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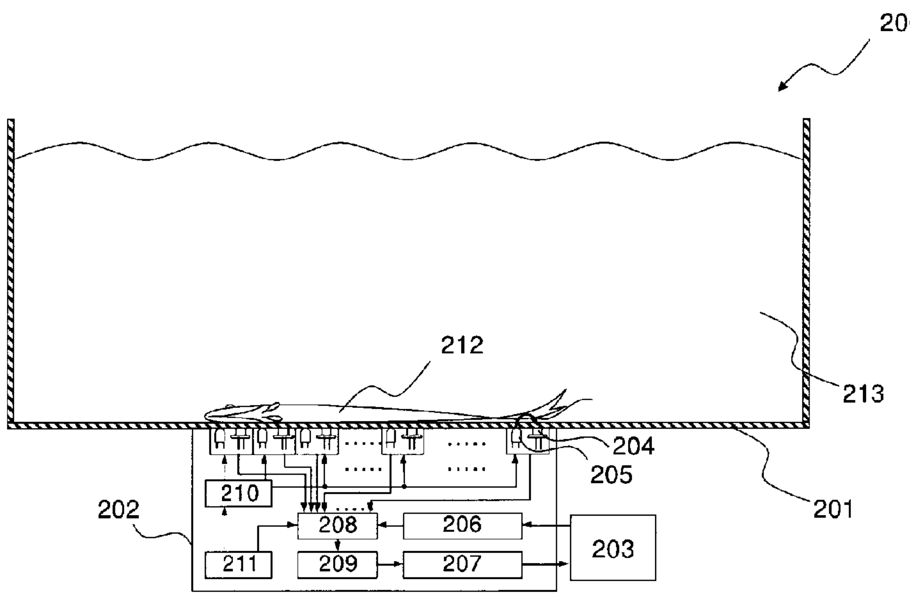

(57) Abrégé/Abstract:
An object of the present invention is to provide a system for monitoring a cardiac condition of a fish wherein the system comprises: a container and a processor, wherein the container is provided with a plurality of detectors on an inner wall surface of said container, and has a space where the fish can swim on an opposite side from said detectors side as viewed from the fish in said container, the processor includes: an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via measurement equipment having the detectors; and an extraction section that extracts a portion reflecting the photoelectric pulse wave in a heart area of the fish the most from the photoelectric pulse waves in the areas that are acquired in the detection period.

ABSTRACT

An object of the present invention is to provide a system for monitoring a cardiac condition of a fish wherein the system comprises: a container and a processor, wherein the container is provided with a plurality of detectors on an inner wall surface of said container, and has a space where the fish can swim on an opposite side from said detectors side as viewed from the fish in said container, the processor includes: an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via measurement equipment having the detectors; and an extraction section that extracts a portion reflecting the photoelectric pulse wave in a heart area of the fish the most from the photoelectric pulse waves in the areas that are acquired in the detection period.

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DESCRIPTION

SYSTEM FOR MONITORING HEART CONDITION OF FISH

TECHNICAL FIELD

[0001] The present invention relates to a system for monitoring a cardiac condition of fish.

BACKGROUND ART

[0002] Environmental degradation of fish mariculture has progressed year by year due to contamination of sediments, eutrophication, and the like in a fish farm caused by residual feed and excreta of farm fish. As a result, fish diseases, red tides, and the like frequently occur in recent years, which keep producing devastating damage to the industry.

While land-based culture has advantages that all aspects of raising environment can be controlled and that safe and healthy farm fish can be produced, due to a completely enclosed system, it is easily anticipated that the farm fish is under persistent stress, and damage by a disease outbreak such as of an infection disease tends to be significant.

In order to solve such problems of the land-based culture, it is strongly desired to comprehend a stress condition and a health condition of fish in real time, to prevent the damage by the disease outbreaks such as of the infection disease by maintaining the health condition, and to improve feed conversion efficiency and the like.

For this reason, a biological monitoring technique for fish in a living state is essential, and several techniques have been researched until today. As a method for monitoring physiology of fish in the land-based culture, for example, such a method is available that fish is periodically sampled from a tank to monitor a cardiac condition of fish.

[0003] As such a monitoring method, for example, a method for acquiring an electrocardiogram by inserting an electrode probe in fixed fish is available (Non-patent documents 1, 3). In addition, a method for measuring a photoelectric pulse wave in an area near a heart of fish under anesthesia in a fixing container by using a transmission probe is available (Patent document 1). Furthermore, a method for imaging the heart of fish by using a container that accommodates target fish in water and has a specified space and analyzing the captured image to analyze the physiology of fish is available (Patent document 2). Moreover, a method for subjecting the stress condition of fish into a chaos analysis on the basis of information acquired by monitoring the cardiac condition of fish has been known (Non-patent document 2).

PRIOR ART DOCUMENTS

PATENT DOCUMENTS

[0004]

Patent document 1: Japanese Patent Laid-open (kokai) No. 2009-195376

Patent document 2: Japanese Patent Laid-open (kokai) No. 2013-116092

NON-PATENT DOCUMENTS

[0005]

Non-patent document 1: Takahito Kojima, "Gyorui no shindenzu doshutsu gijutsu to sono ouyou," *Nippon Suisan Gakkaishi* 79, no. 3 (2013): 319-322.

Non-patent document 2: Yuki Inoue, and Tsuyoshi Miyata, "Jikan bunkai histogram pattern ni yoru stress-relax jikeiretsu sen-i no kashika," *29th Biomedical Fuzzy Systems Association Nenji Taikai Koen Ronbunshu*, November 26, 2016.

Non-patent document 3: Kaoru Fujita, Toshihiro Watanabe, and Xiu Mei Cho, "Hirame no shinpakusu ni oyobosu hikari kankyo to teishitsu no eikyo," *National Research Institute of Fisheries Engineering Technical Report* 18 (1996); 233-238.

Non-patent document 4: Takahito Kojima, Hiroyasu Neishi, Yasuhito Yoshizaki, and Hideo Soeda, "Saidai Entropy-ho wo riyou shita gyorui shinpaku hendo no shuhasu bunseki," *Fisheries Engineering* 38, no. 2 (2001): 145-150.

Non-patent document 5: Satoru Yamauchi, Junji Tsutamono, and Toshihiro Mizuno, "Handy-gata kinsekigai sokuteiki niyoru maaji oyobi sono himono no shibou sokutei," *Journal of the Japanese Society for Food Science and Technology* 53, no. 7 (2006): 393-397.

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0006] In order to monitor the physiology of fish in the land-based culture, it is important to monitor the cardiac condition of target fish in a state similar to a natural culture state.

It is concerned that the method described in non-patent document 1 is an invasive method in points that target fish is fixed and the electrode probe is inserted in fish, and possibly damages or kills fish. The method described in patent document 1 has a problem in terms of a degree of freedom in a position of the measurement probe. In addition, implementation of the method is limited in a laboratory, and it is essential to suppress or stop motion of fish by the anesthesia. Thus, it cannot be said that fish is monitored in the state similar to the natural culture state. In the method described in patent document 2, motion of fins of fish is restricted by the container in specified size. In addition, the container blocks such a characteristic that fish swims forward by right-and-left motion of a body as well as vision of fish. Thus, it cannot be said that fish is monitored in the state similar to the natural culture state.

The present invention has been made in view of such a circumstance and therefore has an object of providing a system for monitoring a cardiac condition of target fish in a state similar to a natural culture state.

MEANS FOR SOLVING THE PROBLEMS

[0007] As a result of the earnest investigation to solve the above problem, the present inventors have found that a cardiac condition of fish could be monitored when a plurality of detectors was arranged on an inner wall surface of a container, a photoelectric pulse wave was acquired from each of the detectors, and a portion reflecting the photoelectric pulse wave in a heart area of the target fish the most was extracted by analyzing the photoelectric pulse waves. The present invention is as follows.

[0008]

According to a general aspect of the disclosure, there is provided a system for monitoring a cardiac condition of a fish, the system comprising: a container and a processor, wherein the container is provided with a plurality of detectors on an inner wall surface of said container, and defines a space where the fish can swim on an opposite side from a side of said detectors as viewed from the fish in said container, wherein the processor includes: an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via a measurement equipment having the plurality of detectors; and an extraction section that extracts from the acquired photoelectric pulse waves a portion reflecting the most the photoelectric pulse wave in a heart area of the fish; wherein a velocity pulse wave is calculated from the acquired photoelectric pulse waves, and wherein in the case where, within the acquired photoelectric pulse waves, a portion from a first extremely small value to a second extremely small value that appears next in time is set as one cycle, the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to a cycle in which at least two extremely large values exist in the velocity pulse wave in a period corresponding to said one cycle and a difference between the extremely large value of said at least two extremely large values that appears first in time and the extremely large value of said at least two extremely large values that appears next in time is equal to or higher than 0.5 V/s.

According to another general aspect, there is provided a method for monitoring a cardiac condition of a fish, the method comprising: acquiring photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period by a plurality of detectors; extracting from the acquired photoelectric pulse waves a portion reflecting the most the

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photoelectric pulse wave in a heart area of the fish; calculating a velocity pulse wave from the acquired photoelectric pulse waves; and wherein in the case where, within the acquired photoelectric pulse waves, a portion from a first extremely small value to a second extremely small value that appears next in time is set as one cycle, the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to a cycle in which at least two extremely large values exist in the velocity pulse wave in a period corresponding to said one cycle and a difference between the extremely large value of said at least two extremely large values that appears first in time and the extremely large value of said at least two extremely large values that appears next in time is equal to or higher than 0.5 V/s.

According to another general aspect, there is provided a processor for a system comprising a measurement equipment having a plurality of detectors provided on a wall surface contacting a space where a fish can swim, wherein the processor includes: an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via the measurement equipment comprising the plurality of detectors; and an extraction section that extracts from the acquired photoelectric pulse waves a portion reflecting the most the photoelectric pulse wave in a heart area of the fish; wherein a velocity pulse wave is calculated from the acquired photoelectric pulse waves, and wherein in the case where, within the acquired photoelectric pulse waves, a portion from a first extremely small value to a second extremely small value that appears next in time is set as one cycle, the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to a cycle in which at least two extremely large values exist in the velocity pulse wave

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in a period corresponding to said one cycle and a difference between the extremely large value of said at least two extremely large values that appears first in time and the extremely large value of said at least two extremely large values that appears next in time is equal to or higher than 0.5 V/s.

Variants, examples and preferred embodiments of the invention are described hereinbelow.

For instance, there is provided [1] a system for monitoring a cardiac condition of fish, the system comprising:

a container and a processor, wherein

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the container is provided with a plurality of detectors on an inner wall surface of said container, and has a space where the fish can swim on an opposite side from said detectors side as viewed from the fish in said container,

the processor includes:

an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via measurement equipment having the detectors; and

an extraction section that extracts a portion reflecting the photoelectric pulse wave in a heart area of the fish the most from the photoelectric pulse waves in the areas that are acquired in the detection period.

[2] The system according to [1], wherein

a velocity pulse wave is calculated from the acquired photoelectric pulse waves in the areas, and

in the case where, of the acquired photoelectric pulse waves in the areas, a portion from a certain extremely small value to an extremely small value that appears next in time is set as one cycle, extraction of the portion reflecting the photoelectric pulse wave in the heart area the most corresponds to extraction of a cycle in which two or more extremely large values exist in the velocity pulse wave in a period corresponding to said one cycle and a difference between the extremely large value that appears first in time and the extremely large value that appears next in time is equal to or higher than 0.5 V/s.

[3] The system according to [1], wherein

a pseudo R-R interval is calculated from the photoelectric pulse waves in the areas acquired in the detection period, and extraction of the portion reflecting the photoelectric pulse wave in the heart area the most corresponds to extraction of the photoelectric pulse wave corresponding to a period in which a standard deviation of the pseudo R-R interval is equal to or smaller than 0.08 seconds.

[4] The system according to any of [1] to [3], wherein

the detectors exist at equally-spaced intervals.

[5] The system according to any of [1] to [4], wherein

fish is Japanese flounder Paralichthys olivaceus or Stone flounder Kareius bicoloratus.

[6] The system according to any of [1] to [5], wherein

each of the detectors is constructed of an element that detects light.

[7] A method for monitoring a cardiac condition of fish, the method comprising:

a process of acquiring photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period by a plurality of detectors; and

a process of extracting a portion reflecting the photoelectric pulse wave in a heart area of the fish the most from the photoelectric pulse waves in the areas acquired in the detection period.

[8] A processor, wherein

a plurality of detectors is provided on a wall surface contacting a space where fish can swim, and

the processor includes:

an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via measurement equipment having the detectors; and

an extraction section that extracts a portion reflecting the photoelectric pulse wave in a heart area of the fish the most from the photoelectric pulse waves in the areas that are acquired in the detection period.

EFFECT OF THE INVENTION

[0009] According to the present invention, it is possible to provide the system for monitoring the cardiac condition of the target fish in the state similar to the natural culture state.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1 is a view illustrating positions of detectors and light sources for target fish according to an embodiment of the present invention.

Fig. 2 is a view of the embodiment of a system in the present invention.

Fig. 3 is a flowchart from detection of photoelectric pulse waves in a plurality of areas to a determination on a stress condition according to the embodiment of the present invention.

Fig. 4 is a view illustrating a positional relationship between Japanese flounder and the two detectors according to Example of the present invention.

Fig. 5 is a view of the detector according to Example of the present invention.

Fig. 6 illustrates a photoelectric pulse wave acquired in Example of the present invention.

Fig. 7 includes (A) the photoelectric pulse wave acquired in a heart area, (B) a velocity pulse wave calculated on the basis of the photoelectric pulse wave, (C) the photoelectric pulse wave acquired in an area away from the heart area, and (D) the velocity pulse wave based on the photoelectric pulse wave in Example of the present invention.

Fig. 8 includes (A) a graph indicative of a pR-R interval that is calculated on the basis of the photoelectric pulse wave acquired from the heart area, and (B) a graph indicative of a pR-R interval that is calculated on the basis of the photoelectric pulse wave acquired from the area away from the heart area in Example of the present invention.

MODE FOR CARRYING OUT THE INVENTION

[0011] The present invention is a system for monitoring a cardiac condition of fish. The system includes a container and a processor. The container is provided with a plurality of detectors on an inner wall surface of the container, and has a space where fish can swim on an opposite side from the detectors side as viewed from fish in the container. The processor includes: an acquisition section that acquires photoelectric pulse waves in a plurality of areas of fish under signal synchronization in time sequence for a specified detection period via measurement equipment having the detectors; and an extraction section that extracts a portion reflecting the photoelectric pulse wave in a heart area the most from the photoelectric pulse waves in the areas that are acquired in the detection period.

[0012] <Container>

The system according to the present invention includes the container. In the container, the detectors are provided on the inner wall surface of the container (including a bottom surface of the container), and the container has the space where fish can swim on the opposite side from the detectors side as viewed from fish in the container. In this way, fish can be accommodated in a state similar to a natural culture state. As long as signals are acquired and the photoelectric pulse waves are acquired in the areas of fish for a specified period, a volume, a material, and the like of the container are not particularly limited. An example of the container is a tank used in land-based culture.

[0013] <Processor>

(Acquisition Section)

The acquisition section performs the following. The detector is not particularly limited as long as the detector can acquire the signal as the photoelectric pulse wave through calculation processing. However, the detector is preferably constructed of an element that detects light. In addition, in the case where a stress condition of fish is analyzed by using the system according to the present invention, for example, by using a velocity pulse wave, the detector preferably exerts performance of such extent that the detector acquires information used for generating the velocity pulse wave, for example, the photoelectric pulse wave in which dicrotic notch appears. A specific example of the detector is a reflective light detector in which the light source and the detector are arranged on the same plane. In the light detector as described in non-patent document 2, fish is irradiated with light from a near-infrared light-emitting diode, and a PIN photodiode detects skin reflected light and backscattering light from inside of a body. An example of the commercially available light-emitting diode is SLR938-CV (central emission wavelength: 945 nm, Sanyo), and examples of the commercially available light detectors are PIN photodiode TPS703 (Toshiba) and S1336-18BQ (HAMAMATSU). The light-emitting diode, a central emission wavelength of which is 945 nm, is preferably used. This is because such light is less likely to be absorbed by fat and is close to an isosbestic point. A near-infrared region is likely to be absorbed by the fat, and it is reported in non-patent document 5 that a peak of the absorption appeared near the wavelength of 940 nm.

[0014] An arrangement region of the detector is the inner wall surface of the container (including the bottom surface of the container), is preferably not interfered by another detector, and may only be a particular region. An example of the particular region is a region where fish prefers to stay, such as a nest or shade.

A description will hereinafter be made on a case where the reflective light detector is used as an example of the detector. However, the detector in the present invention is not limited to this.

[0015] When the reflective light detector is used, a center-to-center distance between the light source and the detector can appropriately be set according to a relationship with a subdermal depth of a measurement point in target fish. In the case where the light source and the detector are defined as a "single set of the light-source and the detector" and a specified clearance is provided from the adjacent set, it is possible to prevent the mutual light from entering and interfering. The clearance can appropriately be adjusted by a person skilled in the art. Size of a light receiving surface of the detector depends on size of target fish. However, in the case where the light receiving surface is large, the number of the measurement points on target fish is reduced. On the other hand, in the case where the light receiving surface is small, only a part of target fish can be measured unless a large number of the detectors is arranged. Thus, in consideration of these points, the suited light receiving surface can be used. An arrangement pattern is not particularly limited, but a regular pattern is preferred, and a pattern with equally-spaced intervals is further preferred. At this time, as illustrated in Fig. 1 (as an example of fish, Japanese flounder 11 is illustrated, and a heart 12 of Japanese flounder is also illustrated), the light sources and the detectors are arranged in a manner to form a row of detectors 13 and a row of light sources 14 in one direction. The row of the detectors 13 is sandwiched between the row of the light sources 14 and another row of detectors 15. Similarly, the row of the light sources 14 is arranged to be sandwiched between the row of the detectors 13 and another row of the light sources (not illustrated). Such a case is preferred due to absence of the interference between the sets of the light sources and the detectors.

[0016] Fig. 2 illustrates an example of a system 200 in the present invention. The system 200 in the present invention includes a container 201, an acquisition section 202, an extraction section 203 (including a calculation section), detectors 204, and light sources 205. For example, the acquisition section 202 may include a detector selection signal generation section 206, a signal process circuit 207, a detector selection circuit 208, an amplifier circuit 209, a drive circuit 210, a synchronous circuit 211, and can appropriately be configured. The synchronous circuit 211 generates a reference clock used to switch operation of each channel. Synchronously with generation of the reference clock, the detector selection circuit 208 in which plural multiplexers are installed sequentially outputs a signal per channel, and the extraction section 203 sequentially determines a valid signal (mode 1). When the extraction section 203 completes the determination on the valid channel, the detector selection circuit 208 is operated such that the multiplexer is only output to the selected channel by the detector selection signal generation section 206 including a logic circuit, and only acquires the valid signal for a specified period (mode 2). Fig. 2 also illustrates fish (target fish) 212 and water 213.

[0017] The specified detection period is not limited as long as it is at least long enough to extract a portion reflecting the photoelectric pulse wave in the heart area of fish the most by the extraction section, which will be described later, from the photoelectric pulse waves acquired in the detection period. For example, a description will be made with reference to Fig. 6. The detection period only has to be equal to or longer than such a period in which one cycle (D1 in Fig. 6) from an extremely small value to an extremely small value that appears next in time can be acquired in the photoelectric pulse wave, which is indicated by Ch1 (a channel 1) and is acquired in an area near the heart, is preferably equal to or longer than three seconds, further preferably equal to or longer than six seconds, and even further preferably equal to or longer than nine seconds. Although an upper limit of the detection period is not particularly limited, the upper limit is equal to or shorter than 10 seconds, for example.

In the case where the velocity pulse wave is used, similar to the above, the detection period only has to be equal to or longer than a period in which one cycle

(D1 in FIGs. 7(A) and (B)) from an extremely small value and an extremely small value that appears next in time can be acquired in the photoelectric pulse wave corresponding to the velocity pulse wave, preferably equal to or longer than three seconds, further preferably equal to or longer than six seconds, and even further preferably equal to or longer than nine seconds. Although the upper limit of the detection period is not particularly limited, the upper limit is equal to or shorter than 10 seconds, for example.

In the case where a pseudo R-R interval, which will be described later, is used, the detection period only has to be a period in which a standard deviation in the pseudo R-R interval can be calculated, preferably equal to or longer than 60 seconds, further preferably equal to or longer than 120 seconds, and even further preferably equal to or longer than 180 seconds. Although the upper limit of the detection period is not particularly limited, the upper limit is equal to or shorter than 600 seconds, for example.

A sampling frequency at which the photoelectric pulse wave is acquired is normally equal to or higher than 1 kHz, preferably equal to or higher than 2 kHz, and even further preferably equal to or higher than 5 k Hz. Although an upper limit of the sampling frequency is not particularly limited, the upper limit is equal to or lower than 10 kHz, for example.

To facilitate an analysis, the detection period is preferably a period in which motion of target fish is slight or target fish remains still.

[0018] Fish is not particularly limited as long as it is taxonomically classified as fish. However, the body of fish is preferably such a body from which the photoelectric pulse waves in plural areas can be acquired. A standard body length (a length from a tip of an upper jaw to a base of a caudal fin) is preferably equal to or longer than 0.8 cm, further preferably equal to or longer than 3 cm, even further preferably equal to or longer than 5 cm, preferably equal to or shorter than 100 cm, further preferably equal to or shorter than 50 cm, and even further preferably equal to or shorter than 30 cm. A body height is preferably equal to or greater than1 mm, further preferably equal to or longer than 3 mm, even further preferably equal to or longer than 5 mm, preferably equal to or less than 3 cm, further preferably equal to or less than 2 cm, and even further preferably equal to or less than 1 cm. A body width is preferably equal to or greater than 0.5 cm, further preferably equal to or longer than 1 cm, even further preferably equal to or longer than 3 cm, preferably equal to or less than 30 cm, further preferably equal to or less than 25 cm, and even further preferably equal to or less than 20 cm.

Fish is preferably classified in *Pleuronectiformes*, and is further preferably Japanese flounder *Paralichthys olivaceus* or Stone flounder *Kareius bicoloratus*. Japanese flounder or Stone flounder tends to remain still for a long period at a spot on a bottom surface in the container. Thus, the photoelectric pulse wave of Japanese flounder or Stone flounder can easily be acquired, and Japanese flounder or Stone flounder is thereby preferred.

[0019] (Extraction Section)

The extraction section performs the following. As will be described in Examples later, the present inventors have found that a phase of the photoelectric pulse wave at a position away from the heart of target fish was displaced from a phase of the photoelectric pulse wave near the heart of target fish. This is estimated to be caused by a difference in vibration propagation duration at the time when the heart is contracted to fill surrounding organs with blood. Furthermore, since gills are operated at blood pumped timing from the heart, vibrations generated by muscles of the gills are also propagated. A description will be made with reference to Fig. 6. In the photoelectric pulse wave that is indicated by Ch1 (the channel 1) and acquired in the area near the heart, in the case where one cycle (D1 in Fig. 6) is set from the extremely small value to the extremely small value that appears next in time, the cycle includes a point (a point a in the period D1 in Fig. 6) at which a gradient is significantly reduced when the photoelectric pulse wave is increased. Meanwhile, in the photoelectric pulse wave that is indicated by Ch2 (a channel 2) and acquired from the position away from the heart, in the case where one cycle (a period D2 in Fig. 6) is set from an extremely small value to an extremely small value that appears next in time, the cycle does not include a point at which the gradient is significantly reduced when the photoelectric pulse wave is increased. This means that coordination of contracted operation of an atrium to contracted operation of a ventricle can be detected.

[0020] This is further clarified when the velocity pulse wave is calculated from the photoelectric pulse wave. Fig. 7(A) illustrates the photoelectric pulse wave acquired from Ch1 (the channel 1), and is the same as the photoelectric pulse wave acquired from Ch1 (the channel 1) in Fig. 6. Fig. 7(B) illustrates the velocity pulse wave that is calculated from the photoelectric pulse wave. At this time, in Fig. 7(B), two or more extremely large values exist on the velocity pulse wave in the one cycle indicated by D1, and a difference between an extremely large value a1 that appears first in time and an extremely large value a2 that appears next in time is large. Meanwhile, Fig. 7(C) illustrates the photoelectric pulse wave that is acquired from Ch2 (the channel 2), and is the same as the photoelectric pulse wave that is acquired from Ch2 (the channel 2) in Fig. 6. Fig. 7(D) illustrates the velocity pulse wave that is calculated from the photoelectric pulse wave. At this time, in Fig. 7(D), two or more extremely large values exist on the velocity pulse wave in the cycle indicated by D2, and there is hardly no difference between an extremely large value a2 that appears first in time and an extremely large value b2 that appears next in time.

Accordingly, in the case where the portion reflecting the photoelectric pulse wave of the heart area the most is extracted by using the velocity pulse wave, the two or more extremely large values exist on the velocity pulse wave, and a cycle in which the difference between the extremely large value that appears first in time and the next extremely large value in time is large is preferably extracted. The difference is preferably equal to or higher than 0.5 V/s, is further preferably equal to or higher than 1.0 V/s, and is even further preferably equal to or higher than 2.1 V/s.

[0021] In addition, a pulse wave peak interval (in the present specification, defined as the "pseudo R-R interval" and may be abbreviated as a "pR-R interval" by abbreviating English translation of pseudo R-R interval) is calculated from the photoelectric pulse wave, and the portion reflecting the photoelectric pulse wave in the heart area of fish the most is preferably extracted on the basis of the pulse wave peak interval. In general, an R-R interval is used as an interval of an R wave at the time of measuring an electrocardiogram, and an a-a interval is used in the case of the photoelectric pulse wave. However, in the present invention, even in the case where acceleration pulse wave is determined to be measured in the area near the heart, a peak height of the waveform is unstable. Thus, the pR-R interval, which is calculated on the basis of the velocity pulse wave, is also preferably used. When the pR-R interval is used, a standard deviation of the pR-R interval in a specified period can be used as an index. When being described by using the example, the standard deviation is Δd illustrated in Fig. 8. In the case where the photoelectric pulse wave is acquired in the area near the heart, the pR-R interval is usually equal to or shorter than 0.08 seconds, is preferably equal to or shorter than 0.05 seconds, and is even further preferably equal to or shorter than 0.03 seconds, and a lower limit value of the pR-R interval is normally longer than 0 seconds. Meanwhile, in the case where the photoelectric pulse wave is acquired at the position away from the heart, a range of the pR-R interval is wider than the above range. Thus, the photoelectric pulse wave corresponding to such a period that the standard deviation of the pR-R interval falls within the above range can be extracted as the portion reflecting the photoelectric pulse wave in the heart area fish the most.

[0022] An aspect of the processor may include the detectors on the wall surface that contacts the space where fish can swim, and may also include: the acquisition section that acquires the photoelectric pulse waves in the areas of fish under the signal synchronization in the time sequence for the specified detection period via the measurement equipment having the detectors; and the extraction section that extracts the portion reflecting the photoelectric pulse wave in the heart area the most from the photoelectric pulse waves in the areas that are acquired in the detection period.

In the case where the processor is used in the system, the wall surface may be the inner wall surface of the container. An example of another aspect of use is an aspect in which the wall surface is a surface of a substrate or the like and the processor is placed stationary in the container filled with water, and an example of a preferred aspect is an aspect in which the processor is placed stationary in a manner to contact the inner wall surface of the container filled with water. As long as the substrate or the like includes the detectors, and the acquisition section and the extraction section can implement functions thereof, a shape, size, and a material of the substrate or the like are not particularly limited.

[0023] (Analysis of Stress Condition)

After the system according to the present invention acquires the photoelectric pulse wave in the heart area of fish as a cardiac condition of fish, for example, as reported in non-patent document 2, a stress condition of fish may be analyzed. At this time, in the case where the photoelectric pulse wave in the heart area in a sufficiently long period is required for the analysis, the analysis may be made by coupling the photoelectric pulse waves extracted by the system according to the present invention to create the temporarily continuous photoelectric pulse wave. Then, in the case where it is determined that fish is under the stress condition by the analysis, a measure is preferably taken for fish to heal, alleviate, or improve the stress condition. Examples of the measures are optimization of water quality (for example, a water temperature, pH, an osmotic pressure, salt concentration, oxygen concentration, carbon dioxide concentration, ammonia concentration, nitrogen concentration, hardness (calcium salt, magnesium salt, and the like), and the like), optimization of farming conditions (for example, light intensity, feed, feeding, the number of fish, density of fish, a water exchange frequency, and the like), an investigation on a feed preference, sterilization, detection and elimination of diseased fish. Each of these measures can be taken by a normal method.

[0024] (Flow from Detection Initiation to Determination on Stress Condition Determination)

In the present invention, the photoelectric pulse waves in the areas of fish are acquired in the time sequence for the specified detection period. Then, the portion reflecting the photoelectric pulse wave in the heart area of fish the most is extracted from the photoelectric pulse waves in the areas acquired in the detection period, and is preferably used for the analysis of the stress condition after the extraction so as to determine the stress condition of fish. Fig. 3 is a flow illustrating DETECTION INITIATION S101 to STRESS CONDITION DETERMINATION S106. The extraction section 203 executes processing from DETECTION INITIATION S101 to STRESS CONDITION ANALYSIS S105. An example of the extraction section 203 is a calculator. STRESS CONDITION DETERMINATION S106 may be made by a person or may be made by the extraction section 203. By the control in S102 and S103 illustrated in Fig. 3, the sufficiently long detection period is secured for the extraction, and the photoelectric pulse waves are acquired in the areas of fish.

In S101, under the signal synchronization, the photoelectric pulse waves in the areas of fish start being detected. In S102, it is determined whether the specified detection period is completed. As the specified detection period, the period corresponding to each of the aspects described in the above section

"Acquisition Section" is applied. If a negative determination is made in S102, the detection is performed again. On the other hand, if a positive determination is made in S102, the processing proceeds to S103, and it is determined whether the photoelectric pulse waves have successfully been acquired in the areas of fish. If a negative determination is made in S103, the detection is performed again. On the other hand, if a positive determination is made in S103, the processing proceeds to S104, and the portion reflecting the photoelectric pulse wave in the heart area of fish the most is extracted from the acquired photoelectric pulse waves in the areas according to each of the aspects described in the above section "Extraction Section". When the extraction is completed in S104, the processing proceeds to S105. Then, for example, the stress condition of fish is analyzed as reported in non-patent document 2, when the analysis is completed the processing proceeds to S106, and the stress condition of fish is determined on the basis of an analysis result.

EXAMPLES

[0025] Next, a further specific description will be made on the present invention by using Examples. However, the present invention is not limited to these Examples.

[0026] (Fish and System)

In this example, the system in which the two detectors are arranged on the bottom surface of the container was built, and Japanese flounder was used as fish. Japanese flounder was provided by Faculty of Agriculture and Marine Sciences in Kochi University, had a body length of 30 cm and weight of 314 g, was healthy, and was raised in a circulation tank in which a water temperature was controlled at 21 °C.

A positional relationship between Japanese flounder and the two detectors is as illustrated in Fig. 4. The channel 1 (denoted by 41 in Fig. 4, having a light source 411 and a detector 412) was arranged in the heart area of Japanese flounder 43 (a heart 44 of Japanese flounder), and the channel 2 (denoted by 42 in Fig. 4, having a light source 421 and a detector 422) was arranged at the position away from the heart. While the photoelectric pulse waves were acquired, Japanese flounder 43 was not physically active or did not move. The detector had light receiving surface size of 1.1 mm × 1.1 mm, and the center-to-center distance of the light source - the detector was set to 8 mm. Fig. 5 illustrates dimensions and the like of the channel 1 and the channel 2.

The water temperature was controlled at 21 °C, the light from the near-infrared light-emitting diode (SLR938-CV, a central wavelength λ = 945 nm, Sanyo) entered Japanese flounder, and the skin reflected light and the backscattering light from the inside of the body were detected by the PIN photodiode (S1336-18BQ, HAMAMATSU). A data logger (GL900, GRAPHTEC) was used to acquire the signal at the sampling frequency of 1 kHz through a low-pass filter 5 Hz for 6 minutes via a DC servo drive.

[0027] (Example 1: Analysis of Photoelectric Pulse Wave)

Fig. 6 illustrates photoelectric pulse wave data that is acquired from the channel 1 (Ch1) and the channel 2 (Ch2). In the photoelectric pulse wave acquired from the channel 1, the point a at which the gradient is significantly reduced at the time of an increase in the photoelectric pulse wave is generated in the cycle indicated by D1 in Fig. 6. Fig. 7(A) illustrates the photoelectric pulse wave acquired from the channel 1, and is the same as the photoelectric pulse wave acquired from the channel 1 illustrated in Fig. 6. Fig. 7(B) illustrates the velocity pulse wave that is acquired by calculating the photoelectric pulse wave. At this time, in Fig. 7(B), it was confirmed that the two or more extremely large values of the velocity pulse wave existed in the cycle indicated by D1. The difference between the extremely large value a1 (3.17 V/s) that appeared first in time and the extremely large value b1 (1.26 V/s) that appeared next was 1.91 V/s.

Meanwhile, in the photoelectric pulse wave acquired from the channel 2, the point at which the gradient of the photoelectric pulse wave was significantly changed at the time when the photoelectric pulse wave is increased was not observed in the cycle illustrated in Fig. 6. Fig. 7(C) illustrates the photoelectric pulse wave acquired from the channel 2, and is the same as the photoelectric pulse wave from the channel 2 in Fig. 6. Fig. 7(D) illustrates the velocity pulse wave that is acquired by calculating the photoelectric pulse wave. At this time, in Fig. 7(D), it was confirmed that the two or more extremely large values of the velocity pulse wave exist in the cycle indicated by D2. At this time, a difference between an extremely large value a2 (2.02 V/s) that appears first in time and an extremely large value b2 (2.09 V/s) that appears next was -0.07 V/s.

[0028] (Example 2: Analysis of pR-R interval)

Figs. 8(A) and (B) each illustrates the pR-R interval that was acquired by sampling a period from 0 seconds to 120 seconds for each 0.1 seconds using an Akima spline at an origin on the basis of the photoelectric pulse waves acquired from the channel 1 (Ch1) and the channel 2 (Ch2) in Example 1. An average of the pR-R interval based on the photoelectric pulse wave acquired from the channel 1 (Ch1) was 1.108 seconds and was 54.2 bpm when being converted to a heart rate, and the standard deviation thereof was 0.024 seconds. Meanwhile, an average of the pR-R interval based on the photoelectric pulse wave acquired from the channel 2 (Ch2) was 1.111 seconds and was 54.0 bpm when being converted to the heart rate, and the standard deviation thereof was 0.096 seconds.

DESCRIPTION OF REFERENCE NUMERALS

[0029]

11, 43: Japanese flounder

12, 44: Heart of Japanese flounder

13, 15, 412, 422: Detector

14, 411, 421: Light source

200: System

201: Container

202: Acquisition section

203: Extraction section (including calculation section)

204: Detector

205: Light source

206: Detector selection signal generation section

207: Signal process circuit

208: Detector selection circuit

209: Amplifier circuit

210: Drive circuit

211: Synchronous circuit

212: Fish (target fish)

41: Channel 1

42: Channel 2

CLAIMS

1. A system for monitoring a cardiac condition of a fish, the system comprising:

a container and a processor, wherein

the container is provided with a plurality of detectors on an inner wall surface of said container, and defines a space where the fish can swim on an opposite side from a side of said detectors as viewed from the fish in said container, wherein

the processor includes:

an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via a measurement equipment having the plurality of detectors; and

an extraction section that extracts from the acquired photoelectric pulse waves a portion reflecting the most the photoelectric pulse wave in a heart area of the fish; wherein

a velocity pulse wave is calculated from the acquired photoelectric pulse waves, and wherein

in the case where, within the acquired photoelectric pulse waves, a portion from a first extremely small value to a second extremely small value that appears next in time is set as one cycle, the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to a cycle in which at least two extremely large values exist in the velocity pulse wave in a period corresponding to said one

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cycle and a difference between the extremely large value of said at least two extremely large values that appears first in time and the extremely large value of said at least two extremely large values that appears next in time is equal to or higher than 0.5 V/s.

2. The system according to claim 1, wherein

a pseudo R-R interval is calculated from the acquired photoelectric pulse waves, and wherein

the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to the photoelectric pulse wave corresponding to a period in which a standard deviation of the pseudo R-R interval is equal to or smaller than 0.08 seconds.

3. The system according to claim 1 or 2, wherein

the plurality of detectors are equally spaced from each other.

4. The system according to any one of claims 1 to 3, wherein

the fish is a Japanese flounder *Paralichthys olivaceus* or a Stone flounder *Kareius bicoloratus*.

5. The system according to any one of claims 1 to 4, wherein

each of the plurality of detectors is constructed of an element that detects light.

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6. A method for monitoring a cardiac condition of a fish, the method comprising:

acquiring photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period by a plurality of detectors;

extracting from the acquired photoelectric pulse waves a portion reflecting the most the photoelectric pulse wave in a heart area of the fish ;

calculating a velocity pulse wave from the acquired photoelectric pulse waves; and wherein

in the case where, within the acquired photoelectric pulse waves, a portion from a first extremely small value to a second extremely small value that appears next in time is set as one cycle, the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to a cycle in which at least two extremely large values exist in the velocity pulse wave in a period corresponding to said one cycle and a difference between the extremely large value of said at least two extremely large values that appears first in time and the extremely large value of said at least two extremely large values that appears next in time is equal to or higher than 0.5 V/s.

7. The method according to claim 6, comprising

calculating a pseudo R-R interval from the acquired photoelectric pulse waves, wherein

the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to the photoelectric pulse wave corresponding to a period in

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which a standard deviation of the pseudo R-R interval is equal to or smaller than 0.08 seconds.

8. The method according to claim 6 or 7, wherein

the plurality of detectors are equally spaced from each other.

9. The method according to any one of claims 6 to 8, wherein

the fish is a Japanese flounder *Paralichthys olivaceus* or a Stone flounder *Kareius bicoloratus*.

10. The method according to any one of claims 6 to 9, wherein

each of the plurality of detectors is constructed of an element that detects light.

11. A processor for a system comprising a measurement equipment having a plurality of detectors provided on a wall surface contacting a space where a fish can swim, wherein

the processor includes:

an acquisition section that acquires photoelectric pulse waves in a plurality of areas of the fish under signal synchronization in time sequence for a specified detection period via the measurement equipment comprising the plurality of detectors; and

an extraction section that extracts from the acquired photoelectric pulse waves a portion reflecting the most the photoelectric pulse wave in a heart

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area of the fish; wherein

a velocity pulse wave is calculated from the acquired photoelectric pulse waves, and wherein

in the case where, within the acquired photoelectric pulse waves, a portion from a first extremely small value to a second extremely small value that appears next in time is set as one cycle, the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to a cycle in which at least two extremely large values exist in the velocity pulse wave in a period corresponding to said one cycle and a difference between the extremely large value of said at least two extremely large values that appears first in time and the extremely large value of said at least two extremely large values that appears next in time is equal to or higher than 0.5 V/s.

12. The processor according to claim 11, wherein

a pseudo R-R interval is calculated from the acquired photoelectric pulse waves, and

the portion reflecting the most the photoelectric pulse wave in the heart area corresponds to the photoelectric pulse wave corresponding to a period in which a standard deviation of the pseudo R-R interval is equal to or smaller than 0.08 seconds.

13. The processor according to claim 11 or 12, wherein

the plurality of detectors are equally spaced from each other.

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14. The processor according to any one of claims 11 to 13, wherein

the fish is a Japanese flounder *Paralichthys olivaceus* or a Stone flounder *Kareius bicoloratus*.

15. The processor according to any one of claims 11 to 14, wherein

each of the plurality of detectors is constructed of an element that detects light.

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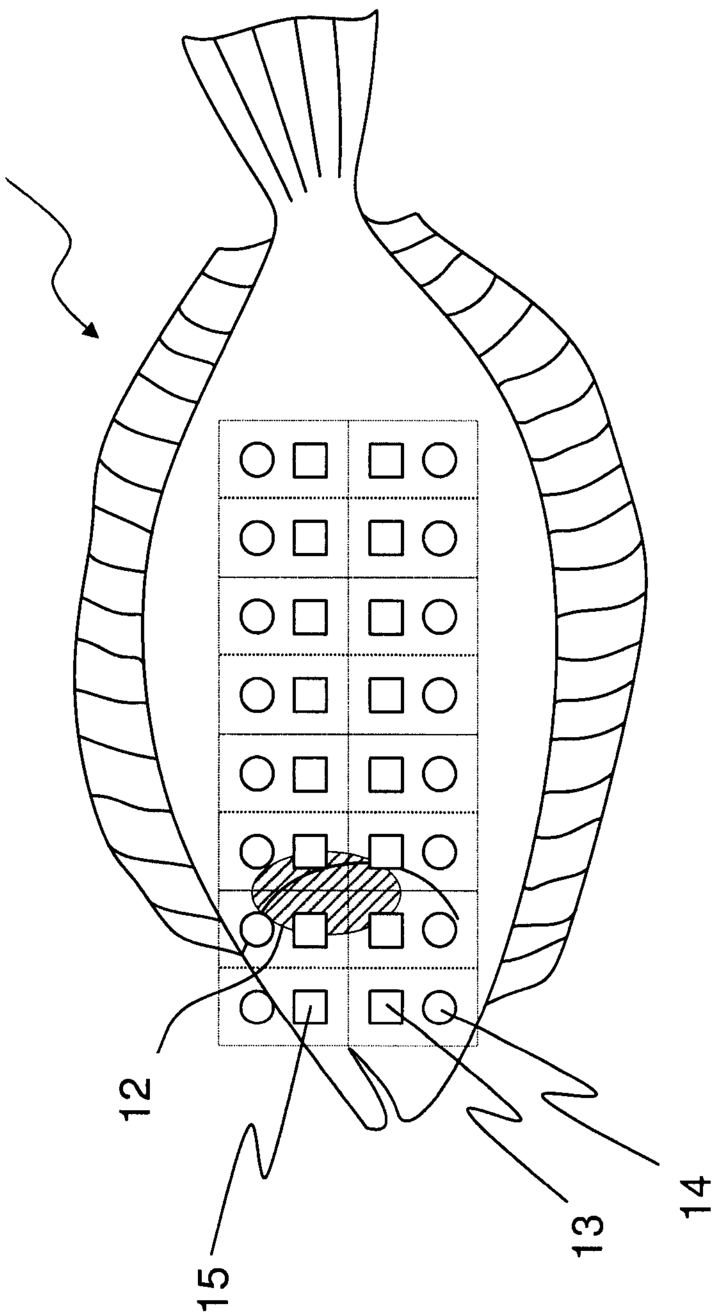


Fig. 1

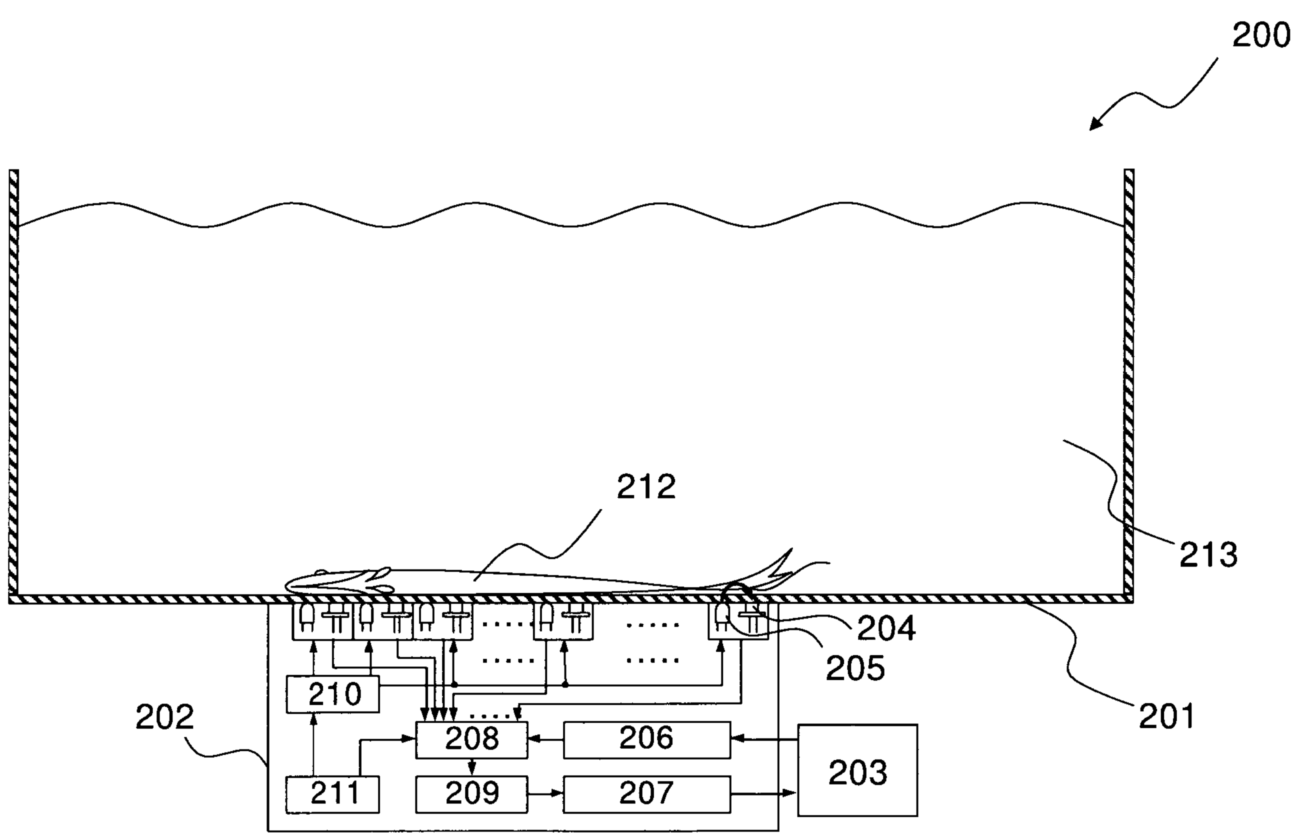


Fig. 2

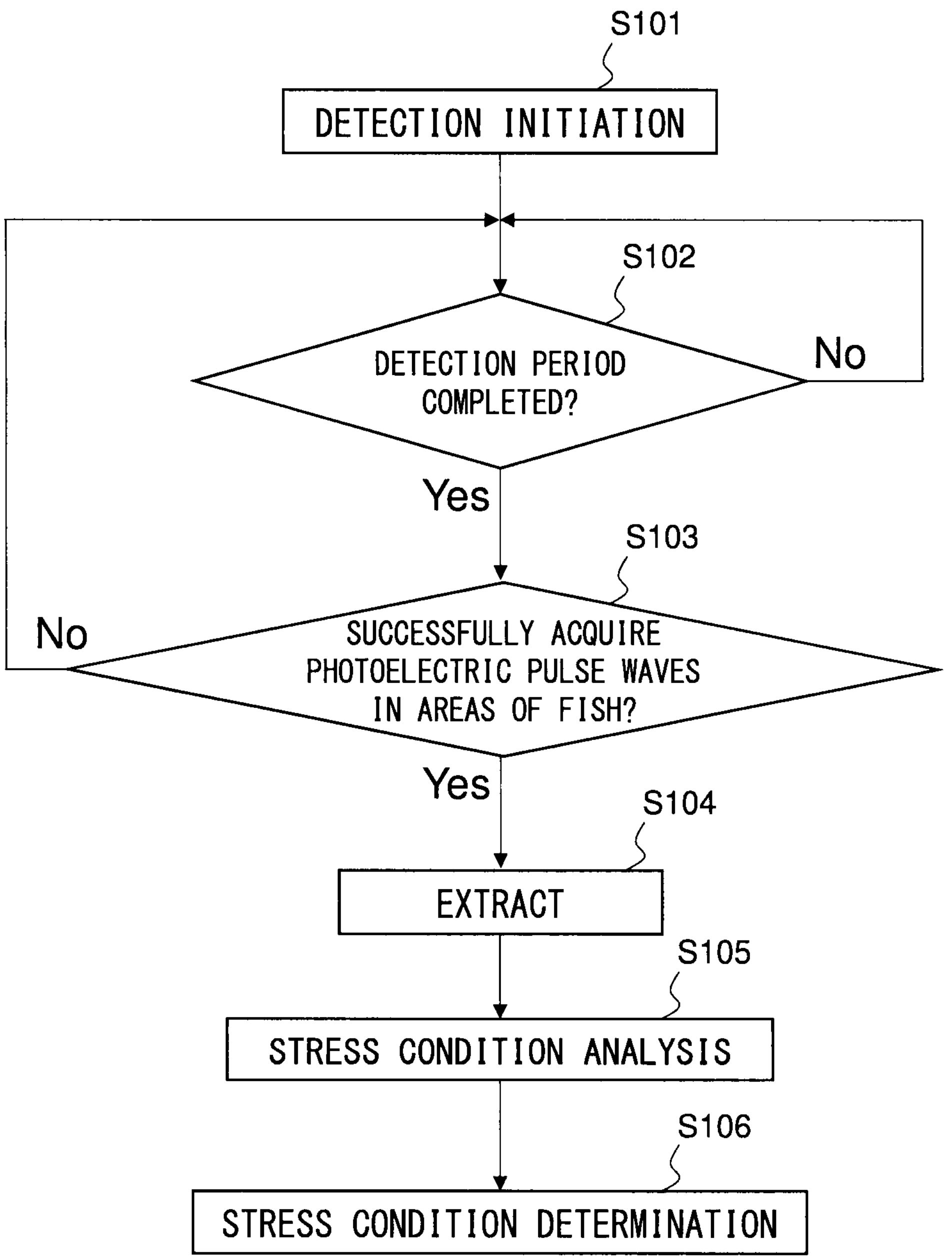

S101
DETECTION INITIATION
S102
DETECTION PERIOD COMPLETED?
No
Yes
S103
SUCCESSFULLY ACQUIRE PHOTOELECTRIC PULSE WAVES IN AREAS OF FISH?
No
Yes
S104
EXTRACT
S105
STRESS CONDITION ANALYSIS
S106
STRESS CONDITION DETERMINATION

Fig. 3

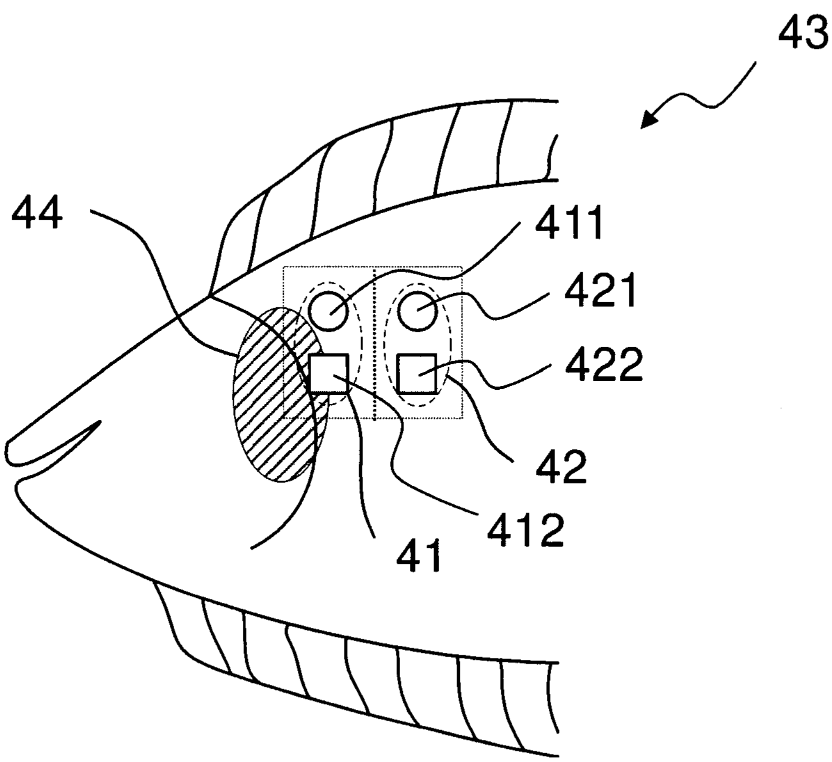


Fig. 4

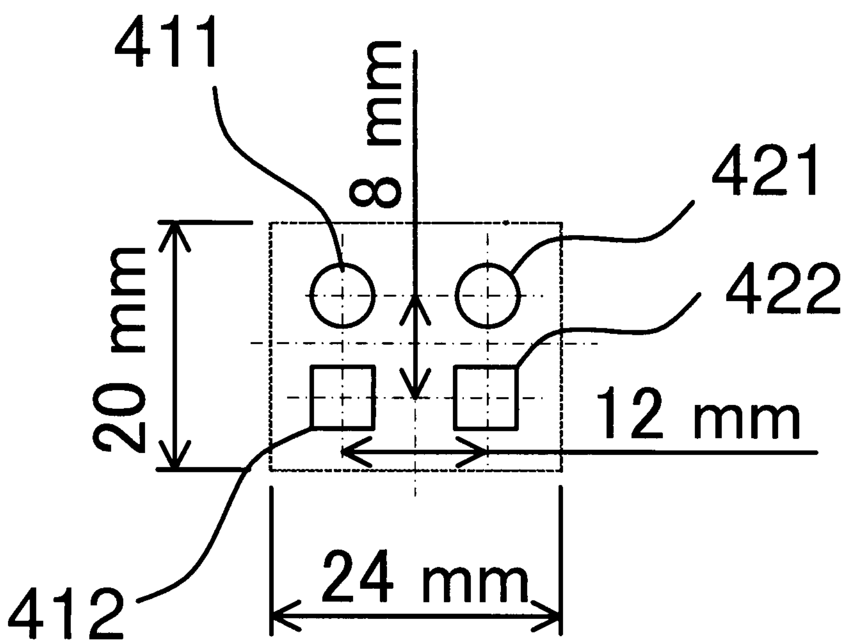


Fig. 5

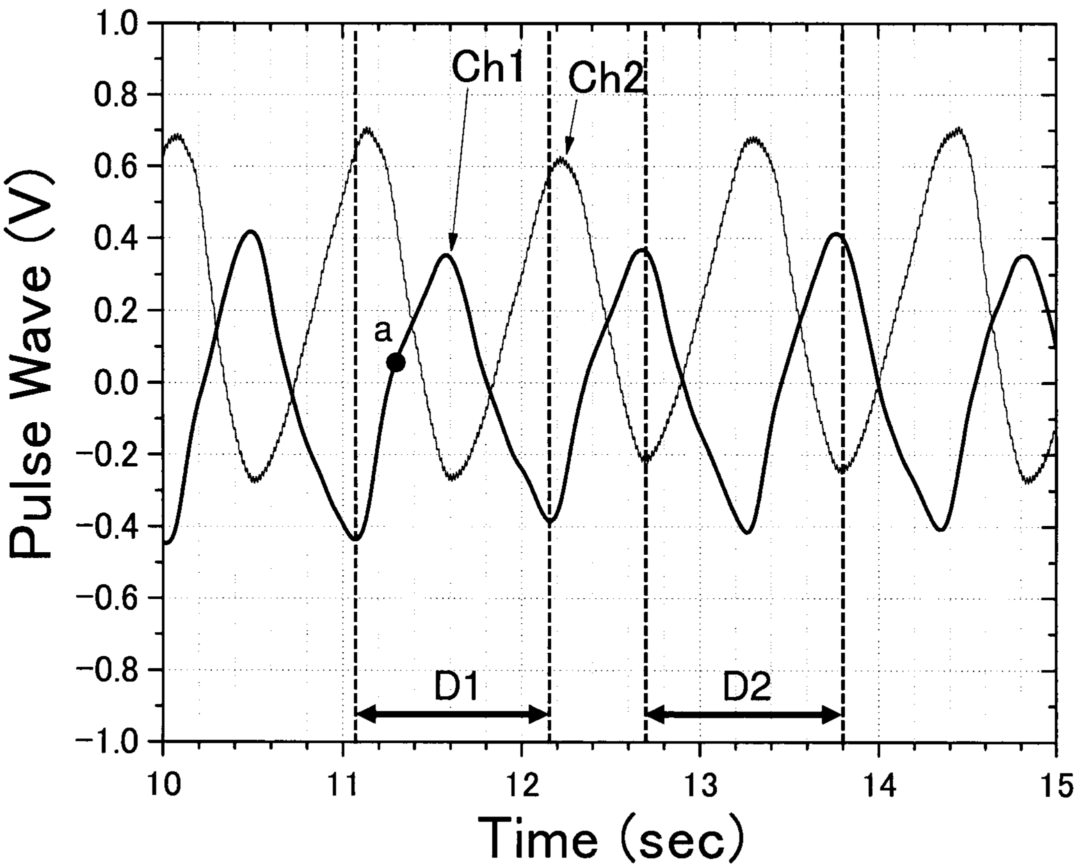

Ch1
Ch2
a
D1
D2
Pulse Wave (V)
Time (sec)
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10
11
12
13
14
15

Fig. 6

Fig.7(A)

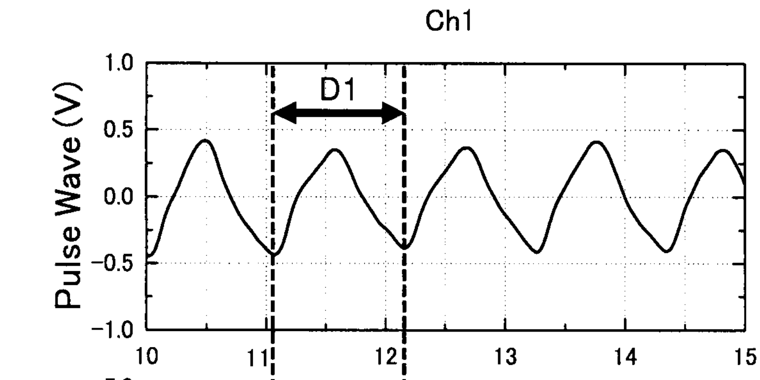


Fig.7(B)

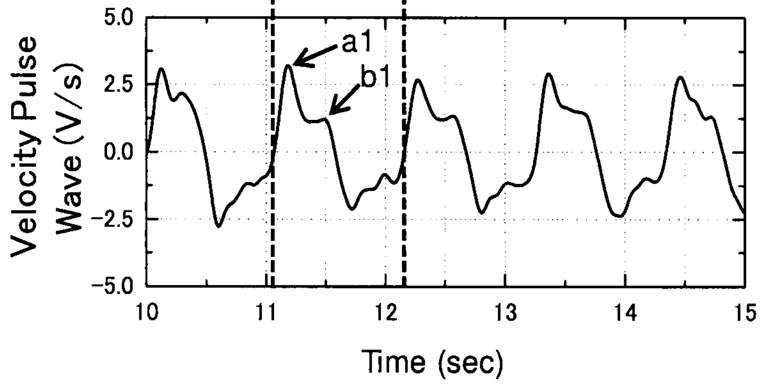


Fig.7(C)

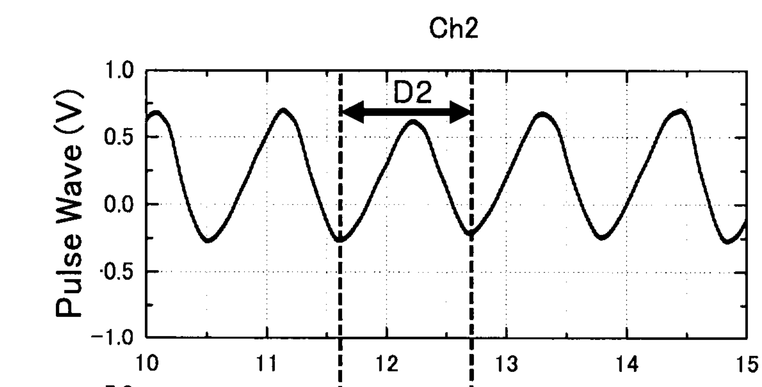


Fig.7(D)

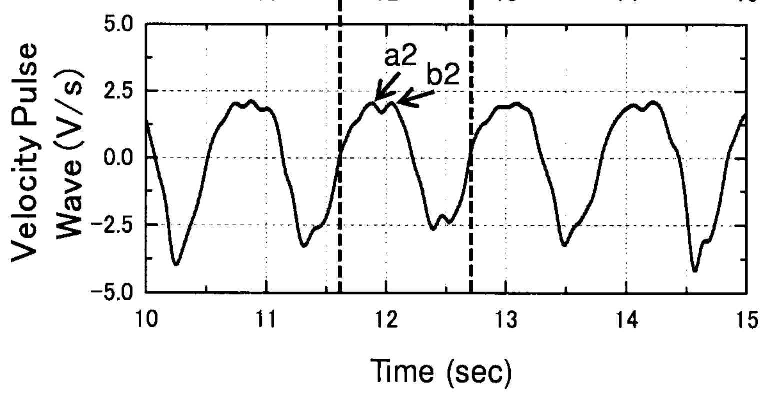


Fig. 7

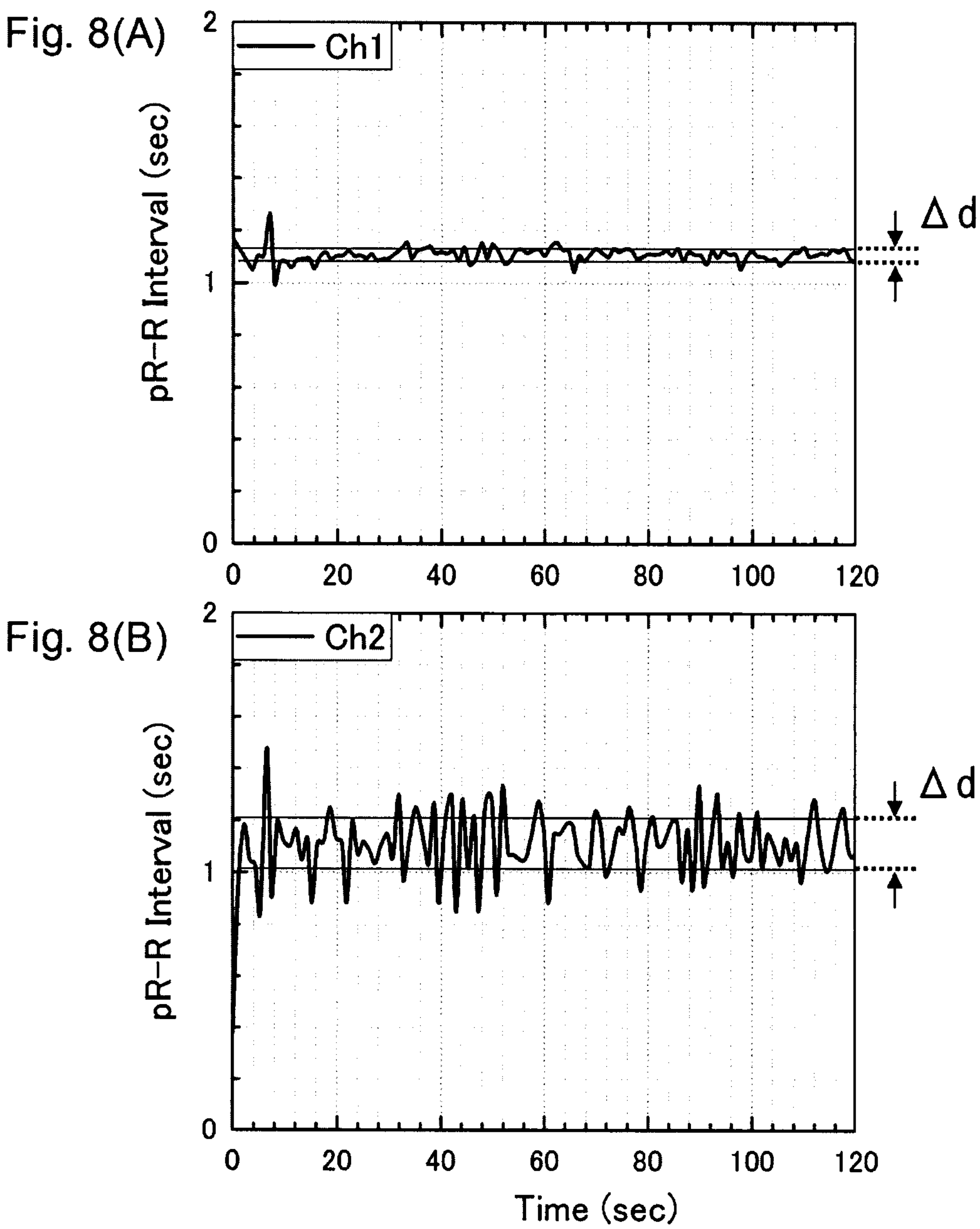
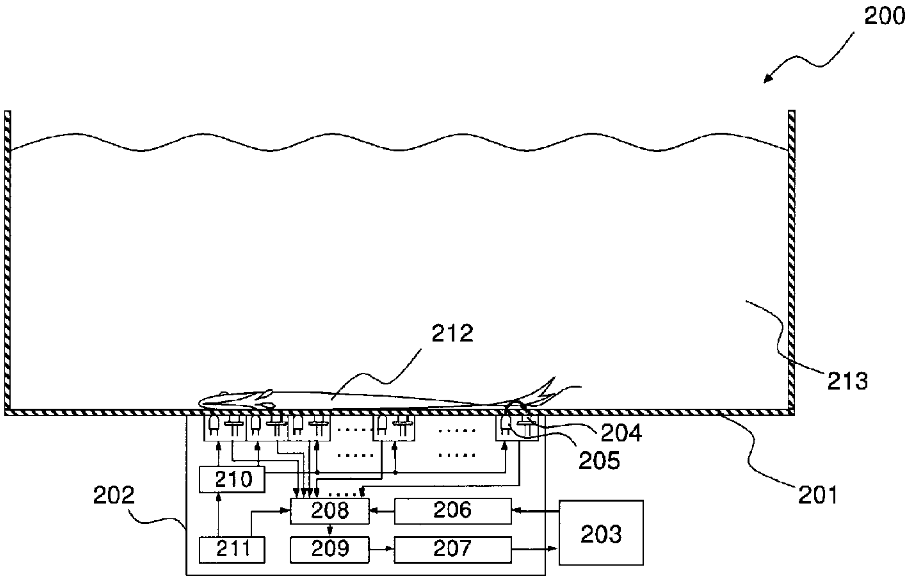


Fig. 8(A)
Ch1
pR-R Interval (sec)
Δd
Fig. 8(B)
Ch2
pR-R Interval (sec)
Δd
Time (sec)
0
20
40
60
80
100
120
0
1
2

Fig. 8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