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Studies on the Accuracy of Counting Seedlings Fry by Image Processing Techniques*

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Abstract: To count fry by an image processing system, a counting system comprising first and second belt conveyors, and a device to prevent multiplication of fry was fabricated, thereby the effects of the optimum circumferential speed difference between the first and the second conveyor belts, the threshold selection method for image analyses, lighting direction and illumination intensity upon counting accuracy were investigated. 1) Threshold selections of fry pictures at threshold values of 40 and 50 are recommended rather than the discriminant analytical method. 2) Lighting from below the conveyor belt are suitable in order to obtain stable video pictures. 3) To achieve an efficient and accurate fry count, it is suitable to maintain the circumferential speed difference between the first and second conveyor belts in the range from −5 cm/s to 25 cm/s. 4) If the circumferential speed of the second conveyor belt is set at 20 cm/s, it is estimated that 24,000 fry per unit time per one processing line can be counted by the image processing thchnique.

1. Introduction

Mechanization of manual fish-counting processes used when seedlings fry is shipped has been strongly desired. Conventionally, the method of counting fry, when in a large number, is to approximate the number through assumptions on the mean unit weight or volume of fish. This, however, involves remarkable counting errors (CHEN, 1992).

In some cases of high-grade fish species, unjustifiably large discrepancies in fish count have caused lawsuits by both buyers and sellers, because of the large economic impact involved. A fry counting system is proposed in studies on counting systems of fry. However, this system has multiple drawbacks including the low counting ability per unit time (YADA *et al*, 1993). Moreover, bubbles generated from fish bodies at low pressures, minute bubbles attaching to gills, and a variety of other bubbles generated at vents in the system and in low-pressure areas are detecred by sensors, giving a false count that is larger than the real count. To solve the problem of such large counting errors, precision techniques are indispensable (CHEN *et al.*, 1993). Nothing the background and the problems above, a fish counting system using image-processing thchniques designed to enhance counting accuracy and efficiency, as well as to prevent duplicated fish counts was test fabricated, and the counting accuracy was evaluated.

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2. Experimental Method

1) *Experimental equipment*

Figure 1 shows experimental equipment comprising a vibrating unit that transfers fishes fed onto the first conveyor by vibratory motion, the second belt-conveyor that separates multiple fish in mass, and a video camera (SONY CCD-TR705) that takes photos of fishes laying on the conveyor.

An unseparated mass of fish precludes accurate fish counting. To solve this problem, different circumferential speeds are given to the first belt conveyor and the second belt conveyor; i.e., the second belt conveyor runs faster than the first conveyor to break the mass of fish into individual fish.

As shown in the figure, photos are taken from above the second belt conveyor with two fluorescent lamps (FL20) provided in the space between the upper and lower belts serving as the light source to radiate beams from below fishes.

The second conveyor belt is made of transilon

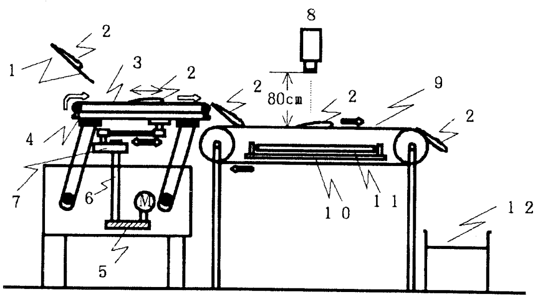

Fig. 1. Outline of the experimental equipment
1: shoot, 2: fish, 3: the first belt conveyer, 4: vibratory plate, 5: belt, 6: shaft, 7: crank, 8: video camera, 9: the second belt conveyer, 10: stand furnished fluorescent light, 11: fluorescent light (20 W×2, length 57.5cm, intervals 13.5cm, illuminance on the belt conveyer 1,100*lx*), 12: water tank, M: motor

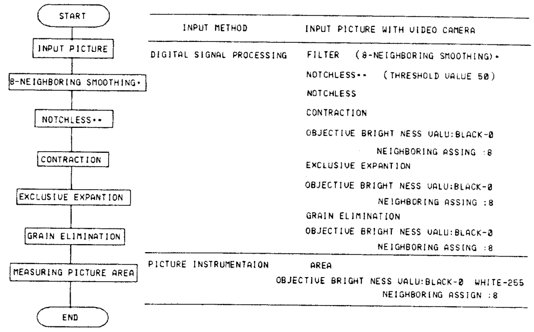

Fig. 2. A flowchart showing the picture area measuring procedure using the image processing technique with particulars
* The pixel at the centre and the eight adjacent pixels are used as the processing object.
** The threshold selection method prodeces a picture by designating brightness values at brightness 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.

(E2/1 UO/UO-NA FDA, white), which has a high transmission factor. Two transparent acrylic partitions (height: 2.3 cm, width: 38.5 cm, thickness: 0.1 cm) are provided 30 cm apart, and the image between the partitions was analyzed.

2) *Image analysis method*

The partition-to-partition picture of the second belt conveyor is inputted to an image analyzer (PIAS, model PIAS Ⅲ), analyzed to count the number of fish, and, by intermittent cycled operations, the sum of the fish count of each image was determined to yield the total number of fish. The performance of an analyzer is an important consideration for image processing, but the art of photographing images adapted well to counting fry in seedlings is more important. The test image analyzer is capable of inputting moving images, but in view of possible deterioration of analyzing accuracy when high-speed motion pictures are inputted, studies were done on the relationship between the circumferential speed of the second conveyor belt and analytical accuracy.

Subsequently, each area of the photographed images taken from the side and back of fish with the intensity of illumination changed was subjected to threshold selections by the image analyzer, and the relationship between the luminous intensities when photographed with beams in both normal and reverse directions and the reduction in image areas was investigated. Figure 2 is an image analysis flowchart. Pictures taken were subjected to threshold selections and left to contract after being smoothened on eight sides for the approximation.

Subsequently, picture areas were measured after removing noise formed after exclusive enhancement by the mass of minute pixels (hereafter referred to as "particles"). The term "smoothening on eight sides for approximation" means to remove image noise from the eight pixels on the periphery of a pixel, "contraction" means to reduce the boundary of a picture by one pixel, and "exclusive enhancement" means to enhance without overlapping adjacent pictures. The term "removing particles" is a generic term indicating the deletion of unnecessary date that cause errors (TAMURA, 1985).

3) *Transferring fish by vibration*

To measure the travelling speed of fish conveyed by vibration motion, the video camera was set 80 cm immediately above the second belt conveyor. One fish placed on the second vibrating conveyor belt was photographed at the video camera shutter speed of 1/100 second, and the travelling speed was determined by image processing.

The coefficient of friction between fish and the conveyor belt was measured by pulling a fish placed on the non-moving first conveyor belt using the method reported by HIGASHIKAWA *et al.*, (1993).

4) *Fish counting method and experimental procedure*

Twelve carp fry with a length ranging from 6 cm to 8 cm were fed from a water-filled vessel to the first belt conveyor through a chute. The circumferential speeds of the first belt conveyor were set at 5 cm/s to 40 cm/s at regular intervals of 5 cm/s, while the circumferential speeds of the second belt conveyor were set at 10 cm/s to 20 cm/s, and the effects of conveyor vibrations upon analytical accuracy were investigated.

Figure 3 is a frowchart showing the fish counting method. According to degree of reduction of picture area after image processing, the picture can be classified into three categories; i.e., the group of the pictures taken from behind the fish, which have relatively small picture areas (hereafter called the "back picture area"), the group taken from the side, which have intermediate picture areas (hereafter called the "side picture area"), and the group taken on a mass of fish in close contact, which have relatively large picture areas (hereafter called the "multiple picture area"). The picture areas after image processing are considered to represent the number of fry with greater accuracy if the numbers of fry in each category are summed. To determine the sectional paramenters of each picture area in the three sections, the back picture area and the side picture area of sample fry are measured in advance with a planimeter, whereby sectional parameters P_1 and P_2 were determined according to the frequency distribution of the picture areas after image processing each picture relative to the class value.

Similarly, parameter P_3, which discriminates the side picture area and the multiple picture areas, was determined according to the frequency distribution of the side picture area and the multiple picture area.

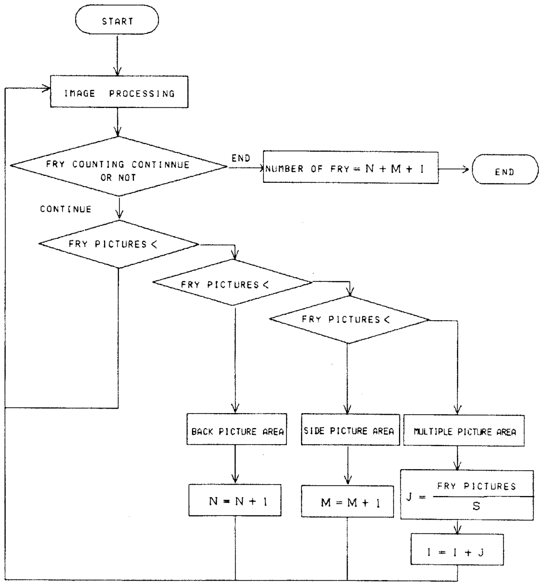

Fig. 3. A flowchart showing the fry counting procedure

Notes:

N: Number of fry after processing fry pictures taken from behind by the threshold selection method

M: Number of fry after processing fry pictures taken from the side by the threshold selection method

I: Number of fry in contact

P_1: Parameter representing the back picture area of sample fry measured with a planimeter

P_2: Parameter representing the side picture area of sample fry measured with a planimeter

P_3: Parameter representing the multiple picture area of sample fry measured with a planimeter

S: Calculated parameter of the back picture area and the side picture area of sample fry measured with a planimeter

Parameter S is a mean value of the back picture areas and the side picture areas. Because there are possibilities of counting picture noise, for example, which is a minute area comparing the back picture area, can be counted as one piece of fry, any area smaller than parameter P_1 was neglected as picture noise.

In summary, areas equal to or greater than parameter P_1 and less than P_2 were classified into the back picture area, areas equal to or greater than P_2 and less than P_3 were classified into the side picture area, and areas equal to or greater than P_3, which were assumed to be duplications of multiple fry, were classified into the multiple picture area. As a result, the respective unit numbers of fry classified into the back picture area and the side picture area were the fry count, the values obtained by dividing the multiple picture areas by section parameter P were also counted as fry number, and the aggregate number of fry was taken as the total fry count. Analytical accuracy is shown by the ratio of the number of fry counted by image processing to the actual fry count.

3. Experimental Results and Discussion

1) *Luminous intensity when pictures are taken and image processing accuracy*

Figure 4(a) shows the luminous intensity of the overhead light and the analytical accuracy of fry images after image processing, converted in to areas. Analytical accuracy on the ordinate is expressed in terms of the ratio of the side picture area determined by the image processing equipment and planimeter to the back picture area.

When lighting is provided from an overhead light source with a intensity of illumination of not less than 1,600 *lx* immediately above the belt conveyor, the area measured with a planimeter reduced to less than approximately 50 persent, due to intense reflection from the fry. Table 1 shows factors that cause variations of picture areas after image processing when lighting is provided from above or below the belt conveyor. For image a analyses with a high accuracy, clear-cut outlines after processing are essential, but lighting is provided from above, variation factors become larger at illumination intensities of 280, 1,100 and 1,950 *lx*, with dispersed analytical accuracy, and no images with clear-cut outlines can be obtained.

Figure 4(b) shows the relationship between the illumination intensity immediately above the conveyor belt when lighing is provided from below the conveyor belt and the analytical accuracy available with the image analyzer. The discriminant analytical method proved that the analytical accuracy of fry back images was high

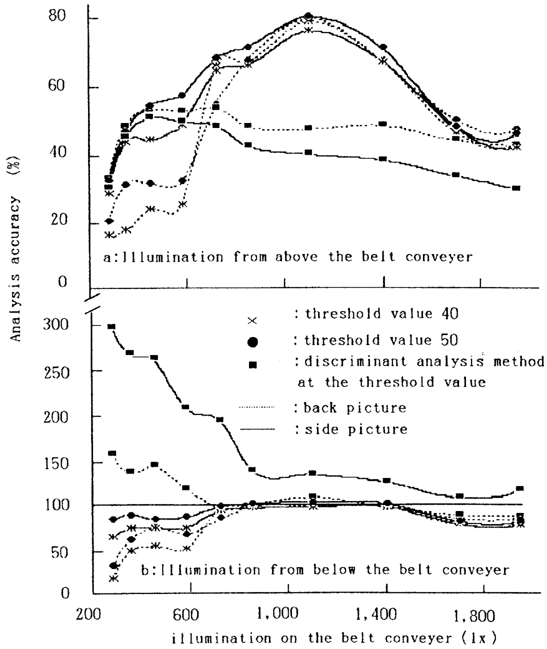

Fig. 4. Illumination intensity when taking video pictures and analytical accuracy
Analytical accuracy (%) = (B/A) × 100
where
A: Area of video picture of fry measured with a planimeter
B: Area of video picture of fry after image processing by the threshold selection method

at the illumination intensities of 850 *lx* to 1,400 *lx*, but that of fry side images dropped at the illumination intensities of 280 *lx* to 1,950 *lx*. The analytical accuracy of fry back and fry side images at the threshold values of 40 and 50 was 100 persent at the illumination intensities of 280 to 1,950 *lx*, decreased slightly at the illumination intensity of 1,600 *lx* and above. When analytical accuracy is evaluated in terms of factors causing variations of image areas after image processing, the factors were small when lighting was provided from below the conveyor belt with pictures taken from above at a high illumination intensity; i.e., 1,100 and 1,950 *lx* comparing with the low illumination intensity of 280 *lx*, where analytical accuracy was high. However, uniform images of fry could not be obtained at the illumination intensity of 900 *lx* or below, and if threshold selections were made at the threshold values of 40 and 50, the picture areas

Table 1. Variation coefficient (%) of picture area after image processing back picture

Directionof lighting	Direction at taking video pictures	Method of notchless	Illumination intensity (lx) 280	1,100	1,950
Lighting from above the belt conveyer	Side picture	Notchless 40	8.9	7.0	10.4
		〃 50	8.7	6.9	10.7
		Discriminant analysis method at the threshold value	15.3	7.7	11.6
	Back picture	Notchless 40	8.1	3.2	13.5
		〃 50	9.3	5.4	13.7
		Discriminant analysis method at the threshold value	11.2	8.7	15.8
Lighting from below the belt conveyer	Side picture	Notchless 40	4.9	1.0	0.5
		〃 50	4.9	1.4	0.4
		Discriminant analysis method at the threshold value	9.6	3.0	4.0
	Back picture	Notchless 40	3.1	1.9	0.8
		〃 50	3.3	2.7	1.0
		Discriminant analysis method at the threshold value	7.2	6.6	2.2

Note: The tabulated data were obtained by processing the back picture areas and the side picture areas of fry (still pictures at illumination intensities: 280, 1,100 and 1,950 lx) by the discriminant analysis method at the threshold values of 40 and 50.

obtained were smaller than those measured with a planimeter.

The picture areas determined by the discriminant analysis method were larger than those determined by the threshold selection method at threshold values of 40 and 50. Because the best threshold values are automatically set on the basis of a density histogram of pictures by the discriminant analysis method, the geometrical structure of pictures is not considered, and they do not necessarily agree with human vision (AUTSU,1980). For these reasons, threshold values in the discriminant analysis method were set lower than those of the threshold selection method at threshold values of 40 and 50. As a result, measured picture areas of fry were considered to become slightly lager. Furthermore, the discriminant analysis method failed to produce fry pictures after threshold selecrion, loosing the original geometric identity of the fry, and this method is considered to be unsuitable for the purposes of this experiment. It is inferred from the discussion above that lighting should be provided from below the conveyor belt, the intensity of illumination should be set at 1,100 lx to 1,400 lx to obtain stable fry pictures, and the threshold selection method at threshold values of 40 and 50 is better than the discriminant analysis method.

2) *Circumferential spped of belt conveyor and analytical accuracy of fry pictures*

Figure 5 shows the relationship between the circumferential speed of the conveyor belt and analytical accuracy. A high analytical accuracy of 98 to 99.5% is available at circumferential speeds of 20 cm/s or below, but the accuracy was low at speeds of 30 cm/s or more. The causes of this are assumed to be that fry pictures taken are displaced in the travelling direction of the fry at a high conveyor belt speed, as a result, the outlines of fry are subjected to threshold selections in minute particles with a resultant reduction of the number of pixels; these particles are deleted, the outlines of fry pictures become vague, and the picture areas after image

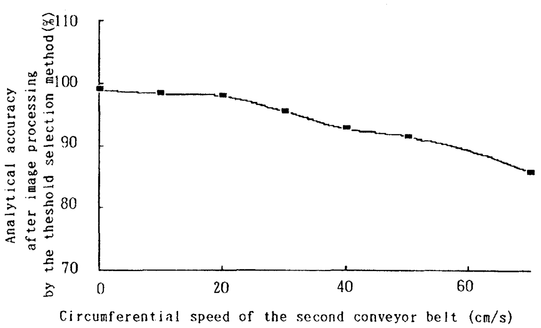

Fig. 5. Circumferential speed of the second conveyor belt and analytical accuracy
Analytical accuracy (%) = (B/A) × 100
where
A: Area of video picture of fry measured with a planimeter
B: Area of video picture of fry after image processing by the threshold selection method

processing decrease.

At a circumferential speed of 20 cm/s or below, the analytical accuracy does not decrease due to the generation of the phenomena mentioned. This proves that the circumferential speed of the second conveyor belt of 20 cm/s or below is suitable in the absence of the aforementioned phenomena.

3) *Behaviour of fry on the vibrating conveyor belt*

It is assumed here that fry lay on a conveyor belt that undergoes sinusoidal vibratory motions as shown in Fig. 6, and the coordinate system of the conveyor belt is denoted by X_1, Y_1, the coodinate system of fry, X_2, Y_2, the circumferential speed of the conveyor belt, V_1, and the travelling speed of fry, V_2.

According to TANIGUCHI *et al.*,(1962), it is considered that fry laying on a flat conveyor belt undergo the following modes of behaviour A, B and C.

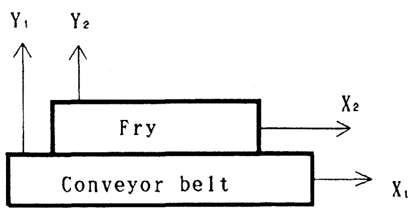

Fig. 6. Co-ordinate axis of conveyor belt and fry

Namely, the conveyor belt moves faster than the travelling fry in behaviour A, and the travelling speed of fry is expressed by the following equation:

$$V_A = \frac{\mu g}{\omega}\,\theta + \alpha\,\omega \tag{1}$$

where,

V_A: travelling speed of fry in behaviour A
μ : coefficient of friction between fry and conveyor belt
g : gravitational acceleration
ω : angular velocity of crank
θ : rotating angle of crank
α : amplitude of crank

Travelling fry in behaviour B move faster than the conveyor belt, and the travelling speed of the fry is expressed by the following equation:

$$V_B = \frac{\mu g}{\omega}\,\theta + \alpha\,\omega \tag{2}$$

where,

V_B: travelling speed of fry in behaviour B

Travelling fry behaviour C move at the same speed as the conveyor belt, where fry undergoes vibratory motrions as an integral part of the conveyor and are not transferred. The travelling speed of fry in this case is expressed by the following equation:

$$V_C = \alpha\,\omega\cos\theta \tag{3}$$

where,

V_C : travelling speed of fry in behaviour C

Variations of these three modes of behaviour are determined by the accelerations of the fry and the conveyor belt. When the amplitude is extremely small, the frictional force of the conveyor belt acting upon the fry is larger than the inertial force. As a result, fry undergo vibratory motions as an integral part of the conveyor belt at all times, and therefore the fry are not transferred.

When type A behaviour and type B behaviour appear in one period with type C behaviour appearing between them, fry are not transferred as they slip. When types A, B and C behaviour appear in a normal sequence within one period, the fry are transferred.

Theoretical travelling speed of fry V_{ave} in this case is expressed by the following equation:

$$V_{ave}=\frac{\mu g}{16}\pi-\frac{\alpha\omega^2}{2\pi}\{1+\sin(\cos^{-1}\frac{\mu g}{2\alpha\omega^2}\pi+\pi)\} \quad (4)$$

Figure 7 shows the theoretical travelling speed of fry V_{ave} when the acceleration of the conveyor belt is changed and at the travelling speeds measured by a video camera.

The acceleration of fry caused by the first belt conveyor when the transfer of fry is started is 7.1 cm/s^2 or thereabouts, at which the theoretical value agrees well with the measured value. However, the measured values of travelling speed are slightly larger than the theoretical values within the acceleration range of apporoximately 7.1 cm/s^2 to 18 cm/s^2 involving disagreements, but they agree in the higher acceleration range than above. These disagreements featuring the trend of a gradual increase are considered to have been caused by mechanical resistance, viscosity, inertial force, and loss of kinetic energy due to collisions among fry, all of which were difficult to measure and were neglected in introducing the theoretical equations.

This, therefore, means that the travelling speed of fry will not increase even if they are subjected to acceleration at 18 cm/s^2 or greater.

4) *Avoiding multiplication of fry on the conveyor belt*

The variations of picture areas of fry due to close contact and multiplication of fry causes a degradation of analytical accuracy, and hence must be eliminated. Figure 8(a) shows the relationship between the speed difference between the first and the second conveyor belts and the analytical accuracy. The circumferential speed defference between these conveyor belts was obtained by deducting the circumferential speed of the second conveyor belt from that of the first conveyor belt. The negative sign on the abscissa shows that the circumferential speed of the second conveyor belt is greater than that of the first conveyor belt. If the first conveyor belt is vibrated when the circumferential speed of the second conveyor belt is at 10 cm/s, the analytical accuracy was 100% for the speed differential range of 10 cm/s to 30 cm/s between these belts, but is dispersed and degraded when the first conveyor belt is not vibrated.

If the first conveyor belt was not vibrated, even when the circumferential speed of the second conveyor belt was 20 cm/s, analytical accuracy was unstable and dispersed as shown in Figure 8(b). When, however, the first conveyor belt was vibrated, the analytical accuracy registered 100% for the circumferential speed deifference range from −5 cm/s to 20 cm/s.

On the basis of the results above, it was concluded that rapid and accurate fry counts by the image processing technique are available if the circumferential speed of the second conveyor belt is set at 20 cm/s, the first conveyor belt is forced to vibrate, and the circumferential speed difference between these conveyor belts is maintained at from −5 cm/s to 20 cm/s. In commercial applications, it is necessary to do these

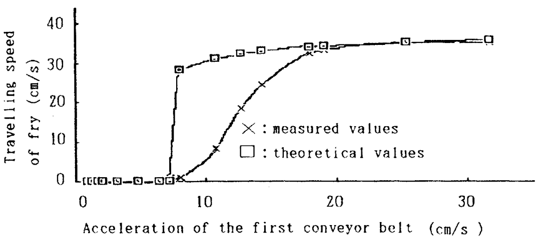

Fig. 7. Acceleration of the first conveyor belt and travelling speed of fry
Note: The coefficient of friction between fry and the conveyor belt was assumed to be 0.2.

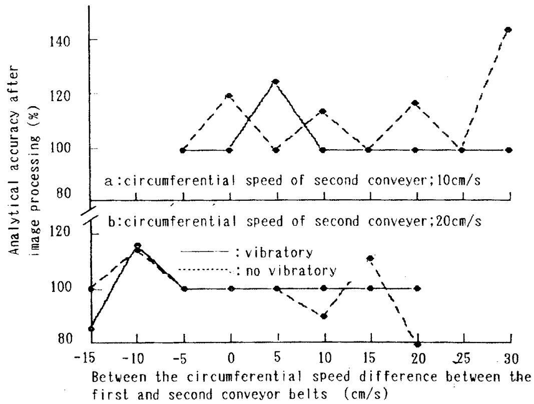

Fig. 8. Relationship between the circumferential speed difference between the first and second conveyor belts and analytical accuracy

operations on a real-time basis.

If the circumferential speed of the second conveyor belt is set at 20 cm/s, it is estimated that 24,000 fry per unit time per one processing line, or 120,000 fry per unit time per five processing lines can be counted by the image processing technique.

4. Conclusion

To count fry by an image processing system, a counting system comprising first and second belt conveyors, and a device to prevent multiplication of fry was fabricated, thereby the effects of the optimum circumferential speed difference between the first and the second conveyor belts, the threshold selection method for image analyses,lighting direction and illumination intensity upon counting accuracy were investigated. The results of the investigation are summarized below:

1) Threshold selections of fry pictures at threshold values of 40 and 50 are recommended rather than the discriminant analytical method.

2) To obtain stable video pictures, lighting from below the conveyor belt and an illumination intensity of 1,100 *lx* to 1,400 *lx* immediately above the conveyor belt are suitable.

3) Excited vibration of the first conveyor belt is effective for preventing multiplication of fry, but the travelling speed of fry neither increases nor decreases at acceleration of 18 cm/s^2 or above.

4) To achieve an efficient and accurate fry count, it is suitable to set the circumferential speed of the second conveyor belt at 20 cm/s, and maintain the circumferential speed difference between the first and the second conveyor belts in the range from −5 cm/s to 25 cm/s or thereabouts.

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画像解析による種苗幼魚の計数精度に関する研究

矢田貞美・樋口宏一・小池孝知

要旨：画像解析装置による種苗幼魚の尾数計数を目的として，魚体の重複防止装置における２本のベルトコンベヤの組合せ方法，材質，構造及び適正周速度，魚体画像の２値化方法，照明方法と適正照度について究明した。