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Jellyfish Monitoring Methods with Image Processing Techniques

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Abstract

This paper presents the outline concerned with the measuring methods, an illumination intensity and a water depth when an image is captured, the possibility of counting of a jellyfish, and the analyzing correctness of jellyfish image with various filters, etc. The various images of jellyfish into the seawater surface layer which are captured with a CCD camera is inputted to an image analyzer in order to count jellyfish quantitatively, and an image was analyzed. The results are summarized as follows: 1) In order to keep an image area percent of more than 50 % after processing, a water depth of less than 20 cm must keep. 2) The capturing and processing of image are suitable when an illumination intensity is larger and the threshold value is 120. 3) The touching jellyfish and the seawater as the background can be discriminated with a visible light cut-filter. 4) When a projection plate to which the salicylic acid is adhered is used, since the image qualities could be prevented to fall down by an irregular reflection of the seawater surface, the "notchless" is also useful when abbreviating the rank filter process. 5)The authors judged that jellyfish can count by using the brightness values of M type's shapes, stomach number and the wavelength reflection ratio of jellyfish with the visible light cut-filter.

INTRODUCTION

As for the large obstacle factors in the generation of the heat power and atomic power in the summer season, there are decreases of the pumping up quantities of the cooling water because of the seawater-gate blockade which occur by jellyfishes on a large scale (TERAMOTO, 1991). The problem for stable generation occur because the season of the electric power demand and the jellyfish inflow into the seawater-gate overlap. Many species of jellyfish inhabit near seawater of Japan archipelago, however, the inflowing jellyfish into the power plants of the coast of Tokyo bay are the Medusa, *Aurelia aurita* LAMARK mainly. The problem occur often because the breeding season is from May to September (KUWAHARA *et al.*, 1969; SAITO *et al.*, 1990).

For the methods for prevention of jellyfish inflowing into the seawater-gate for pumping up, some techniques have been studied such as the equipments in order to flow the seawater powerfully (SATO, 1990; TODA, 1990), an aeration (IIZIMA *et al.*, 1990) and the vibration system with supersonic waves. Moreover, a jellyfish inflowing is prevented by the double methods by using the fishing nets (TODA, 1990) installed forward the seawater-gate and jellyfishes with the large plant for escaping dust (ISHII, 1990). In order that the prevention function is the most effective, these equipments must begin operating before jellyfish inflows into the seawater-gate. Therefore, it is necessary that the inspecting work be continued all day, in which a human inspector gazes at the monitoring images of jellyfishes in the water surface by a camera installed at the top of seawater-gate (NOGAMI, 1990). It has been difficult to count jellyfish in the seawater efficiency and quantitatively without human operator's monitoring. For the labor-saving of the inspecting work and an automatic controlling of the various equipments for prevention of jellyfish inflowing, the authors have considered that an automatic and quantitative counting methods of jellyfish in the seawater must be developed.

To count jellyfishes, the target strength data of

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jellyfish by the supersonic wave (SAITO *et al.*, 1990; OTA, 1990; INAGAKI and TOYOKAWA, 1991) were studied as the estimating methods of jellyfish quantities in the seawater by the searchlight-sonar. However, these study could not count jellyfish quantitatively because of the signal noise by the bubbles and planktons, etc. So, the authors (TODA *et al.*, 1995) investigated monitoring system of the trial constructions for counting of jellyfish quantitatively by the difference of density of the milled jellyfish and seawater, and confirmed its visibility. However, because this system must be pumped up the seawater, the counting area of jellyfish was limited.

Consequently, the authors tried to count jellyfish quantitatively because of regarding these backgrounds, a jellyfish images of the seawater surface layer which were captured with a CCD camera (hereafter called the "camera") were analyzed by an image analyzer. For the quantitative counting methods of jellyfish, this paper was constructed from two methods with an image processing; the estimating method by the calibration line's values of parasol area and mass of jellyfish, and direct counting method of jellyfish. For concrete method for these, the authors present on an outline concerned with an illumination intensity and a water depth when an image is captured, the counting methods of touching or non-touching jellyfish with the various filters, etc.

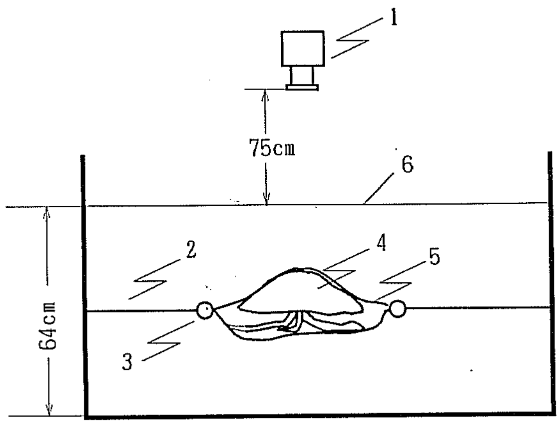

Fig. 1. Method for photographing jellyfish in water. 1: CCD camera, 2: Nylon monofilament, 3: Bamboo for fixing jellyfish floating position, 4: Jellyfish, 5: Nylon monofilament net, 6: water surface.

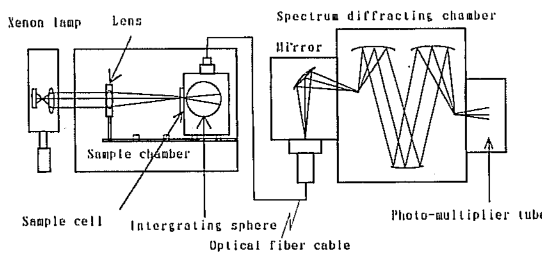

Fig. 2. Schematic diagram of spectrum analyzer.

Experimental Instruments and Methods

Experimental instruments

Four apparatus were used in the experiment; an imaging system of jellyfish of the seawater, an image analyzer (model PIAS Ⅲ), a spectrum analyzer (TODA *et al.*, 1995) of the trial constructions and an analyzing methods of jellyfish image with the projection plate and visible light cut-filter. An imaging method of jellyfish in the seawater is shown in Fig. 1. A Jellyfish was held between nets by the nylon monofilament at depths of zero, 21, 42 and 64 cm from the water surface in a tank. The authors investigated the relationship between a water depth and the measuring correctness of an image area after processing of the jellyfish image when a camera was installed 75 cm over of the water surface.

An outline of a spectrum analyzer of the trial constructions is shown in Fig. 2 and Table 1. The system is composed of each parts of the luminous source, xenon lamp, sample cell, integrating sphere, spectral diffracting chamber and photo-multiplier tube, computer for controlling of each systems and measuring of data, etc.

Influence of water depth for process of jellyfish image: A flowchart in Fig. 3 shows an image area after process of image. "Area percent" is an amount of an image area after process of an image divided by an image area before process of an image. Because the island state "hole" inside an image after

Table. 1. Specification of spectrum analyzer

Luminous source	UV-xenon 150W
Sample cell	Fixe-type crystal cell content : 4.40ml
Spectral diffication	Grating mirror (pulse motor drive)
Photo-transmission	Optical fiber
Range of wavelength	200–700nm
Resolution of wavelength	0.5nm
Interface	GPIB

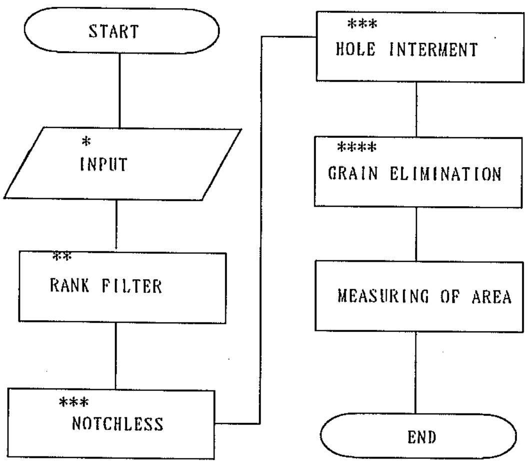

Fig. 3. A flowchart showing the image area measuring procedure using image processing with particulars.
* : smooth image getting by means of spike noize (noise seen as supper spark point) elimination in image.
* * : The threshold selection method produces a image by designating brightness values at brightness zero and brightness 255 without any intermediate brightness. Concretely, when black is designated at brightness zero, those with threshold values of 50 or less are converted into black, and those there-above are converted into white.
* * * : Interring of hole in image by brightness values of image (range where background has same brightness values)
* * * * : Interring of grain less than a certain values in image

hemming of image was interred with the brightness value of an image, an image area before process of an image was measured. Next, an images after process were measured by the process of a

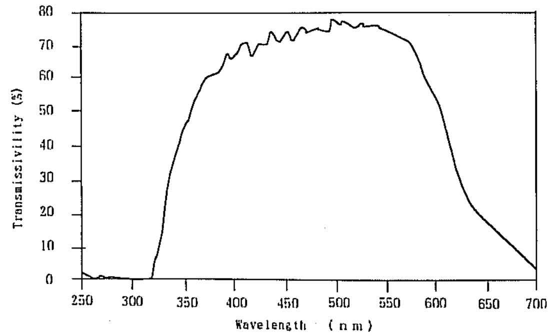

Fig. 4. Transmissibility of wavelength with visible light cut-filter.

work which showed in the above mentions flowchart (shown in Fig. 3).

Processing correctness of image and illumination intensity when capture: The authors investigated the effects of an illumination intensity on the process correctness when capture. A held jellyfish between nets was kept in floating states (shown in Fig. 1). When a jellyfish capture with a camera, an illumination intensities of jellyfish position were controlled at 60, 128, 155, 213 and 280 *lx*.

Discrimination of touching and non-touching jellyfishes: The touching and non-touching jellyfishes were held between the nets, an air of 2 *ml* per stomach (jellyfish has 4 stomaches) was injected respectively with an injector. So, a jellyfish powerfully surfaced after the parasol was set on the water surface, and captured jellyfish with the visible light cut-filter and the filter for protection of an irregular reflection. As shown in Fig. 4, the visible light cut-filter can cut an ultraviolet rays less than the wavelength of 320 nm, and transmits relatively the wavelength from 320 nm to 620 nm.

A jellyfish image when non-touching jellyfishes divided unequally into positions of 14 for the direction of the X axis in the center of jellyfishes by the body character (shown in Table 2 and Fig. 5 a and b). The touching jellyfishes were also divided at 12 positions by the same method, and the brightness values of divisional positions were measured (shown in Table 2 and Fig. 5 c).

Then, because the brightness value of image

Table. 2. Number of divisional positionas and intervals in each experiments. (cm)

No. of divi. posi.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Non-touching jellyfish	5.0	2.8	2.0	1.3	1.7	3.1	1.4	1.4	3.3	3.2	1.3	2.1	2.5	5.0
Touching jellyfish	5.0	2.8	2.0	1.3	1.6	2.1	–	–	3.3	3.2	1.3	2.1	2.5	5.0
With projective plate	5.0	2.8	2.0	1.3	1.7	3.1	5.	–	–	–	–	–	–	–

No. of divi. posi: Number of divisional positions

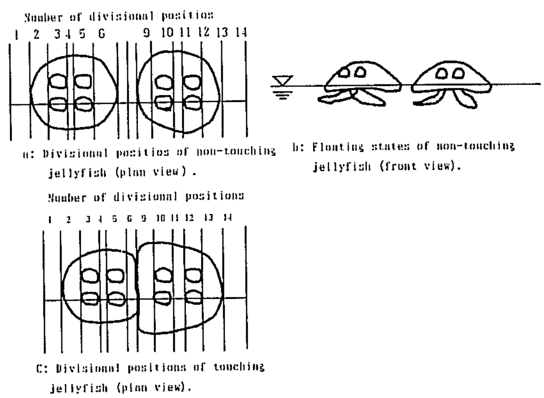

Fig. 5. Dividing methods of non-touching and touching jellyfish image.

data shows just a quantitized analog voltage as eight bit decimal from zero to 255, the value doesn't have a unit.

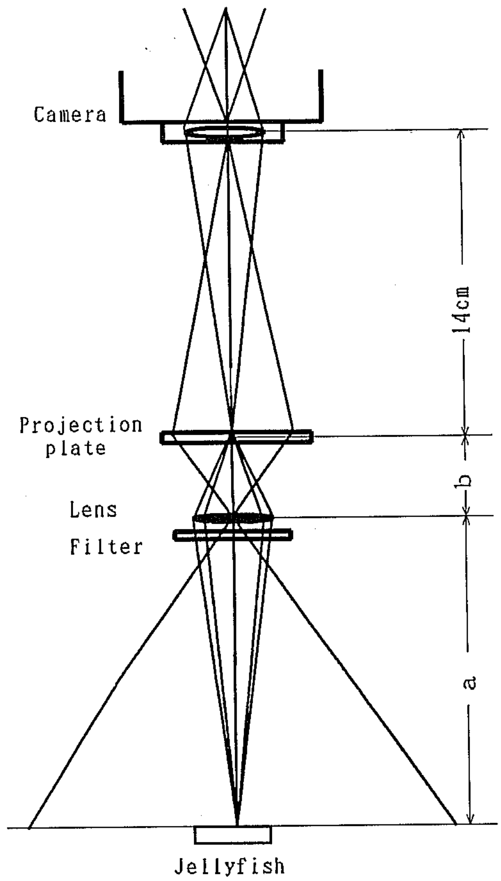

Fig. 6. Optical image of projection equipment.
a : Distance between jellyfish and lens
b : Distance between lens and projection plate

Correctness after processing of image with various filters: An optical image from the projection equipment is shown in Fig. 6. The projection equipment is composed of the filter, lens, projection plate and camera. This apparatus works as follows; Ultraviolet light was irradiated an image, an irradiated ultraviolet by an ultraviolet lamp (UVM-57) transmitted a jellyfish. And when light of non-ultraviolet after an ultraviolet lay was cut completely by the cut-filter (U-330) is irradiated on the projection plate to which is adhered salicylic acid of the fluorescent substance, the authors can observe the reflected image from the projection plate. And, an image after projection is captured by a camera, and processed an image. The following four experiments were done under the same methods.

When the distance between a jellyfish and lens is a, the distance between lens and projection plate is b, because an image magnification became 3 times from the relationship of a and b, an image of largeness of 50 mm on the projection plate can seen as the largeness image of 150 mm. The difference which occurs in an image at the center and end of fluorescent plate is shown as the expansional angle θ, and the relationship of image magnification by the distance ratio of a and b, is given by the following equation (KUBOTA, 1959; ILLUMINATION GAKKAI, 1990).

$$\frac{1}{a}+\frac{1}{b}=f$$

In the experiments, because the focus distance f of lens is 50 mm and a of the distance between a jellyfish and lens installed at 200 mm, b of the distance between lens and projection plate is calculated as 66.7 mm. Then, the brightness showed average values of 7 sections.

Results and Discussion

Parasol diameter and mass of jellyfish: The parasol diameter and mass of jellyfish is shown in Fig. 7. The correlation coefficient between parasol diameter and mass is at 0.955 approximately. This shows that the quantity of jellyfish can be estimated on the counting possibility of the one by the relationship between an average mass of one and the measurements of total parasol area.

Influence of water depth on process of image: The relationship between a water depth and an area percent of image after process of image is shown in Fig. 8. An area percent of image after process of image became 40-83% at a water surface, 0-70% at a water depth of 20 cm, 40% at a water depth of more than 40 cm. When the threshold values are larger, an area percent after the notchless becomes smaller. The higher an area percent is, the higher process correctness. When an area percent is less than 50 %, the small jellyfish can not see after process. A water depth becomes deeper until a depth of 60 cm irrelevant to the largeness of threshold value, however, an area percent is smaller. An image of jellyfish on a water surface can be discriminated jellyfish irrelevant to the largeness of threshold values. When the threshold values are 130-150 at a water depth of 20 cm, 130-140 at a water depth of 40 cm, and 130 at a water depth of 60 cm, however, a jellyfish image can be discriminated. When a water depth is less than 20 cm and the threshold values are smaller than 130, an image can not discriminated jellyfish because of the signal noises when an image is captured. An

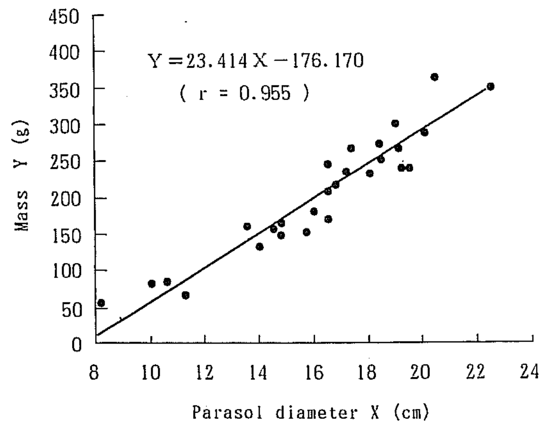

Fig. 7. Parasol diameter and mass of jellyfish.

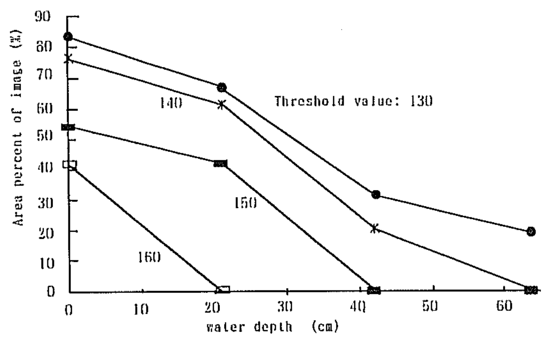

Fig. 8. Water depth and area percent of image after processing.

image area is extremely decreased when the threshold value is at 160 over. However, when a water depth is less than 20 cm, for practical usage, a jellyfish must be floated until a water depth of less than 20 cm in order to keep an area percent of more than 50 % after process.

Process correctness of image and illumination intensity when capture: The relationship between an illumination intensity and an area percent of image after processing under 60-280 lx is shown in Fig. 9. When an illumination density is less than 130 lx, an area percent of image after processing is less than 10% irrelative to the largeness of threshold values. When the threshold values are at 120-140, a jellyfish image can be discriminated; especially, in case the threshold value is at 120, it is suitable for process of an image because an area percent is higher. When an illumination intensity

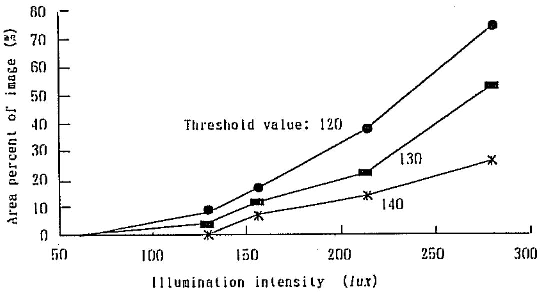

Fig. 9. Illumination intensity when photographed jellyfish and area percent of image after processing.

is 280 *lx* and an area percent of image after the processing are at 70, 50 and 25 %, the threshold values are 120, 130 and 140, respectively. That is, when the threshold values became smaller 10 approximately, an area percent of image is wider 20-25 %. And, when an illumination intensity is lower, an increase rate of area percent of image decreases and an area percent are smaller.

Consequently, the capturing and processing of an image are suitable when an illumination intensity is higher and the threshold value is 120.

Discrimination of touching and non-touching jellyfish: The brightness of the divisional positions of non-touching jellyfish with the visible light cut-filter and the filter for protection of an irregular reflection is shown in Fig. 10 (shown in Fig. 5 a and b, and Table 2). The brightness of the water surface is at 120 with non-filter and the visible light cut-filter, while the surface brightness is at 23 with the filter for protection of an irregular reflection. The brightness of stomach positions is at 200 approximately with the non-filter, 180 with the visible light cut-filter, 60 with the filter for protection of an irregular reflection. The brightness of image between the stomaches (hereafter called the " center position of a jellyfish ", divisional positions : 4 and 11) is at 160 approximately with non-filter, 170 with the visible light cut-filter, 55 with the filter for protection of an irregular reflection.

As the above mentions, the decrease of brightness with the filter for protection of an irregular reflection is larger than with the visible light cut-

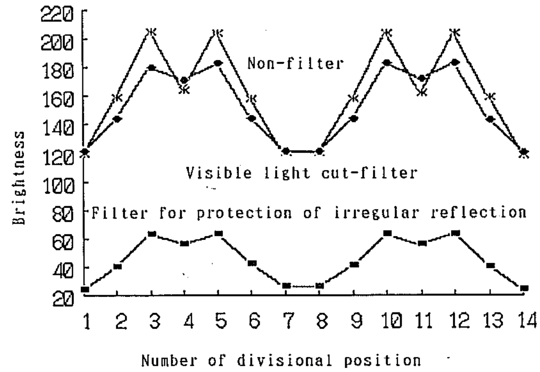

Fig. 10. Brightness with various filters of non-touching jellyfishes.

Note: the brightness value of image data represents just a quantitized analog voltage as eight bit decimal from 0 to 255.

filter, and the brightness value when the visible light cut-filter and the non-filter is used has almost the same .

In the case of an image of non-touching jellyfishes, the brightness values of stomach positions (divisional positions : 3, 5, 10 and 12) with non-filter are larger than that center positions (divisional positions : 4 and 11); the broken-line shapes of brightness of divisional positions is the shapes of M type. And, because the brightness of center positions (divisional positions : 4 and 11) is higher than a water surface (divisional positions : 1, 7, 8 and 14), the authors estimated that each jellyfishes can be discriminated when the threshold values between stomaches and center positions can be decided. An appearance of M type's shapes is remarkable with the non-filter, when the visible light cut-filter and filter for protection of an irregular reflection are installed on a camera, the brightness decrease of center positions is large since the brightness difference between center positions (7 and 8) and seawater (1 and 14) is small; the brightness hollowing of center positions is shallow. In case the brightness is changed for the jellyfish number, when the brightness hollowing of center positions is installed as the threshold values, the authors estimated that the counting error is small. When the visible light cut-filter is installed on a

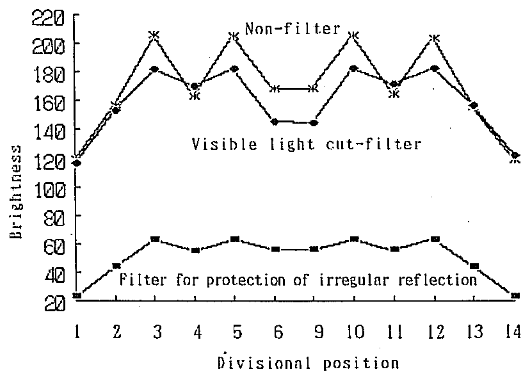

Fig. 11. Brightness with various filters of touching jellyfishes.
Note: the brightness value of image data represents just a quantitized analog voltage as eight bit decimal from 0 to 255.

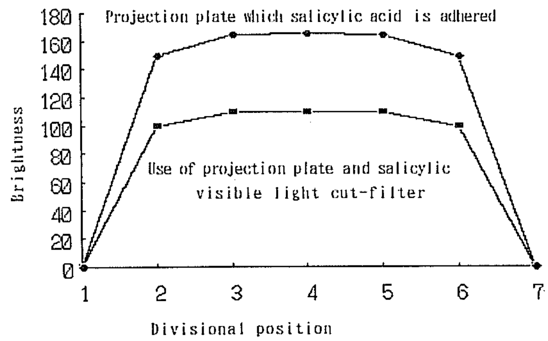

Fig. 12. Brightness of body positions when used projection plate and visible light cut-filter are used projection equipment.
Note: the brightness value of image data represents just a quantitized analog voltage as eight bit decimal from 0 to 255.

camera, a jellyfish can be counted easily because the brightness values can use M type's shapes of the jellyfish character.

The brightness values of each positions when the touching jellyfishes are captured with the various filters are shown in Fig. 11 (shown in Fig. 5 c and Table 2). In the case of the touching jellyfishes, the threshold values can not be decided because the brightness values of center positions (divisional positions : 4 and 11) and touching positions (divisional positions : 6 and 9) with non-filter are mostly equal. So, the authors judged that the counting of touching jellyfishes with non-filter is difficult. When the visible light cut-filter is used, the brightness value of image is 140 in the touching positions (divisional positions: 6 and 9), 170 in the center positions (divisional positions: 4 and 11). Thus, as both brightness values are obviously dissimilar, the threshold values can be determined. Nevertheless, when the filter for protection of an irregular reflection is used, it is difficult to count jellyfish by the same reason with non-filter.

To count the jellyfish, therefore, the authors have also considered on the counting of stomach by the brightness difference between stomach positions (divisional positions : 3, 5, 10 and 12) and water surface (divisional positions : 1, 7, 8 and 14). Since the brightness difference between stomach position and water surface is larger than that between the center positions (divisional positions: 4 and 11) and the brightness of stomach positions (divisional positions : 3, 5, 10 and 12), if possible, the counting of stomach is more easy. Because a jellyfish has 4 stomaches, a jellyfish can count when an amount number of stomaches divide by stomach numbers.

Processing correctness of image with various filters: It is not too much to say that the processing correctness of an image is decided on the various conditions when capture. Because it is many required processing number when the processing treatment of image is many, the processing correctness after capturing fall down. Therefore, for the" notchless" in order to inter of "hole" in an image by same brightness values which background has easily, the large difference image of brightness values between a jellyfish and a water surface must be captured. So, if possible, an algorithm for processing of image must be simplified. The divisional positions of jellyfish image with the projection plate and the brightness values of divisional positions when the projection equipment is used are shown in Fig. 12 (shown in Table 2). In case the projection plate on to which the salicylic acid adhered is used, the brightness value of an

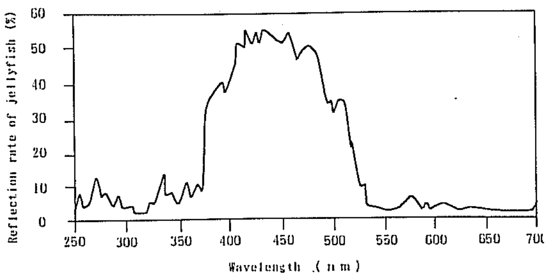

Fig. 13. Reflection rate of jellyfish.

image is a constant of 150 approximately. And so, the notchless, that is, the discrimination of jellyfish and a water surface is simple. When the projection plate and the visible light cut-filter are used together, the brightness value is a constant of 110 approximately irrelative to the divisional positions, and the brightness value of water surface is zero. Thus, the notchless is easy extremely.

However, when the visible light cut-filter is used, the brightness value of water surface as the background is 120 approximately at the first divisional positions (shown in Figs. 10 and 11). When the filter for protecting of an irregular reflection is used, the zero of brightness value can not be judged as the water surface since the brightness value is 20 approximately at a water surface (shown in Figs. 10 and 11).

As the above mentions, when an image is projected on a projection plate manufactured by the quartz to which the salicylic acid is adhered in order to eliminate an irregular reflection light in the seawater surface from an image, an image qualities can be prevented from falling down because of an irregular the reflection of seawater surface. And so, the notchless is also possible in case of an abbreviation of the rank filter process.

Then, the light intensity reduce generally when the filter is used. However, the brightness with various filters is lower than non-filter (shown in Figs. 10 and 11). For this reason, the authors estimated that the sensitivity was automatically corrected because the function of white-valance works automatically when the camera shutter works.

Wavelength reflection ratio of jellyfish : An each wavelength reflection ratio of jellyfish with the visible light cut-filter (shown in Fig. 5) shows in Fig. 13. The wavelength reflection ratio of jellyfish is reflection intensity divided by an intensity of luminous source, therefore, the one doesn't compared jellyfish reflection with the seawater reflection. The wavelength reflection ratio of jellyfish shows 50 % approximately from 380 to 480 nm and the wavelength reflection ratio of seawater shows less than 10 % approximately. Because the difference of the former and the latter is large, the authors considered that a jellyfish can be discriminated easily.

Consequently, the authors judged that a jellyfish can count by using M type's shapes of the brightness values, the stomach number and the wavelength reflection ratio of jellyfish with the visible light cut-filter.

Within these three methods for count of jellyfish, both the methods by using M type's shapes of brightness values and the stomach number can count one by a camera and counting program only. However, the methods by using the wavelength reflection ratio of jellyfish with the visible light cut-filter need filter besides a camera and counting program. And moreover, it must done field test in order to use these results practically.

References

IIJIMA, K. and M. KAWABE (1990) Inflowing conditions of jellyfish and pollution counter by air bubbling. A jellyfish ecology and counter plan of protection (presentation paper), association of electric, chemical and confabulation meet of pollution counter for marine life, 15–41.

ISHII, M. (1990) Jellyfish protection's counter with the escaping plants of dust in seawater-gate. A jellyfish ecology and counter plan of protection (presentation paper), association of electric, chemical and confabulation meet of pollution counter for marine life, 78–86.

ILLUMINATION GAKKAI (1990) Optical measuring manual. 249–251, NIPPONRIKO.

INAGAKI, T. and M. TOYOKAWA (1991) Studies on counting methods of jellyfish *Aurelia aurita* by acoustic means. *Japan Soc. Fish. Oceanogr.* **55**, 25–34.

KUBOTA, H. (1959) Application Optics. IWANAMI, 181–184, Tokyo.

KUWAHARA, R., S. SATO and N. NOGUCHI (1969) Ecological studies on the Medusa, *Aurelia aurita* LAMARCK-Ⅰ. Distribution of *Aurelia* Patches in the north-east region of Tokyo bay in summer 1966 and 1967. *Nippon Suisan Gakkaishi*, **35**, 156-162.

NOGAMI, Y.(1990) Inflowing foreknowledge with the light sensor. A jellyfish ecology and counter plan of protection (presentation paper), association of electric, chemical and confabulation meet of pollution counter for marine life, 7-12.

OKADA, K. (1965) New Japan's animal image's book (Upper). 237, Hokuryukan, Tokyo.

OTA, Y. (1990) Inflowing foreknowledge by acoustic means. A jellyfish ecology and counter plan of protection (presentation paper), association of electric, chemical and confabulation meet of pollution counter for marine life, 13-14.

SAITO, K., E. HAMADA, Y. THENPAROONRAT and T. SASAKURA (1990) Study on target strength of *Aurelia aurita* LAMARCK. *Proc. of Fisheries Engineering Symposium*. 111-114.

SATO, K. (1990) Equipment for occurring of watercourse. Jellyfish ecology and counter plan of protection (presentation paper), association of electric, chemical and confabulation meet of pollution counter for marine life, 42-58.

TERAMOT, K. (1991) Aquarium of jellyfish. 133 - 142, Kenseishia, Tokyo.

TODA, K. (1990) Net for protection of watercourse and protection counter of jellyfish by pump system. A jellyfish ecology and counter plan of protection (presentation paper), association of electric, chemical and confabulation meet of pollution counter for marine life, 57-78.

TODA, M., K. HIGUCHI and S. YADA(1995) A jellyfish monitoring system for the power plants with a spectrum analysis methods. *Japan. Soc. Fish. Oceanogr.* **59** : 416-423.

画像処理による浮遊クラゲの検知方法

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火力発電所等における夏場の安定発電の阻害要因の一つに，クラゲによる冷却水取水口の閉鎖により生じる取水量の減少がある。このため，取水口に高感度カメラ等を設置して電送画像を凝視する監視作業が行われており，クラゲの流入監視業務の省力化や同装置の最適制御には，前述の装置を自動作動させるクラゲ検知システムの確立が待望されている。本報では，CCDカメラを用いて海面に浮遊するクラゲの画像解析により浮遊量推定の可能性について検討した。すなわち，撮影時の所要照度と水深の関係，クラゲ体の接触に有無による個体数の識別の可能性，並びにフイルタの種類による画像処理精度の測定方法等について概要を報告する。1）クラゲの画像撮影は水深64cmまでは可能であるが，画像処理後の面積率を50%以上にするためには，しきい値は130が，また水深は20cmより浅いことが必要である。2）画像処理後の面積率を50%以上に確保するためには，撮影時におけるクラゲの照度は280 Lx以上が必要である。3）画像処理には画像撮影時の照度が高く，2値化に必要な輝度のしきい値は120が有効であった。4）接触するクラゲと水面の識別には可視光カットフイルタが有効である。5）投影板を使用すると，海面の揺らぎによる画質の低下を防止でき，2値化処理を直接行えるのでランクフイルタ処理を省略できる。6）クラゲの個体計数は，クラゲの輝度値のM型数または胃袋数を計数することにより可能である。

1997年2月11日　受理

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