XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

IN VIVO FLATFISH SIZE AND WEIGHT MONITORING BY IMAGE ANALYSIS

EIKO THIESSEN[1], EBERHARD HARTUNG[1]

[1]E. THIESSEN, Institute of Agricultural Engineering, Max-Eyth-Str. 6, 24118 Kiel, Germany, ethiessen@ilv.uni-kiel.de.
[1]E. HARTUNG, ehartung@ilv.uni-kiel.de.

CSBE101551 – Presented at Section II-B: Aquacultural Engineering Conference

ABSTRACT In Recirculating Aquaculture Systems (RAS) the knowledge of fish size is important for an adequate management: Feed-size and feed quantity should be based on the mean fish size (and number). Sorting is complex and if fish have not reached their full grown slaughtering weight harvest is not possible. In this project a camera system in combination with image analysis is used to estimate parameters like shape, size and weight of turbots (*Psetta maxima*). Different camera setups (above surface, glass bottom box and submerged) were tested for optimising the hardware. For the software, different algorithms (threshold, edge, motion detection) were tested and enhanced. The camera system worked stand-alone 24 hours a day with a mean frame rate of five per second. Images for analysing were automatically selected by motion detection. So, only motion-less flatfish lying on the ground were measured. A pixel-to-centimetres calibration was used to save the measured values and to do the statistical analysis (mean fish length and weight estimation). The comparison of the different camera setups was done in a test tank. Best performance results were achieved with a submerged monochrome camera in a sloped view with an error less than 3 % in length estimation. A trial in a commercial plant leads to consistent values of manual weighting with a deviation of 5 % to the mean fish weight.

Keywords: Image analysis, Turbot, Recirculating Aquaculture Systems (RAS)

INTRODUCTION A lot of parameters are measured online in aquaculture: Water, food and fish size during sorting or slaughtering. But rarely information about the fish is available during rearing. Image analysis could provide precise and continuous data about the fish, like size, weight and therefore growing and spreading. In this study it was important to get the variation in the fish population of one tank. So the date for size grading can be determined without disturbing the fish.

Some work is done with image based size estimation in net cages [e.g. Beddow and Ross, 1996, Costa et al 2006, McFarlane and Tillet, 1997]. For example, a commercially available optical frame can be used. It records the shape when fish are randomly swimming through this frame [Vaki 2010].

The main idea of this approach for flatfish in RAS is to wait for pictures with turbots still lying on the ground. So the distance and therefore the real size of the fish is defined and is calculated via a calibration and no torso distortion of swimming fish is troubling the measurement.

1 EQUIPMENT One of the goals was to find out the optimal camera technique and installation. The main focus is on practical convenience and measurement precision.

Camera setups A standard monochrome digital CCD-camera with 640x480 pixels was used. The camera was mounted either

1. directly over water (approx. 1.5 m) or
2. in a glass bottom box with 1 m x 1 m transparent plastic bottom just under the surface and a shadowed casing or
3. submerged in a waterproof casing with transparent plastic window (see fig. 1 B).

Calibration It is possible to calculated real-world-coordinates (i.e. the length of an object in centimetres) with only one camera in a plane with known distance to the camera (i.e. the ground of the tank). For this pixel-to-centimetres calibration the geometry of both – the camera (objective and chip) and the position (distance and orientation camera to plane) – is important and was determined with an algorithm supplied with some images with a well known object. This object should have clearly observable marks (normally a chequerboard). It was used underwater (the system in as-is state) to consider the optical properties of water. But a normal pattern (e.g. black points on a white table, see fig. 1B at the bottom) evinces difficulties in turbid water. So we constructed an active pattern plate with points illuminated backwards with bright LEDs (see fig. 1A).

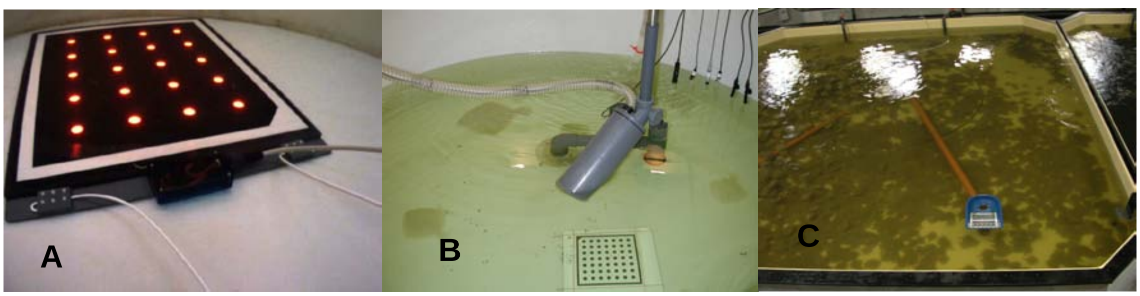

Figure 1. A) extended calibration-table wit LEDs B) underwater camera in test tank with the normal pattern plate C) commercial turbot production

Tanks Two different locations were used for the experiments: A small trial tank (2 m diameter, 40 cm water height, see fig. 1B) with test turbots at the University in Kiel, Germany, and a commercial plant located at the North Sea, Büsum, Germany (see fig. 1C). The test turbots at the University were fed restrictively and the tank was only used for testing the equipment. At the commercial plant about 100 tons turbots per year are produce in shallow tanks (8 m x 8 m, 70 cm deep) and the turbot density and feeding was usual like in turbot production (20-40 kg/m², approx. 1% of fish-weight feed per day).

Computer technique A standard PC (Intel Pentium Dual-Core @ 1.6 GHz and 1 GB RAM) was used for image acquisition and analysis. The algorithm was programmed with the software "Halcon 7.1" from MV Tec, Germany.

2 IMAGE ANALYSIS A time flow of the used algorithm for fish detection is shown in fig. 2. The chronology is motion detection, object extraction, transformation in real-world-coordinates, object selection (i.e. the fish) and documentation.

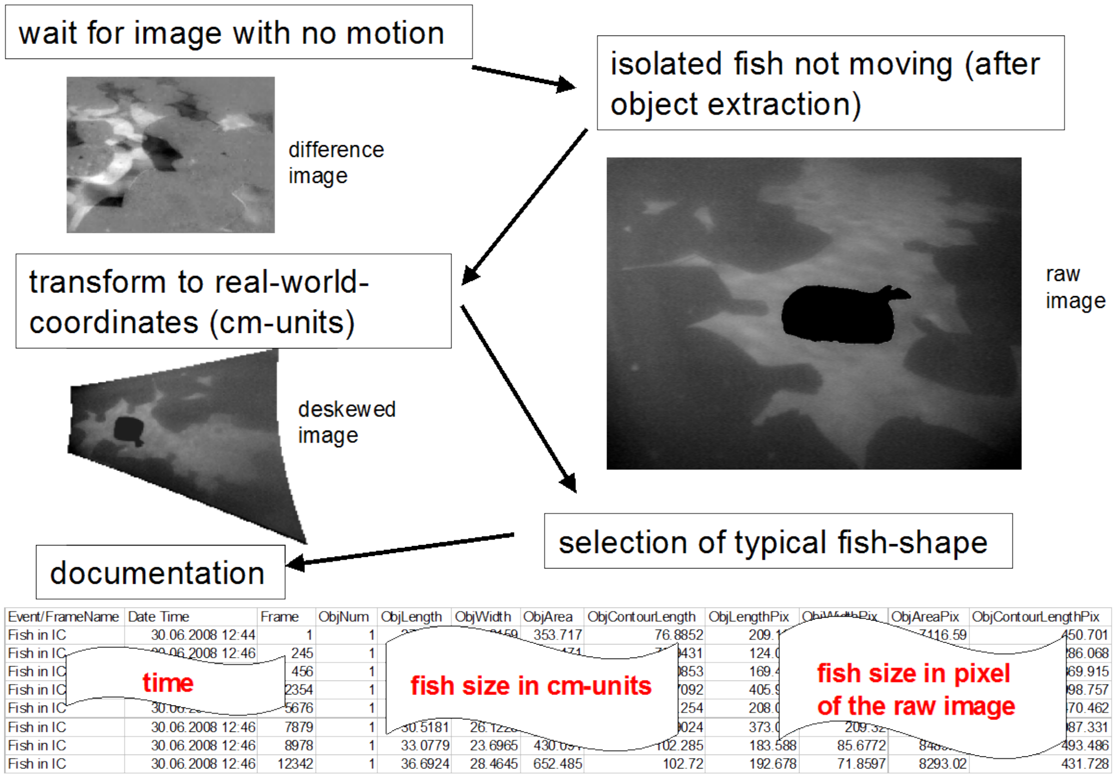

Figure 2. The algorithm of image analysis in principle.

Motion detection The main idea is to use only images with known distances from the camera to the fish. This was realized by using only motion-less flatfish as they are lying on the ground when not swimming.

The changes in the image are detected with image subtraction of two successive images and analysis of the grey values in this difference image. The standard deviation of all pixels in the subtracted image is taken as “activity” index. An object extraction is only executed once if a certain threshold of “activity” is under-run (indicating still lying fish). It is waited for a new scene (indicated by a rise of activity and replicated under-run of the threshold) for executing the next object extraction to avoid measurements of almost the same image.

Object extraction In our trials the fish were darker than the background. So first, a simple threshold algorithm was tested. It shows that it worked not very well because of lighter region inside the fish-shape (turbots are spotted) and the boundary of the fish to the ground was not very clear (data not shown). An edge-filter-algorithm (“lanser”) is used instead and is adjusted to detect the contrast fin-to-background. It links the edge-filter output points into edges by using an algorithm similar to a hysteresis threshold operation. Points with an amplitude larger than a high-threshold (typ. gray value 20) are immediately accepted as belonging to an edge, while points with an amplitude smaller than a low-threshold (typ. gray value 10) are rejected. All other points are accepted as edges if they are connected to accepted edge points. All the edge-points are thinned to give lines and connected to form one object if the distances between the edge-lines are lower than a connection-threshold (typ. 15 pixels or 15 % of edge-length). So some missing boundaries due to low contrast are reconstructed. Finally the objects are closed to form a polygon.

Object selection The extracted objects are analysed if they represent one single fish. It is important to discriminate between one single fish and overlapping fish or dirt for getting exact results.
After the transformation to real-world-coordinates, the total area and length as well as the position of the object is examined. So only medium-sized objects (depending on the expected fish-size, typ. between 20 and 50 cm) not located at the margin of the image (i.e. distance more than typ. 5 pixels) are considered. Then the shape is examined. This is done by selecting only objects with form-parameters in a fish-like range. Typical form-parameters in the population were created with images of defined single fish of different size. Only objects with contour/length in a certain range are selected as fish (see Results).

3 TRIALS One of the main goals was to find out which camera setup is the best. Therefore trials in the test tanks were performed with known conditions: background illumination, fish colour, reference plastic fish and water disturbances (waves).

Comparing the setups The camera was installed in the test tank at the different setups (see fig. 3). A reference fish (gray plastic) was taken to compare the precision of the length measurement with the different camera setups. It was placed at 18 different positions covering the entire sensor area. The length was measured with the above explained image analysis and the variation of the length in the different positions (reproducibility) and the mean deviation to the reference length (precision) was calculated.

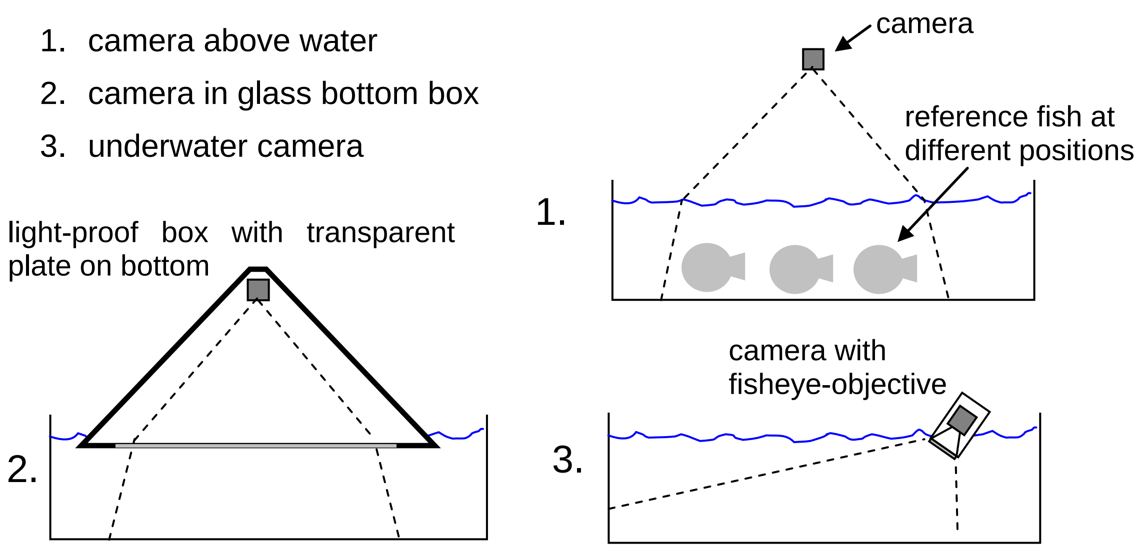

Figure 3. Camera setups.

Single fish measurements For getting the relation size to weight and the typical form parameters, single living fish were caught randomly out of different production stages and put in a water-box with transparent surface. The camera was mounted above this box and recorded images from the fish constrained not moving in a defined distance to the camera. After that the fish was weighted and the length was measured manually with a measuring tape. Altogether 55 turbots at three dates were measured covering the range between 20 and 45 cm.

Tracking the whole group and individual fish Due to the small sensor area it is important to know how fish are moving in the tank to avoid that not only the same fish is measured or the camera is placed at a position which is not frequently used by fish. The fish distribution of the entire population was measure with a camera in time-lapse mode over the whole tank and a simply performed image analysis Dark grey values are interpreted as fish and bright grey values are interpreted as background. The images were averaged over a period of 4 weeks.
Monitoring individual movement of single fish was conducted similarly but one fish was marked with a bright flashing light ("FlashBait") with battery power for 72 h. The position of the bright area was documented via a simple threshold image analysis.

Monitoring a fish population The main test was an application in a commercial fish-farm with a validation of the camera-measured fish sizes. The submerged camera was placed at the margin of the tanks (8 m x 8 m) where fish were frequently sojourned. The camera was operated in auto brightness-control. The illumination was the normal light in the production building and was sufficient to deliver images during day (approx. 200 lux) and night (approx. 50 lux). After 17 days of operation the fish were sorted and weighted manually. These weights represent the "real" values and are used for validation.

4 RESULTS One of the main goals was to find out which setup is the best and to use this in a practical trial. It is also important to install the camera at a well and homogenously frequented location. For this the distribution and movements of the fish were explored.

Table 1. Comparison of the different camera set-ups (SD: standard deviation).

	camera over water	**glass bottom box**	**camera submerged, slope 69°**
sensor area [m²]	1.45	1.35	1.15
advantages in operation	easy installation, big area	no distortion through reflexion or waves	no distortion through reflexion or waves
disadvantages in operation	reflexion at the surface, distortion due to waves	bulky installation, shadow due to box, air-bubbles on glass pane	small area, increasable only with slope
reproducibility (SD of the single measurement) [cm]	smooth surface: 0.32 with waves: 1.2	0.12	0.25
precision (mean deviation to reference length) [cm]	smooth surface: 0.75 with waves: 1.4	0.57	0.41

Comparison of camera setups Pre-tests were conducted with different cameras (colour, resolution) and additional illumination (visible light, infrared). These settings do not enhance the performance (data not shown).
The results of the selected monochrome camera in combination with the different setups are listed in tab. 1. The setup with the camera over water has the main disadvantage that reflexion of the ambient light and waves on the water surface (induced by fish movements) cause distortions of the fish shape. The setup with the glass bottom box eliminates these distortions but shows a shadow due to the big casing. The submerged camera shows a clear image with no extra shadows or reflexions – only the light from outside the water is influenced by waves for all three setups (e.g. photos in fig. 2).
The performance - expressed as reproducibility and precision – is very good for all setups except of the camera over water if waves are existing. The reproducibility of the sloped underwater camera is not as good as the perpendicular looking camera in the glass bottom box because of the smaller resolution (pixel per cm) in the more distant regions of the image. The precision of the underwater camera is smaller than 0.5 cm which is approx. the precision of the manual measurement of living fish.

Illumination and motion For convenience and not annoying the fish the normal background illumination was used as light source. In the turbot production even at night there is artificial light because of slowing down the sexually mature process.
Automatic brightness control of the camera is used to compensate the changes of illumination for getting well exposed images. The contrast K depends on the brightness of the object B_0 and the background B_B and is defined as

$$K = \left| \frac{B_O - B_B}{B_O + B_B} \right|. \tag{1}$$

The contrast should be maximised for image analysis. The automatic brightness control leads to almost constant contrast between fish and background (see fig. 4) if the background illumination is in the typical range of the light intensity in production.

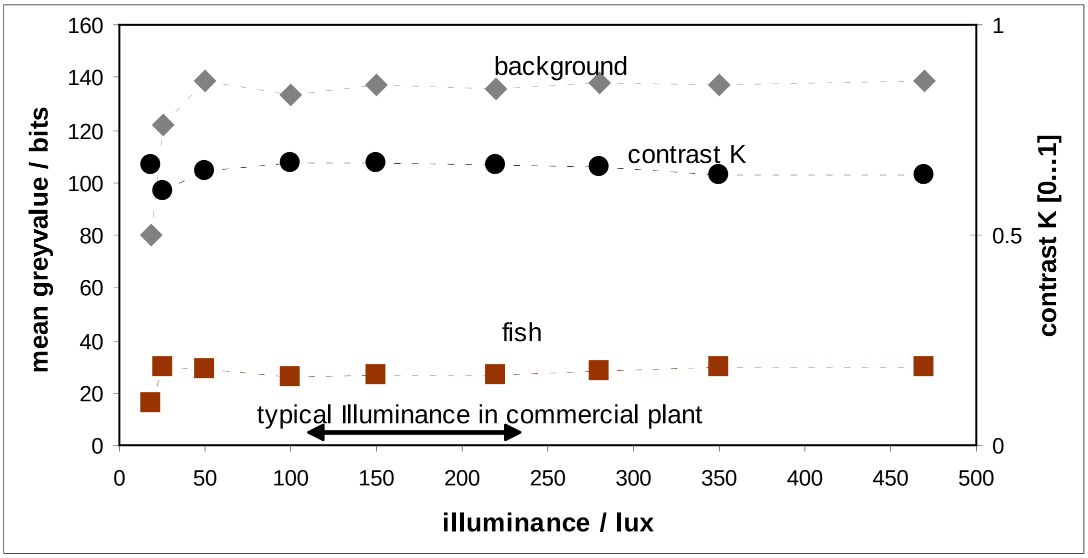

Figure 4. Contrast at different illumination.

Fish activity To demonstrate the power of the activity index the fish in the test tank were fed every 10s with pellets to induce a motion. In fig. 5 the activity index is plotted over time: The first 60 s the fish were not moving and the activity was below a certain threshold only showing the noise of the camera. When feeding started a lot of fish were moving and the activity was rising. After that every pellet induced a motion which is clearly seen by the activity. The pellet was not seen by the camera.

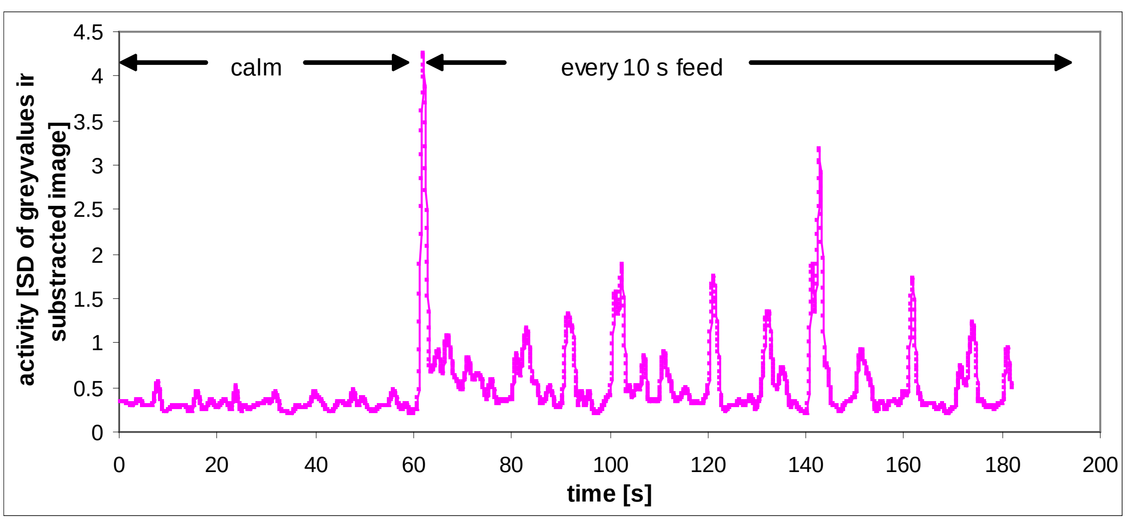

Figure 5. Activity during feeding (SD: standard deviation).

Single fish measurement The camera measured length correlates very well with the manual measured length (see fig. 6) The error - expressed with the root mean squared error predicted (RMSEP) and the offset - is in the same order (0.45 and 0.59, respectively) than the errors of the test measurements at the setup comparison.

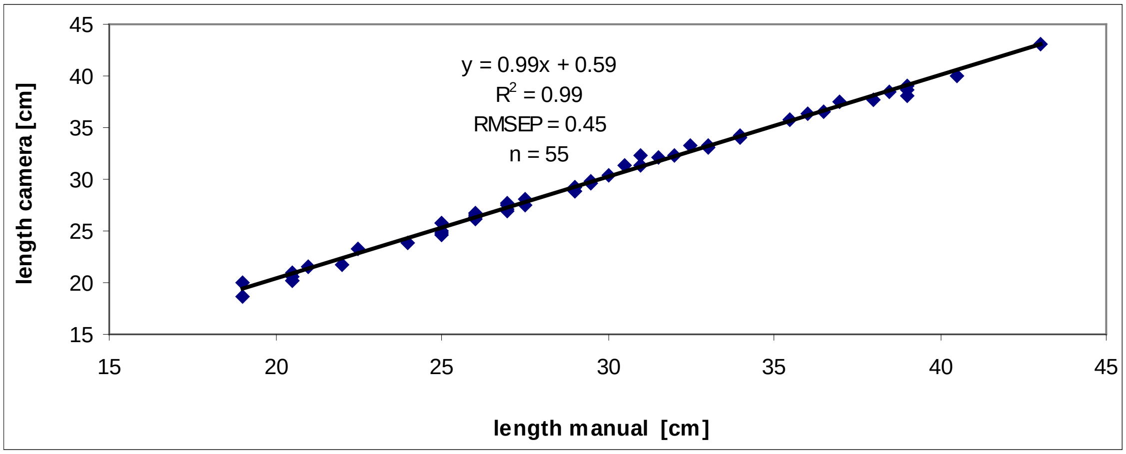

Figure 6. Length of the camera vs. manual estimated length of single fish

The camera measured size also correlated well to the weight of the fish (fig. 7). The length shows roughly a cubic relation to the weight as found by others (factor 0,0105 g/cm and exponent 3.26, Robert and Vianet, 1988) and the area is slightly better correlated with a linear to quadratic weight dependency. For future weight estimation the equation for the length was used.

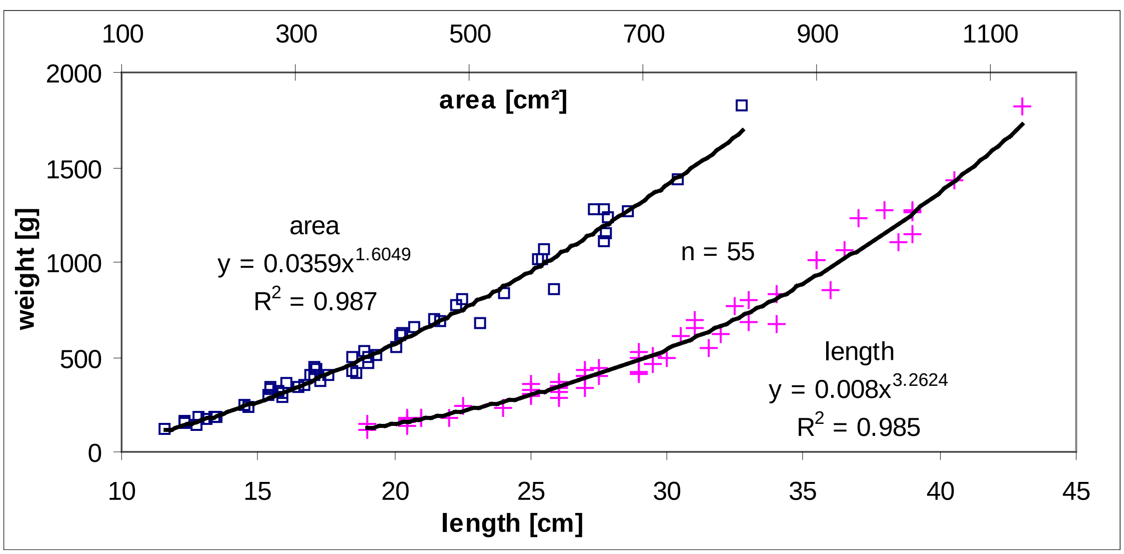

Figure 7. The relation between weight and size expressed in length and area

Typical form parameters and their variation in the population were calculated from the images of the single fish. The contour U, area A, and length d were analysed and the normalized parameters A/d, U/d, U/A and the circularity C

$$C = \frac{U^2}{4\pi A} \quad (2)$$

and their variation – expressed over the variation coefficients VC = SD/mean - were calculated. In tab. 2 one sees that the parameter U/d shows the lowest variation in the fish population and therefore it was used as a selection criteria for a typical fish shape (only objects with typ. 2.6 > U/d > 3.4 were selected as fish).

Table 2. The variation of the form parameters in a fish population (SD: standard deviation, VC: variation coefficient).

	C	A/d	U/d	U/A
Mean	1.64	12.97	3.00	0.24
SD	0.26	2.85	0.20	0.06
VC	16%	22%	7%	24%

Tracking the whole group and individual fish The analysis of the time-lapse video shows that fish distribution is concentrated at the margin of the tank and that one single fish moves across the entire tank (data not shown). The recognition of the marked fish in the sensor area is linear to the relation from sensor area to total area (data not shown). So it can conclude that the sensor area is a representative sample of the entire population.

Practical trial Monitoring a fish population From the manual sorting the mean weight and the standard deviation of the fish population (1839 fish) is 725 g and 265 g, respectively. The automatic online analysis measured over 800 fish in the time of 17 days. The recognition events are well distributed over time even during the night there was enough light for fish detection. On average only two fish are monitored per hour. The main statistical analysis from all measured fish sizes is the calculation of mean and standard deviation because this is the main description of the fish population. The mean weight of this first analysis differs 10 % to the “real” value (see tab. 3, method A). It is possible by the programmed algorithm that a fish is measured several times if it is not moving but there are other motions in the image that triggers a new object extraction. This can be corrected with the knowledge of the time and object position. Although this correction can be done quasi online (e.g. every 1 h) it is named post-processing.

Post-processing. If a fish is not moving - but due to other motions a new object extraction causes the selection of this fish again – this fish should not be measured twice, which would change the statistic. After the shape-based selection of objects, it is also possible to select objects out of a time-series of images. It is checked if a fish is measured twice in a short time-interval (typ. 1 min) and at the similar position (typ. 10 cm) and at the similar size (typ.2 cm). In incidence of all three cases only one measurement is considered for the statistic.

Another correction is done with respect to the absolute position of the fish: due to the sloped view of the camera fish in the back of the image shows a higher distortion and lower resolution than fish in the front of the image. This was considered by weighting the fish sizes with the ratio of object area in pixel² to cm² for the statistical analysis. These results only vary 5 % to the real weight and the standard deviation was overestimated

with 33 % (see tab. 3, method B).
For this trial a manual evaluation of all automatically detected fish images was performed by an human observer in addition. This causes the sorting of 27 % wrongly detected fish, leading to a slight lower mean weight (-4 %) but a more accurate standard deviation. It should be mentioned that the false recognition mostly show marginal mismatch, e.g. the tail was not detected or a little bit dirt was detected as a part of the fish.

Table 3. Comparison of camera estimated weight and manual sorting results (SD: standard deviation).

manual weighting: 725 g ± 265 g method	fish	fish/h	mean weight (*)	SD of weight (*)
A) all fish-detection	828	2.0	799 g (10 %)	366 g (38 %)
B) without replicants, weighted mean	576	1.4	763 g (5 %)	352 g (33 %)
C) without replicants and false detections, weighted mean	419	1.0	699 g (-4 %)	253 g (-5 %)

* relative difference to manual weighting

4 CONCLUSION AND DISCUSSION Overall it can be concluded that the performance of this automatic online estimation of fish size is good enough to get reliable data. A practical application in a commercial plant leads to concurrent results with manual weighting. The representativeness of the sample area seems to fulfil the requirements. This is also confirmed by tracking individual fish.
The main disadvantage is the sample frequency of approx. one fish per hour: This is enough to describe the population distribution within two weeks but weekly growth rates could not be determined. It was not tested if every single lying fish was detected. It is plausible that at normal fish density only a few times per hour a single fish is lying isolated on the ground. In future projects - if the object extraction is enhanced, i.e. that fish lying on fish can be detected - it should be possible to monitor weekly or even daily growth rates.
Describing the standard deviation of the fish population is not as precise as the mean. This could also be solved with an enhanced object extraction leading to a more real contour and avoiding smaller contours without tails and bigger contours with enclosed dirt.
One more theoretical aspect is the systematic error based on the small sensor area of approx. 1 m²: It is more probable that smaller fish are lying single or with the entire shape in the image whereas bigger fish are more frequently located at the margin of the image. But this was not observed in the trial because the size differences in the fish population are not as big compared to the sensor area.
The motion detection is not obligatory the first step in image analysis: It was also tested to do first the object extraction and selection and to compare the position of the detected fish from successive frames to decide if the fish is moving or not. With this approach also still lying fish are detected although other fish are swimming but the computing time rises so that only approx. one frame per second is analysed online.

Acknowledgements This project was part of „e-region Schleswig-Holstein plus“, an agenda of the Ministry of Science, Economic Affairs and Transport and the

Foundation of Innovation Schleswig-Holstein (ISH) – aided by the ISH and the European Union (EU) from the European fund for regional development.

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