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Length measurement of fish by computer vision

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ABSTRACT

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A machine is described for the length measurement of fish by computer vision. The error in length measurements of fish presented to the machine oriented and with a minimum distance between them is ±1%. If the fish are randomly oriented this increases to ±3%. The machine can cater for gutted and flexed fish, and has a throughput of greater than one fish per second.

INTRODUCTION

In the UK there are three particular reasons why fish need to be graded by length and/or mass.

(1) The EC have issued regulations (EC, 1986) which require that all fish for which marketing standards have been set have to be graded for freshness, species and mass before they are sold for human consumption. Since the mass of each fish is difficult to measure at sea due to the motion of the boat, a concession has been made so that length may be used instead. Table 1 gives

TABLE 1

EC size grades for haddock

EC grade	Mass (kg)	Length (cm)
1	1 and over	49.5 and over
2	from 0.57 up to but excluding 1	from 41.5 to less than 49.5
3	from 0.3 up to but excluding 0.57	from 33.5 to less than 41.5
4	from 0.17 up to but excluding 0.3	from 27 to less than 33.5

The EC regulations lay down certain tolerances. It allows a 'lot' to be considered uniform if not more than 10% of the total quantity lies within the next category (up or down) of mass or length.

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the length regulations for haddock (*Melanogrammus aeglefinus*). Hence the fishermen need some method of measuring the length of fish so that they can be boxed according to the EC regulations. Inspectors also have to measure the fish, usually at the fish market, to check that the EC regulations are being adhered to.

(2) The UK Ministry of Agriculture, Fisheries and Food (MAFF) and the Scottish Office Agriculture and Fisheries Department (SOAFD) have fish length measurement programmes implemented at the fish market and at sea on board research vessels. This requires an accurate, rapid method for measuring the length of fish.

(3) Fish need to be graded by length by fishermen and fish processors so that they can be directed into the appropriate size set gutting, filleting and head cutting machines. The length of the fish can then be used to estimate the yield (Heldbo et al., 1990).

Table 2 gives the accuracy and throughput required for the above three applications.

Length grading of fish at present is done either by eye, using a ruler, using a roller grader (which measures the thickness of fish from which the length and mass can be estimated) or by using an optical system based on the occlusion of light emitting diodes.

Depending on the feeding system the fish can be presented to the grading system in a number of levels of complexity (Arnarson et al., 1991):
Level 1 — Objects oriented and with a minimum distance between them.
Level 2 — Objects not oriented and with a minimum distance between them.
Level 3 — Objects oriented, with no minimum distance, and not overlapping.
Level 4 — Objects not oriented and not overlapping.
Level 5 — Objects not oriented and overlapping.

By eye (see Table 3), length measurement is inaccurate, slow and labour intensive. Using a ruler the measurements are much more accurate but even slower.

The roller grader consists of two conveyor belts (or rollers) (Kawka and

TABLE 2

Requirements of length grading machine for different applications

Application	(1) EC regulations	(2) MAFF program	(3) Feeding gutting/ filleting machines and yield control
Maximum error in accuracy	±10%	±2%	±2%
Speed (fish per min)	100	100–300	100–300

TABLE 3

Properties of the different methods to measure the length of fish

	Method of measuring fish				
	Eye	Ruler	Rollers	LED	Computer vision
Accuracy	±10%[a]	±3%[a]	±5-±10%	±2%[b]	±2%
Speed (fish per min)	20	12	100–200	100–400	100–400
Level of feeding	1–5	1–5	1–5	1	1–3
Ability to deal with flexed fish	Yes	Yes	Yes	No	Yes

[a]This accuracy was measured by the author.
[b]This is for feeding level 1 only.

Plociak, 1974). The space between the belts is increased from the start to the end of the machine. The fish then fall through the machine at different positions along it dependent upon their thickness. From this their length can be estimated but with a fairly low accuracy (see Table 3). There may be problems of mechanical damage to the fish but the machine is capable of a large throughput and the fish can be presented to it at level 5.

When light-emitting diodes are used to measure length (Taylor, 1974). The fish break a light beam whilst travelling along the conveyor. From a measurement of the time for which the light beam is occluded, together with the known speed of the conveyor the length can be evaluated. These systems can operate very quickly but work in level 1, which is not practical because of the flexible nature of the fish. The errors in the length measurements can therefore be large.

There is no machine commercially available which satisfy the criteria for levels 2 and 3, so another alternative method of measuring the length or size of fish is required.

Some other methods for estimating the size of fish are by weighing, or making area and volume measurements. Weigh scales are used throughout the fishing industry. The scales used are usually static scales, but the use of dynamic scales is becoming more common. The speeds of these graders are reasonably fast, 50–70 objects per min for the static grader and 60–120 objects per min for the dynamic graders. The accuracy of the equipment is very good, with errors of about 0.1–1%. Feeding is done manually at level 2, ie the fish are presented one at a time and not oriented. As has already been stated the biggest problem with weighing is that it is difficult to do it accurately at sea.

Area measurements can be made using a video camera. This works best on flatfish (Strachan, 1990) but large discrepancies of up to 30% occur for roundfish (e.g. cod, haddock, etc) if the fish have been gutted. This is due to poor correlation between silhouette and length, e.g. presence of fins and belly flaps.

Storbeck and Daan have described a computer imaging system and structured light to measure the volume of fish. This can achieve a fast throughput of up to 100 fish per min with an error of $\pm 5\%$.

Another method for measuring the length of fish is by using an image processing system (Arnarson et al., 1991). Researchers in the fish industry have discovered potential uses of machine vision, e.g. to detect parasites (Pippy, 1970) and bones (Huss et al., 1985), and recently vision system performances and prices are approaching ranges where they can become acceptable to the industry.

Arnarson et al. (1991) have described a computer vision system which can measure the length of fish with an error of $\pm 2\%$ and a throughput of 75 fish per min. The machine works at level 2 and compensates for the flexible nature of the fish, however no detailed explanation is given of the algorithms used.

The aims of the work reported in this paper are:

(1) to develop and explain algorithms for measuring the length of fish and determining their orientation using a computer vision system

(2) to see if the results of Arnarson et al. could be repeated and improved upon using the four different EC size grades of haddock.

MATERIALS AND METHODS

Computer vision system and conveyor. A photograph of the conveyor and housing for the video camera is given in Fig. 1. The conveyor which was manufactured by Oakliffe Engineering (Yorkshire, England) was set to a speed of 20 m/min. The conveyor belt was transparent, so that the fish could be backlit to yield their silhouette. It was purchased from Marel (Reykjavik, Iceland) and was 4.95 m in length and 0.3 m in width. The backlighting was achieved by using a lightbox constructed at Torry Research Station. To stop the problems of beating, caused by the 50-Hz mains frequency, high-frequency (20 kHz) ballasts were used to drive the fluorescent tubes.

The signal from the video camera (Sony DXC 325PK) was digitised to an image of 512×512 pixels with 8 bits per pixel using a frame grabbing board (Imaging Technology Inc). The images were then processed by a computer workstation (Sun 3–160C) using algorithms written in the C programming language.

Fish. Four boxes of gutted haddock, one for each of the four EC size grades (Table 1) were purchased from the Aberdeen fish market.

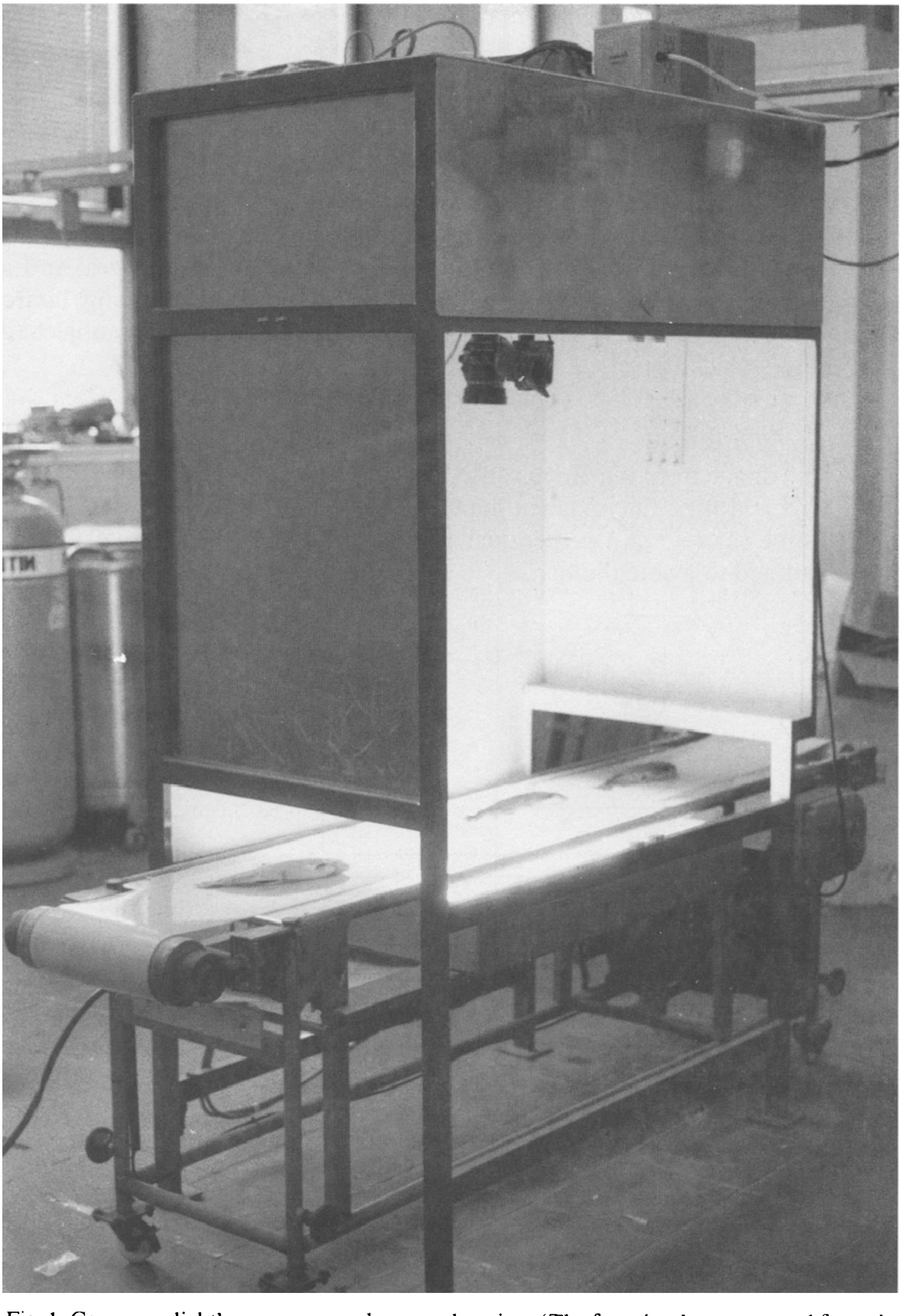

Fig. 1. Conveyor, lightbox, camera and camera housing. (The front has been removed from the camera housing so that the camera can be seen.)

Algorithm for length measurement of fish

A flow chart of the algorithm for length measurement of fish is given in Fig. 2. The algorithm is composed of five parts and these are described below.

1. Initialise system

Computer system, video camera and lighting are switched on. The system is allowed to warm up (30 min). The aperture level on the camera, and a software selectable threshold level are selected on the video digitising board so that the conveyor belt is set to white (pixel value=255) and any object (a fish) on it is black (pixel value=0) (Fig. 3a).

2. Search for fish

(a) The image from the video camera is 'grabbed'. This is done by software and involves storing the image in the frame store's video RAM.

(b) A line (at $x=x_{look}$) perpendicular to the direction of the conveyor (Fig. 3a) is scanned to locate the fish.

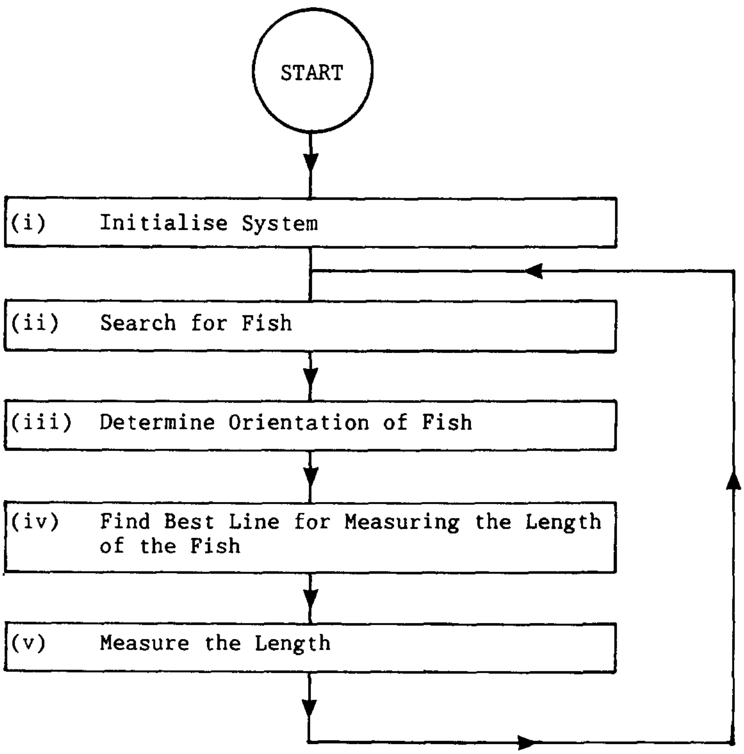

Fig. 2. Algorithm for length measurement of fish.

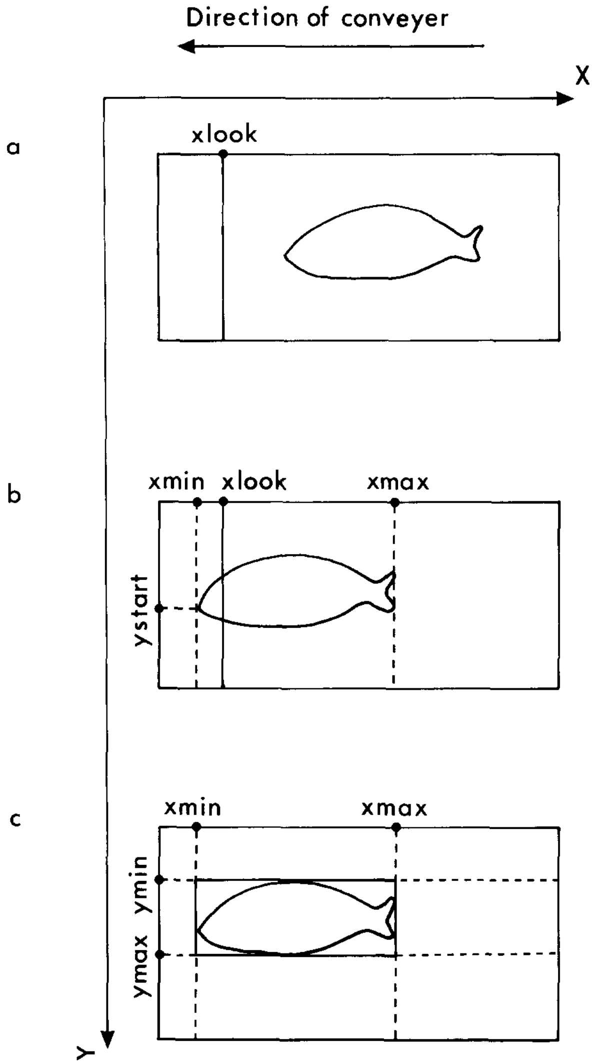

Fig. 3 (a) Looking for the fish, (b) detecting it, and (c) enclosing it within a rectangle (region of interest).

(c) If the fish is not found, the cycle is repeated from (a). If the fish is found then the program continues.

(d) The value of x using the perpendicular scanning lines is reduced until the value of the coordinates (x_{min}, y_{start}) (see Fig. 3b) are found. Similarly x is increased until x_{max} is found.

(e) y_{min} and y_{max} are found in the same fashion starting at y_{start}.

(f) A rectangle (region of interest) is now drawn around the fish as in Fig. 3c.

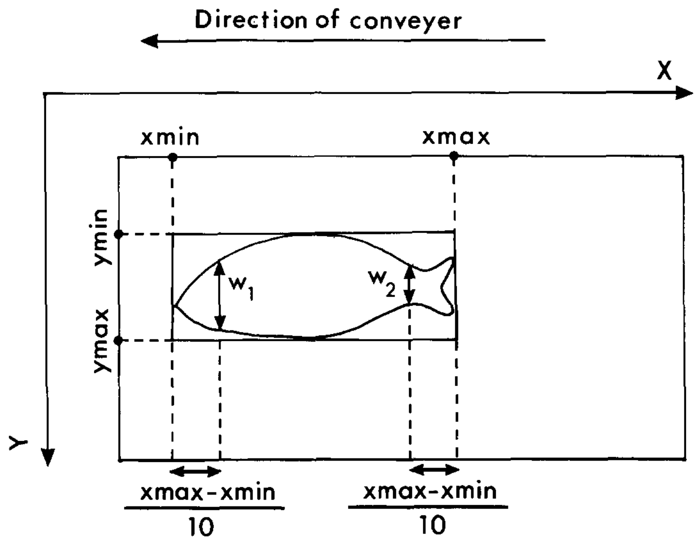

Fig. 4. To determine if the fish is head first or tail first, two width measurements are made, W_1 and W_2. If $W_1 > W_2$ the fish is head first, if not it is tail first.

3. Determine orientation of fish

(a) Whether the fish is horizontal (lying along the x-axis) or vertical (lying along the y-axis) is determined. If $x_{max} - x_{min} > y_{max} - y_{min}$, the fish is classed as lying along the x-axis. Otherwise the fish is classed as lying along the y-axis and the coordinate axes are rotated by 90° so that the fish is then lying along the x-axis.

(b) To define which way the head and the tail are pointing the computer measures two widths (W_1 and W_2) of the fish as shown in Fig. 4. The larger width indicates the head of the fish. If $W_2 > W_1$, the x-coordinates are reversed.

(c) It is not necessary to detect if the fish is lying belly up or belly down because the fish is symmetric along its principal axis (x-direction in Fig. 4).

4. To find best line for measuring the length of the fish

A line has to be found which:

(a) is defined from the nose of the fish to its tail fork;
(b) is not affected by the belly flaps and fins;
(c) can accommodate the flexible nature of the fish;
(d) can accommodate the fish being at an angle of 45° with respect to the x-axis.

To satisfy conditions (c) and (d) the midpoints of the width of the fish at various positions along the x-axis can be joined together to define a line which represents the length. To cater for (b) no measurements are taken between 15% and 50% from the head of the fish. To locate the tail fork the midpoints

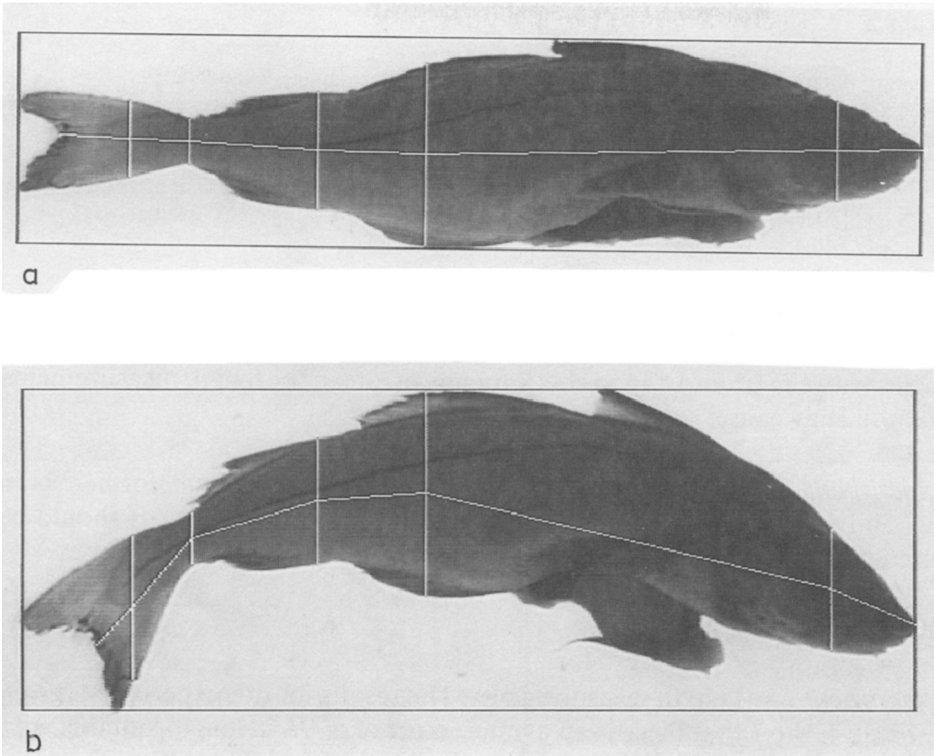

Fig. 5. A line for measuring the length of a fish (a) straight and (b) deformed.

of two vertical lines 10% and 20% from the end of the tail are joined together and carried on until the tail fork is found (Fig. 5).

Experiments to evaluate length measuring algorithm

Experiment 1 — Length measurements. Thirty-five haddock of each of the four EC size grades were measured by a ruler and these values were compared with values obtained by the length measuring algorithm. For this experiment the haddock were placed one at a time, parallel to the direction of the conveyor and their length was measured using the computer vision system. This was repeated 5 times for each fish.

Experiment 2 — Orientation detection. The orientation algorithms were assessed by presenting fish to the video camera head first, tail first and vertically.

Experiment 3 — Determination of errors due to fish being at an angle of between 0° and 45° to the direction of the conveyor. A fish was presented at

TABLE 4

Accuracy of the length measuring algorithm for the four EC size grades of haddock

EC grade	Average length of fish in grade (cm)	Average error (cm)
1	51.6	± 0.6 ($\pm 1\%$)
2	40.8	± 0.4 ($\pm 1\%$)
3	35.5	± 0.4 ($\pm 1\%$)
4	31.2	± 0.4 ($\pm 1\%$)

angles between 0° and 45° to check for any errors in the length measurements that this may cause.

Experiment 4 — Deformation errors. Fish were deliberately deformed as in Fig. 5b to see if this had an effect on the length measurements. It should be noted that this may occur naturally because of the effects of rigor mortis.

RESULTS

Experiment 1 — Length measurements. The results for this experiment, given in Table 4, show that there is an average error of $\pm 1\%$ in length and this is an improvement on the $\pm 2\%$ error given by Arnarson et al. (1991). The algorithms took approximately 0.8 s to measure the length of each fish.

Experiment 2 — Orientation detection. The algorithm successfully (100% accuracy) determined the orientation of the fish. This part of the algorithm took on average a further 0.1 s.

Experiment 3 — Detection of errors due to fish being at an angle of between 0° and 45° to the x-axis. It was found that the errors in the length measuring algorithm for a fish of length 29 cm oriented between 0 and 45° to the x-axis was ± 1 cm ($\pm 3\%$).

Experiment 4 — Deformation errors. Errors in measuring the length of a fish due to it being in various deformed states (e.g. Fig. 5b) were found to be ± 1 cm ($\pm 3\%$) for a fish of length 29 cm.

DISCUSSION

The experiments show that presenting the fish to the computer vision system at level 1 has an error of $\pm 1\%$ whilst at level 2 it is $\pm 3\%$.

Levels 3 and 4 may be possible by detecting each fish using the perpendicular scanning lines and filling each one in (ie labelling the fish) to separate one from another. Doing this though would take much longer computationally, perhaps up to 5 s per fish using the present computer. Feeding the computer vision system at level 5 would be very difficult because of the overlapping of the fish.

Using for example the latest RISC processors, the processing time of approximately 60 fish per min would be decreased by a factor of 15. This would then easily achieve the desired throughput of 300 fish per min (Table 2).

CONCLUSIONS

A computer vision system together with appropriate algorithms have been successfully tested on making length measurements of fish. The system has produced similar accuracy to that of Arnarson et al. (1991) and has been used to size grade all four different EC size grades of haddock. The system can determine the orientation of the fish which must not overlap and has a throughput of one fish per second which could be considerably increased using more modern computers.

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