same as the background. Fish reaction of the total 6 stages was compared, and the relative value of the intervals were 0, 0.2, 0.4, 0.6, 0.8 and 1.0. The tangential velocity of the visual target was also $\pi/3$ (rad/sec) in each condition. The protocol of this experiment is the same as the inducement of the optomotor reaction written above.

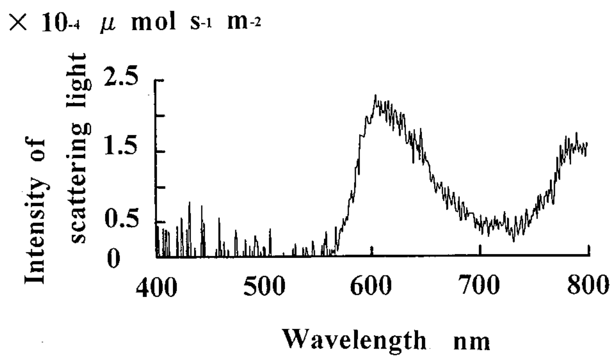

Fig. 3. Spectral diffraction energy characteristic of the light stripe pattern passing the interference filter (BPB60) at kaolin concentration of 20ppm.

Retention and attractiveness experiment

A cylindrical acrylic tank of 800mm in diameter, 300mm in height was used as the experimental tank. The optomotor reaction device by using optical fiber was installed right under the central basal plane of the tank. The light which passed the interference filter (Fujitoku) of the largest transmitted wave length, 560nm as a stimulation light was used as the visual target. The configuration of the equipment used in the experiment is shown in Fig. 4. The following were measured : the number of individuals which advanced to within 150mm from the position of the whirling light stripe pattern in the tank and the approach duration. Ten fish were used in this experiment. In the control, only the optical illumination was conducted without the whirling light stripe pattern as a visual target. Attraction and retention effects on the fish school from this device were evaluated by comparing the control experiment with the case in which the visual target was whirled.

Results and Discussion

Inducement of optomotor reaction

The result of optomotor reaction rate of the control experiment using the black-and-white tape screen as the visual

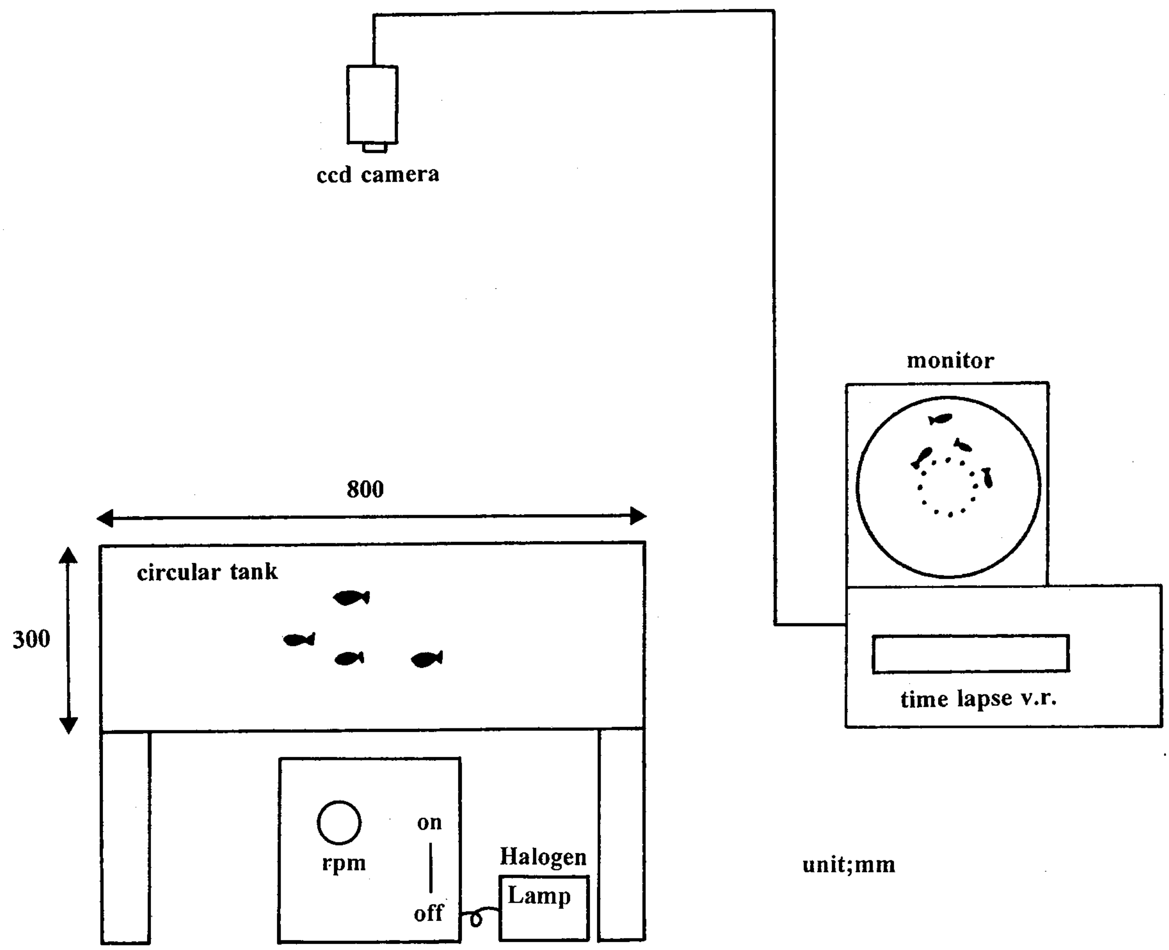

Fig. 4. The schematic of the configuration of the equipment of the retention and attractiveness experiment.

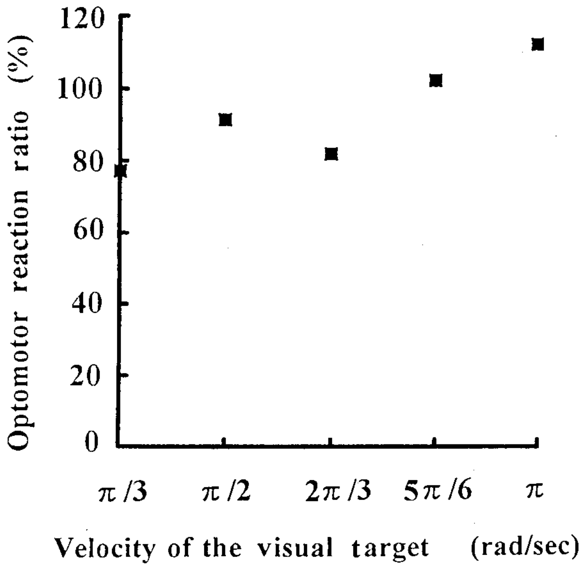

Fig. 5. The result of the red sea bream group of 30mm average total length in using standard optomotor reaction equipment.
The dots in the figure are the average value of 5 trial fish in each velocity.

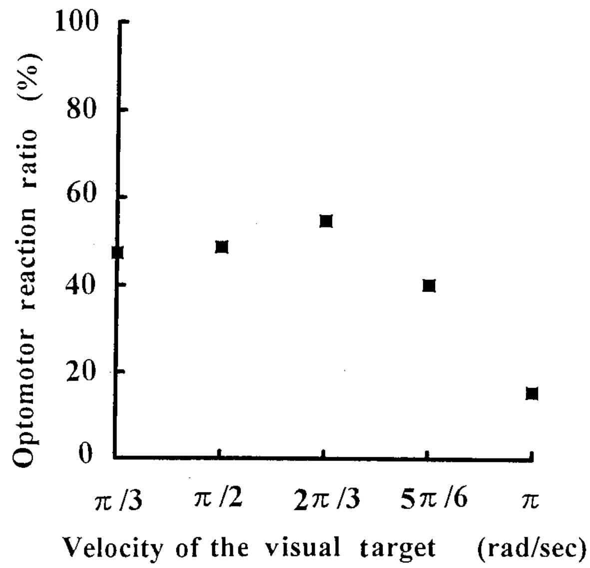

Fig. 6. The result of the same red sea bream group as in Fig. 5 using an optical fiber optomotor reaction device.
The dots in the figure are the average value of 5 trial fish at each velocity.

target is shown in Fig. 5. The tangential velocity of the visual target was separated into the largest π (rad/sec) and smallest $\pi/3$ (rad/sec) in 5 stages in the $\pi/6$ (rad/sec) interval. Reaction rates over 80% were mostly observed in each tangential velocity. The reaction rate tends to rise, as the speed increases in the tangential velocity of this range. Especially, in $5\pi/6$ and π (rad/sec), the reaction rate exceeded 100%, the red sea bream would quickly swim further than the turning of the visual target at these velocities. While the result of using the optical fiber optomotor reaction device developed in this study is shown in Fig. 6. Each tangential velocity was also compared with the control experiment in this case. The reaction rate was low, but the optomotor reaction using the target of light stripe pattern was observed. The relation between reaction rate and tangential velocity of the visual target did not show a linear relationship like as in the control experiment, the largest reaction rate was shown at the $2\pi/3$ (rad/sec), which was a velocity in the middle of the measurement range. The water surface illuminance (250 lx) in the experiment was equal to the control experiment. It is thought that the environmental optical intensity of the circumference influences the light stripe pattern in the visual target of this device. Optomotor reaction was then observed using the fish with an average total length of 60mm in case of water surface illuminance (250 lx) equal to the aforesaid experiment and case of lower value (4.5 lx). The measurement result is shown in Fig. 7. The results obtained showed that in high water surface illuminance (250 lx), the reaction became extremely bad, and that it does not compare to the fish with an average total length of 30mm, and that there is hardly any reaction. However, the whole reaction rate in the case of low water surface illuminance (4.5 lx) shows a higher reaction than the value from fish with an average total length of 30mm, carried out in high water surface illuminance (250 lx), even if it was an individual of equal size. In this case, the relation between reaction rate and tangential velocity of the visual target showed a linear relationship also seen in the control experiment. However, the tendency was completely reversed, and the reaction improved, when it is the slowest tangential velocity ($\pi/3$ (rad/sec)).

From these results, it was confirmed that the fish behaviour could be controlled by the optical fiber optomotor reaction device as well as the usual equipment. Simultaneously, it was indicated that the reaction might be inhibited by the intensity of the background light.

Effect of monochromatic background light

From the previous experiment, an effect of background light was indicated, when the fish behaviour was controlled by this device. Therefore, the effect of making the monochromatic light of the wavelength equal to the light of the visual target to be background light should be examined. The measurement result is shown in Fig. 8. The relation between optomotor reaction rate and relative intensity of background light was rectilinear, and it inhibited the optomotor reaction, as the background light becomes stronger. This result harmonizes with comparing high water surface illuminance (250 lx) already described in the preceding item with the low case of water surface illuminance (4.5 lx). The reaction rate, as before

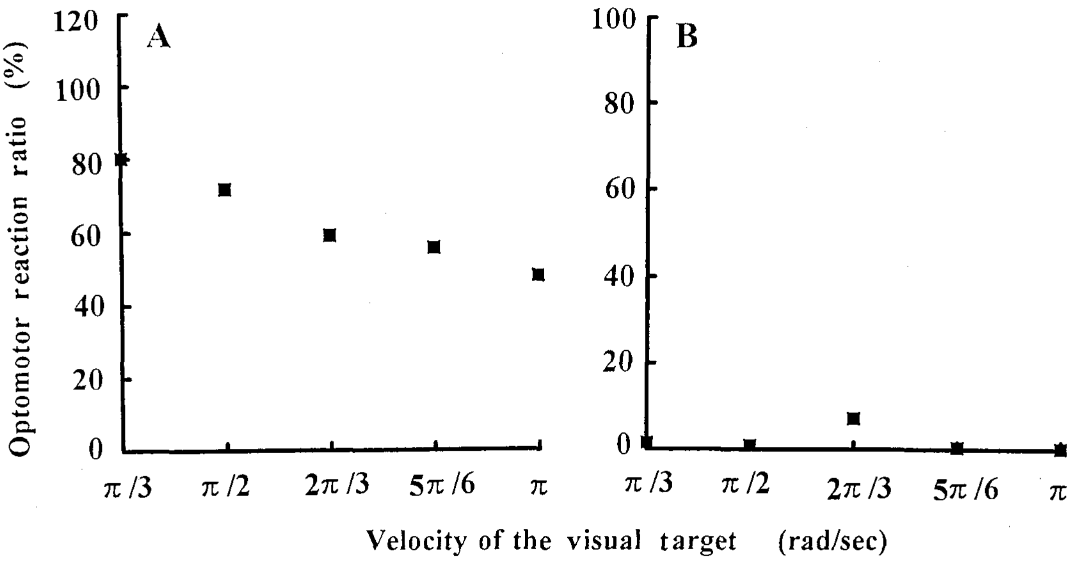

Fig. 7. The result of the red sea bream group of the 60mm average total length using an optical fiber optomotor reaction device.
The dots in figure are the average value of 5 trial fish at each velocity.
Water surface illuminance: A ; 4.5 lx, B ; 250 lx.

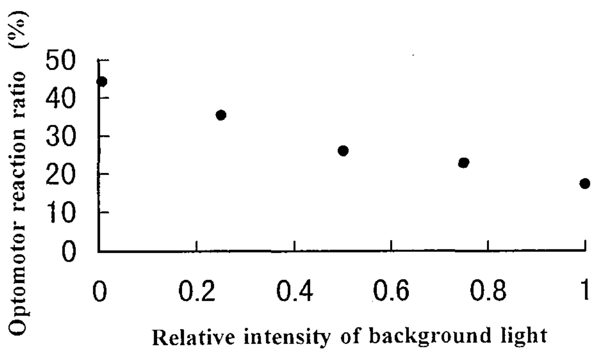

Fig. 8. The result of optomotor reaction rate at the relative intensity of various monochromatic background lights,
The dots in figure are the average value of 10 trial fish for each condition.

was completely no background light was the maximum, and the value was shown was about 45%. While a reaction rate of about 20% was shown, when the intensity of the light stripe pattern and background light of the monochromatic light from the large spectrograph intervened, and the optomotor reaction did not disappear. Both radiation should assimilate, if the optical intensity of the visual target is equal to the optical intensity of background light. As the result, it does not seem to induce an optomotor reaction itself, since the light stripe pattern as a visual target for showing optomotor reaction disappears. However, the trial fish recognized the light stripe pattern on showing an optomotor reaction. The light stripe pattern used in this experiment is the passage of light through the BPB60 filter, as shown in Fig. 3. The maximum wavelength of the transmitted light is 600nm. However, it seemed to recognize a visual target made by the light, because it was the light including the wavelength component, except at 600nm. It is anticipated that an optomotor reaction does not appear, if wavelength characteristic and intensity of light stripe pattern are completely equal to the values of the background light. The methodology which measures the scotopic spectral sensitivity characteristics of the fish in making an optomotor reaction to be an index, has already been reported[10]. This device enables the method of measurement of the photopic spectral sensitivity characteristics of the fish, in the case of a light stripe pattern with monochromatic light in which the effect of background light does not intervene, as Eguchi[11] mentioned.

Retention and attractiveness experiment

It was proven that the behaviour of the fish could be controlled by an optical fiber optomotor reaction device from the experimental results of the preceding item. It is necessary to consider the fish school which is distributed in a wide non-closed space, because it is not the environment in which the fish as an object exists in a small, circular tank used the experiment, for the purpose of this device is to be used in the field. Then, the effect range by placing the same device in the basal plane central part of the cylindrical tank with 20 times the volume of the tank for the optical fiber optomotor reaction device, as it was described in the experimental method, should be confirmed. The total number of individuals which advanced to within 15cm of the light stripe pattern area in the observation hour for the 5 minutes was counted. This experiment was carried out a total of 13 times in the time interval,

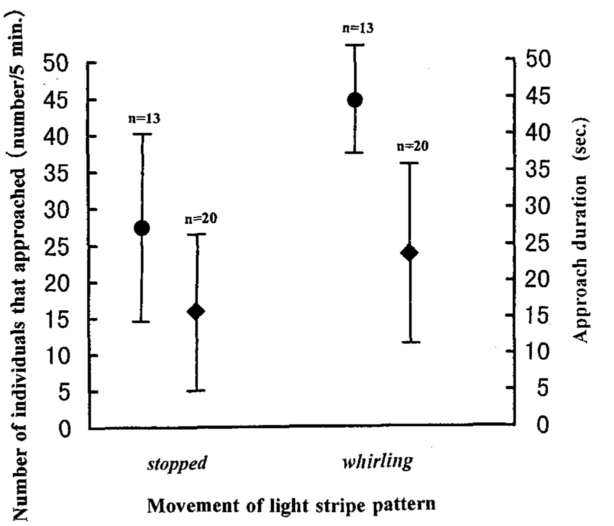

Fig. 9. Total number (●) of individuals which advanced to within 15cm from the light stripe pattern area and each individual's approach (◆) duration in the region.

and the approach duration in the region of each individual was counted by the selection of 20 individuals. The results are shown in Fig. 9. The presentation of not whirling and rested light stripe pattern was made to as the control experiment. The case in which the light stripe pattern was whirled in comparison with the control experiment also increased the greater the value of total individuals, approaching duration. The difference of the mean value was significant for both the number of approach individuals and approach duration, when a T-test was done, and the level of significance became 0.1% and 5.0% respectively. It is regarded from this that the whirling light stripe pattern had some attractiveness and retention effect on the red sea bream, inducing an optomotor reaction by this ocular-irritation.

Conclusion

The function of the device introduced in this paper for fish behaviour control was confirmed by the results of some experiments mentioned above, The application method of this device in the field was considered. For example, that it utilizes solar cells or wave power generation, etc. as an irradiation energy source of laser beam and whirling power source and improvement of the maintenance-free type device are desired, when the utilization of this device is considered as a result of expecting the fish shelter effect. Moreover, it is necessary to also examine the spectral sensitivity characteristics of the object fish species, the contrast between background and light stripes pattern which the water systems of the sea area makes or time variations of the light environment condition in detail. Various adjustments are needed in order to deal with the field, and in order to attempt the completion of a finished product. However, the behaviour control using the optomotor reaction of the fish is expected with a utility value found in all aspects of fisheries.

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References

1) J.E. Brett, M. Hollands and D.F. Alderdice: The effect of temperature on the cruising speed of young sockeye and coho salmon. I. Fish. Res. Bd. Can., 15(4), 587-605 (1958).
2) E. Shaw and Sachs B: Development of the optomotor response in schooling fish, *menidia menidia*. J. Comparative and Physiological Psychology, 63(3), 385-388 (1967).
3) D.S. Pavlov: The optomotor reaction of fish. F.A.O. Fish Reports, 62(3), 803-808 (1967).
4) B.B. Parrish: A review of some experimental studies of fish reactions to stationary and moving objects of relevance to fish capture processes. F.A.O. Fish Reports, 62(3), 233-245 (1967).
5) Y. Imamura: Etude de l'effet du feu dans la peche et de son operation (I). La mer, 6 (1), 17-43 (1968). (in Japanese)
6) M. Inoue and T. Kondo: On the optomotor reaction of fish relevant to fishing method. J. Tokyo Univ. Fish., 58(1,2), 9-16 (1972). (in Japanese)
7) M. Inoue and T. Kondo: Form vision of dace and anchovy for moving fish-figures. J. Tokyo Univ. Fish., 59(2), 55-67 (1973). (in Japanese)
8) T. Arimoto, H. Shiba and M. Inoue: On the optomotor reaction of fish relevant to fishing method V. Reaction of rainbow trout, *Salmo Gairdneri*, toward the illusive movement of a flickering light. J. Tokyo Univ. Fish., 66(1), 37-46 (1979). (in Japanese).
9) S.E. Brockerhoff, J.B. Hurley, U. Janssen-Bienhold, S.C. Neuhauss, W. Driever and J.E. Dowling: A behavioral screen for isolating zebrafish mutants with visual system defects. Proc. Natl. Acad. Sci. USA. 92(23), 10545-10549 (1995).
10) E.I. Hasegawa: Study on measurement of spectral sensitivity under scotopic conditions using optomotor reaction in fishes. Nippon Suisan Gakkaishi, 64(4), 626-630 (1998). (in Japanese)
11) E. Eguchi: Test of the ability of discriminating the color. SEITAI NO KAGAKU, 45(5) 572-573 (1994). (in Japanese)