EXACTUS Technical report

EXACTUS RA 1

T1.1 Technology survey

Authours

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EXACTUS Technical Report. T1.1 Technology Survey.

Revision

Rev.	Date	Authours	Approved bt
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Table of contents

1 Introduction

1.1 Background

The work reported in the present document has been carried out as part of the EXACTUS project, Research Area 1 – Instrumentation for Biomass Measurement. (SINTEF, 2009) The objectives of RA1 are to identify, develop and innovate basic technologies as candidates for implementation in future biomass systems, mainly with regard to fish counting and size distribution measurement. Possibilities and potentials in combining technologies into a complete biomass measurement system are focused as a contribution to improving accuracy. CMR Instrumentation, SINTEF IKT, and University of Oslo are the participating research institutions on RA1.

Aarhus (2009) reports that estimation of biomass in salmon and trout farming is one of the key issues that farmers, processing plants and sales face. The reason why biomass is not correctly estimated are complex, and includes a combination of technology for counting and sizing and the use of such technology in addition to biology, fish welfare and environmental conditions. It is estimates that on average the error in estimated biomass lie within +/- 5%, it may however vary from close to 0 to +/- 40 %. Underestimation of fish accounts for 65 % of the cases where biomass is wrongfully estimated according to a major fish farming company.

In the context of EXACTUS the industry partners have identified long term goals of 0.1 % uncertainty in fish count in a fish farming facility, and 1 % uncertainty in fish weight. In addition to improved practices and better use of existing instrumentation, improved measurement technology may also be needed to reach these very ambitious goals. The present report presents the results from Research task T1.1 – Technology Survey. Properties and uncertainties of currently available instrumentation for fish counting and sizing will be discussed as well as present and earlier attempts to achieve better accuracy. The contents of this report is based on publically available material such as product information and articles (scientific and industry related) as well as direct contact with equipment producers, resellers, scientists and fish farmers.

1.2 Basic problem analysis

1.2.1 Fish counting

Farmed fish is usually counted when fish handling operations provide opportunities:

- Vaccination
- Transfer to fish cage (into well boat, out of well boat)
- Splitting of cage populations (often accompanied by sorting)
- From sea cage to slaughterhouse (into well boat, out of well boat)
- Counting of processed fish in slaughterhouse

Practice varies somewhat as to where and when counting is performed. Not all opportunities are necessarily taken (e.g., out of well boat if the carried quantity is assumed to be known). Counting as often as possible should thus be regarded as a first step towards better knowledge of fish count.

Three main types of counters are commonly used on well boats, for somewhat different purposes:

- table counter (fish/smolt and little water) – smolt and stocking fish
- pipe counter (fish and little water) – primarily for cage splitting, 1–2 kg fish
- full water counter (pipe flow of fish and water) – fish for slaughter

No present method has been identified for counting fish swimming freely in cages. Handling large cage size and dependence upon tracing individual fish can be seen as two main challenges for such in-cage counting. Statistical methods could be imagined to provide a fish count based on e.g.

extinction of light or sound beams crossing through cages, but would not necessarily yield sufficiently high accuracy to be useful in this application. For example, the distribution of fish throughout the cage volume is far from random.

1.2.2 Fish weight measurement

Fish sizing in cages and onboard vessels is most commonly performed by measuring dimensions such as length, height, thickness, or volume. The weight (mass) of the fish is calculated from these geometrical measures, using empirical relations that depend on the species and condition of the fish. A general fisheries model is on the form (e,g,, Jones *et al.* 1999; Froese, 2006):

$$m = f(l) = al^b, \tag{1}$$

where m is mass, l is length. When the parameter b is set equal to 3, the parameter a becomes the Fulton condition factor (see also Nash *et al.* 2006). Alternative models exist, e.g., including the height h of the fish (VAKI manual, 2008),

$$m = f(h,l) = chl^2, \tag{2}$$

where c is another empirical parameter. An additional factor is sometimes included to place the decimal point if non-standard units are used (e.g., cm for length). The dimensions of the fish (e.g., l and h) are most commonly measured optically by means of light curtains or cameras. The following instruments types are used the most in cages and well boats in Norway and UK:

- Rectangular optical frame (in cage)
- Stereo camera (in cage)
- pipe counter (pumped fish)
- full water counter (pumped fish)

When an uncertainty as low as 1 % is expressed as a goal for the measurement of fish mass, one must assume that both length-weight models and measurement methods for fish dimensions may represent significant contributions to measurement uncertainty.

1.3 Expression of measurement uncertainty

1.3.1 Best practices

No measurement result is meaningful without proper specification of its uncertainty, preferably conforming to international recommendations. The present study will not include detailed uncertainty analyses of each considered technology or product. A basic outline of measurement uncertainty treatment may still be useful as background when assessing what accuracy may be achieved using different technologies.

The *Joint Committee for Guides in Metrology* provides an international set of guidelines for how measurement uncertainties should be expressed, which is broadly used in science and industry. The most important documents regarding measurement uncertainty are JCGM 100:2008 (GUM) and JCGM 200:2008 (VIM). An introduction to the guidelines is also provided by the Committee (JCGM 104:2009). EA 4/02 – "Expression of the Uncertainty of Measurement in Calibration" is another useful reference, written by European Co-operation for Accreditation in conformance with the predecessor of JCGM 100:2008.

1.3.2 Measurement models and combined uncertainty

A measurand (quantity to be measured) Y, which in the present application could be, e.g., a number of fish or the mass of a fish, is often related to several input quantities X_1, X_2, …, X_N. Such input quantities could, e.g., be the length and height of a fish measured to obtain its mass. A general measurement function can then be expressed as

$$Y = f(X_1, X_2, \ldots, X_N) \tag{3}$$

The result of a measurement is an estimate y of the measurand and an associated standard uncertainty $u(y)$. The estimate of Y is based on estimates x_1, x_2, …, x_N of the input quantities.

Sensitivity coefficients c_1, c_2, …, c_N describe how a measurement result is influenced by small changes in the estimates of each input quantity. If a measurement function such as Eq. (3) is given and the input quantities are independent of each other, the sensitivity coefficient c_i is the partial derivative of the measurement function with respect to X_i at $X_i = x_i$. The standard uncertainties for each estimated input quantity combine to the standard uncertainty for the measurand estimate through quadratic summation,

$$u_{\mathrm{c}}^2(y) = c_1^2 u^2(x_1) + \cdots + c_N^2 u^2(x_N) \tag{4}$$

For example, if the formula in Eq. (1) were to be used as a measurement model for fish mass, it would yield the following expression for the combined standard uncertainty of the mass estimate:

$$u_{\mathrm{c}}(m) = \sqrt{\left(abl^{(b-1)} \cdot u(l)\right)^2 + \left(l^b \cdot u(a)\right)^2 + \left(al^b \ln l \cdot u(b)\right)^2} \tag{5}$$

Here it is proposed that the two factors a and b be treated as input quantities with corresponding standard uncertainties, in the same way as the measured fish dimensions. Separate analysis is needed to determine the standard uncertainties $u(l)$, $u(a)$ and $u(b)$ in this example. “Uncertainty budgets” are often set up to account for all sources of uncertainty, using standard uncertainties and sensitivity coefficients to quantify each uncertainty contribution. If two input quantities are not independent of each other their covariance must be included in the uncertainty budget.

It is important to identify and quantify all possible contributors when specifying the uncertainty associated with a measurement result. For example, most so-called parameters and constants (such as, e.g., condition factors) are clearly estimates and should be accompanied by corresponding standard uncertainties. Without analyzing and quantifying the uncertainties of all contributions in a measurement model it is difficult to truly assess the potential measurement accuracy of a corresponding measurement method or technology.

When, alternatively, measurement uncertainty is estimated on the basis of a large body of empirical data (i.e., “prior experience”), it is important to be aware that the same principles of propagation of uncertainty still apply. Past observations may for example carry common bias effects with them, or they could in some cases be indicative of a somewhat different quantity than the assumed measurand. Careful consideration of measurement mechanisms and the quality and validity of reference data is therefore important also in this case. For example, if a significant amount of time has passed between two measurements of the mass of a fish, they may not be comparable (due to e.g. growth or starving).

1.3.3 Level of confidence

The definition of standard uncertainty is based on the statistical standard deviation and refers to a statistical probability distribution for the quantity to be measured. An estimate y with corresponding combined standard uncertainty $u_{\mathrm{c}}(y)$, has a “level of confidence” of approximately 67 % (JCGM 100:2008), that is, 67 % probability that the measurand quantity Y is within the interval given by

$$y - u_{\mathrm{c}}(y) \le Y \le y + u_{\mathrm{c}}(y). \tag{6}$$

An expanded uncertainty U can be used to obtain another interval

$$y - U \le Y \le y + U \tag{7}$$

with a higher level of confidence. U is found by multiplying the combined standard uncertainty with a coverage factor k,

$$U = ku_c(y), \tag{8}$$

where k is commonly in the range 2 to 3 depending on the application. Particularly, if the probability distribution characterized by y and $u_c(y)$ is approximately the normal distribution and the number of effective degrees of freedom of $u_c(y)$ is sufficiently high, a coverage factor $k = 2$ produces an interval with approximately 95 % level of confidence and a coverage factor of $k = 3$ produces an interval with approximately 99 % level of confidence. In general, however, the probability distribution is not necessarily normal, and one may need further knowledge of the probability distribution to ascertain the coverage factor associated with a certain level of confidence.

A general observation is that one can rarely guarantee that a quantity is inside an interval such as e.g. given by Equation (7). The probability distribution associated with a measurement most often indicates that deviations greater than any stated uncertainty will occur from time to time, even if the probability of such an event can be generally be made low by increasing the coverage factor.

2 Review of technologies for biomass estimation / fish sizing

The methods for biomass estimation is based on various ways to find the volume of individual fish, and calculating the biomass by averaging over a large population (>1000). The statistical size distribution is also estimated. Having accounted for the number of individual in the cage, the total biomass in the cage is estimated from the distribution. This makes two condition very important for the accuracy of the biomass estimate, namely the number of fish in the cage, and how representative the subpopulation that have been sized is for the total population in the cage. A third factor is that the statistical estimate of the fish volume is unbiased, which will ensure that one get increasingly better estimate with the number of fish sized. These three factors apply for nearly all methods that are discussed here.

The total biomass may also be estimated from the feed consumption, or from the amount of acoustical backscatter of the total population. These methods are deemed not to have sufficient accuracy for this application, but might find use as supporting/revision technology. Few products based on acoustic technologies have been on the marked for this application with the exception of Simrad FMC 160 and AquaSonar.

Size measurement of fish in aquaculture cages is commonly performed using optical measurement of fish dimensions. The mass of individual measured fish is inferred from external measures such as length, height, and to some degree width. The conversion from external size to weight is performed using empirical coefficients that depend on the species and condition of the fish. The technologies to find the mass of the individual fish are mainly what are discussed in the following chapter.

Basic information provided by the producers are summarized in Table 1 in Appendix A 1.1

2.1 Optical fish sizing

2.1.1 Frame systems

There exists two frame based system for biomass estimation in cages today, produced by Vaki and Storvik respectively. The hardware solution of the systems is nearly similar, but they differ in recommended operating modes, and in the software system delivered with the system. Whereas Vaki offers a comprehensive online system with a continuous internet logging of the cage via Vaki's "Biomass Daily" server, and with the frame permanently installed in the cage during the breeding period, Storvik offers a system recommended for shorter period deployment in the cages with possibility to move the system from cage to cage, and where de data is recorded in the frames onboard computer, and is transferred wirelessly to an handheld terminal at wish, and further to a PC with the accompanying soft ware.

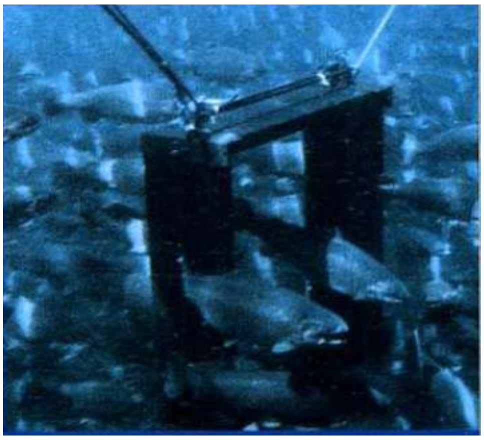


Figure 1. Vaki frame deployed in cage

Figure 2. Storvik frame deployed in cage.

The technology

Both systems are built up around a double light curtain that maps fish shadow in horizontal and vertical direction when a fish is passing through the frame. By mapping both horizontally and vertically one can decide whether the fish passes the frame at an angle or not, and if there is more than one fish in the frame at the time. Length of the fish is calculated from passage time and a velocity estimated from first crossing times of the two curtains, and the crossing times when the fish leaves the frame. The Vaki system chooses to discard the measurement, if the velocity for the front and the aft of the fish differs,

System assessment

Fish sizing by diode frames is a well established measuring technology. There is, however, a discussion among fish farmers on the feasibility of the method. This may be connected to the ability to obtain representative sampling of the cage population due to different behaviour among the fish. This subject is addressed in RA3. On the other hand the equipment manufacturers claim that with proper implementation and use the frame system will predict the slaughter weight to within 2% compared to weight reported by the slaughters

To introduce a foreign object into the cage will cause some disturbance for the fish. Ideally it should be as invisible for the fish as possible. But the frame does not introduce any active lighting or produce any sound that the fish can perceive.

Disturbance may, however, be introduced by unnatural movement of the frame caused by waves that move the fixation points of the frame, thus making the frame move relative to the surrounding water masses. This effect may be the reason for problems to obtain reliable estimate in some locations. Another potential error source related to fish motion is deviation in the swimming pattern caused by local currents.

To obtain a good estimate of average weight and weight distribution it is necessary to size a large number of fish. This has the effect that the absolute accuracy in the measurement of each individual fish is not critical as long as the statistical estimation methods are unbiased, that is, converging to the correct mean value. It is planned to perform separate measurements on the accuracy of measurements in RA1.2

A potential to improve these systems is seen in the combination with other sensors like echo sounders or sonars to monitor the position of the frame relative to fish schools within the cage and to use this information to actively position the frame to always have an optimal position. The usefulness of this information will hopefully be established in RA3.

As to technical improvements to the frame itself, we find that a slimmer and, for the fish, less visible frame may be useful. Also a new method to measure the velocity of the fish through the frame may be useful to improve the accuracy to length measurement of the fish and decrease the number of discarded measurements. A way to do this may be to use a camera image of the side of the fish a do correlation measurement to establish the instantaneous velocity.

2.1.2 Stereo camera

The VICASS system by Akva group uses a stereo camera setup to estimate the fish size distribution within a net cage. The system consists of two standard black and white video cameras arranged in a stereo view configuration (the two cameras have a vertical displacement while having overlapping fields of view. The camera system is placed at one or more locations in the cage while images of passing fish are captured. A minimum number of images should be obtained from different locations to get a representative sample of the fish. The images are later analyzed off line by manually marking the outline of the fish (mouth, tail, top and bottom) in images where good views of the whole fish are available. The distance to the fish is determined from the offset of the fish position between the two stereo images, and the absolute size and weight of the fish can then be estimated from the marked points.

The main drawbacks of this system is the relatively labor intensive process, the individual variations between manual operators, and manual image capturing process that makes continuous monitoring difficult and costly.

AQ1 Systems' uses the same principles as AKVA group in their AM100 fish sizing system. AM100 consists of two 1.4 Megapixel color cameras arranged in a stereo view configuration. The manufacturer recommends that at least 100 fish should be measured in total, at three different depths in each cage (AQ1 Systems, pers. comm.). The AM100 algorithms are continuously evolving and algorithms for approximately 10 species are implemented, including Atlantic salmon. AQ1 Systems main focus though has been on fast swimming species such as Tuna (Harvey et al, 2003). A 2% difference between sampled weight and actual weight in real life application is considered a good result, and the specifications for accuracy are 1-2 % of measured length up to eight meters from the cameras.

2.1.3 Common considerations – optical sizing

Size measurement of fish in aquaculture cages is commonly performed using optical measurement of fish dimensions. The weight of individual measured fish is inferred from external measures such as length, height, and to some degree width. The conversion from external size to weight is performed using empirical coefficients that depend on the species and condition of the fish.

2.2 Acoustic fish sizing

2.2.1 AquaSonar (Aqua-DRUMS)

Guigné International Ltd. developed several products based on their DRUMS (Dynamically Responding Ultrasonic Matrix Systems) technology. One of these products was the Aqua-DRUMS (International patent no, PCT/IB2000/001500, "Fish sizing sonar system") sonar for fish sizing in aquaculture. This company is not longer operative and the Aqua-DRUMS technology was brought in to a new company Aquatic Sensing Technologies Ltd. (http://www.astl.ca) and renamed AquaSonar. One of the inventors behind the Aqua-DRUMS, Thomas McKeever, runs the company and continues to develop the system. According to Aquatic Sensing Technologies Ltd. the AquaSonar is sold to and in use on all continents with salmonid fish farming.

The AquaSonar is a noninvasive fish sizing system (McKeever, 1998) that can be mounted outside of the cage and size hundreds of individuals in a short order of time. The AquaSonar manufacturer claims that the system can size over 2000 fish in one hour, with better than 96% accuracy on average weights. The sonar system consists of an electronics module, an underwater sensor (transmitter/receiver with tilt and temperature sensor) and a 25 m cable connecting the electronics module and the sensor. An estimate of average fish size is shown on the display of the electronics module within five minutes. Data is also stored on the electronics module, and may be transferred to a computer for analysis using the AquaSonar software package.

Figure 3. AquaSonar electronics module (Photo: Aquatic Sensing Technologies).

Figure 4.AquaSonar transducer module (Photo: Aquatic Sensing Technologies).

Some of the advantages of the AquaSonar technology are the systems ability to dynamically respond to fish swimming speed, rearing density, and that it requires no additional post-processing investment on behalf of the farmer. Like other acoustic methods, the AquaSonar can also operate in conditions of low visibility including during nighttime. The system may also be fitted with an underwater camera system to allow for fish health and behavior monitoring, and it requires minimal set-up time and no special training. If the system accuracy is as high as stated by the producer it might be a convenient tool for inventory control purposes, since it is able to size a large number of fish in a relatively short period of time. Additional plans exist to develop the AquaSonar system to be capable of determining fish biomass in an entire cage system therefore having additional advantages of monitoring for theft, acute escapement, or high mortality.

If the sonar is positioned in near the edge of the cage, there is a question of whether or not the sonar obtains representative samples. As the sonar cannot penetrate the entire cage, fish in the outer parts of the aggregation will be sampled while fish in the centre will not. This is especially relevant for large cages, where fish might also form dense aggregations in one area of the cage in for example rough weather conditions. It will not pose a potential problem however if the sonar can be moved inside the cage.

Storvik Aqua who resold AquaDRUMS in Norway reports that they experienced unsatisfactory accuracy with the sonar (Storvik, pers. comm.). They also experienced problems with unstable measurements; some measurements had an error higher than 100%. The Norwegian fisheries directorate performed initial field trials to test the technology on trout in Osterøy (Fiskeridirektoratet, pers. comm.). The trials were unsuccessful as the results showed a large deviation from the true mean weight. The reason for this is likely that the instrument was not calibrated for trout. The instrument was also an older version of the AquaSonar (a Aqua-DRUMS). Aqua-DRUM has also been used by Lerøy in Canada, but without great success (pers. comm.). Reports from one of the salmon farming companies that have incorporated AquaSonar in their production planning and control are more positive (Michael Clinch at Cooke Aquaculture, North America, pers. comm.). Cooke Aquaculture has nine AquaSonars in their inventory, and uses them in cages ranging from 24 m steel cages to 150 m circular cages. AquaSonars are deployed from a rope installed in each cage, allowing the sonar to be positioned anywhere between the edge and centre of the cage along this rope. Each pen is measured once a month and a satisfactory sample is achieved between 30 and 45 minutes (minimum 15000 fish sampled). Sonar data is used to monitor growth throughout the lifecycle of the fish and to plan harvesting. The company's goal is to have a +/- 5 % accuracy, which is usually achieved. VICASS and AquaSonar are Cooke Aquacultures primary sampling systems, and they have found these systems to be equally accurate. In general they use VICASS on high current good visibility sites and AquaSonar on low current poor visibility sites.

2.3 Existing technologies in other fields

2.3.1 3D imaging with structured light and camera triangulation

The use of structured light combined with one or two cameras for 3D imaging of objects has become a well established technology in the industry. The principle is that a known pattern of (structured) light is cast on the scene, and this pattern is imaged with a camera from a location offset from the light source in a different view angle. By recognising the light pattern in the camera image one can derive the distance to and the 3D geometry of the object from which the light pattern is reflected, by triangulation methods.

A very common solution is to use a laser stripe as the structured light as shown in Figure 5. As the object, e.g. a fish, passes the camera the stripe will scan the whole object and the 3D geometry of one side of the object is obtained. Two or three systems looking from different sides can be used to obtain a complete 3D model of the object.

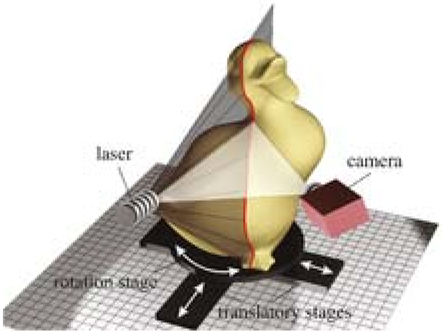


Figure 5. Illustration of a laser triangulation system using a laser stripe. The stripe is scanned across the object to produce a one-sided 3D geometry of the object. (From Wikipedia)

If the object can not easily be moved passed the camera a full field structured light system can be used. One popular method in the industry has been to project a sequence of different grey level patterns onto the scene, where the patterns are chosen such that the sequence of grey levels measured in each pixel of the camera can be used to determine which position of the light patterns that each pixel images. A standard video projector is used for generating the different light patterns. With this principle the distance to the object is obtained for each pixel in the image, in addition to a grey level image of the scene. Figure 6 shows an experimental system and a resulting 3D model.

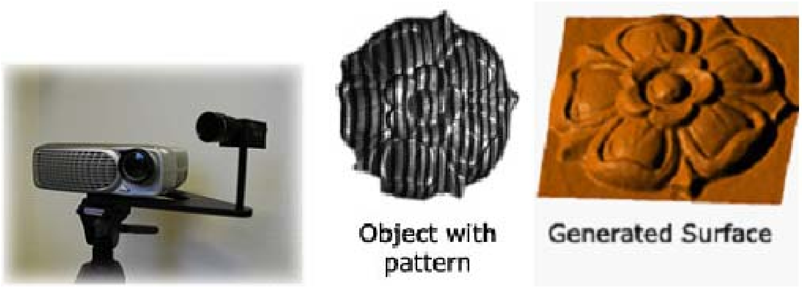


Figure 6. An experimental full field structured light system based on a video projector and a camera (left), an illuminated object (centre) and the final 3D model of the object (right).

The main drawback with this solution is that the object to be imaged needs to stand still during the illumination and image capturing sequence. This can take from a fraction of a second to more than a second.

There exist full field structured light systems that are able to produce real time measurements, e.g. 25 full 3D images per second. The Kinect from Microsoft is an example of such a system that recently has become available at a low cost for their video gaming system Xbox. This projects an infrared dense pattern of spots over the entire scene, and the spot pattern is uniquely identifiable in an image taken with a camera viewing the scene from a slightly different angle. The depth to the scene is obtained in each image pixel as shown in Figure 7 based on identifying and measuring the position of each pixel in the spot pattern.

All the above methods seem relevant for detecting and measuring the size of fish in net cages.

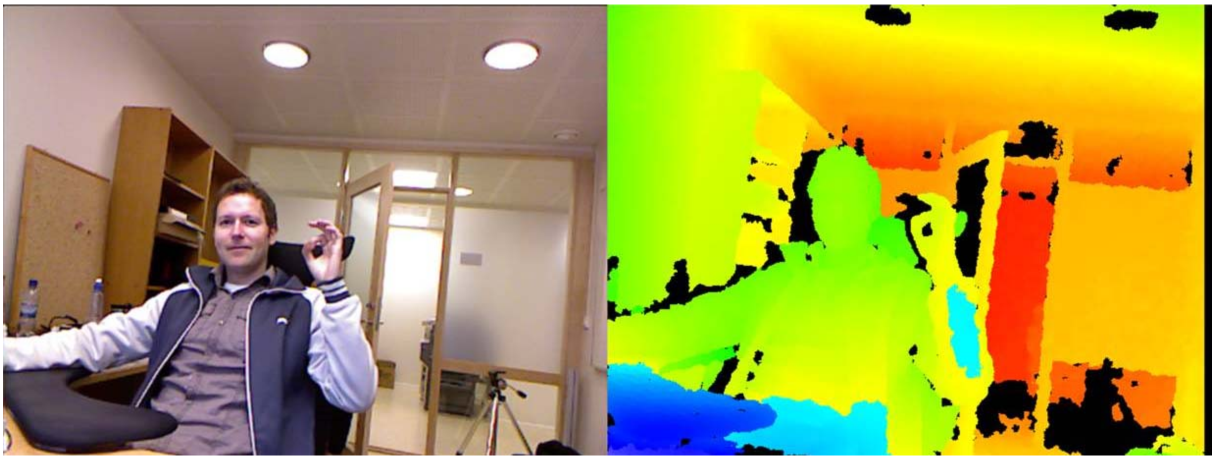


Figure 7. Example of a color and a 3D depth map captured with a Kinect camera system

2.3.2 3D time of flight camera

As far as we know there are two concepts using the time of flight for light to retrieve depth information. The first is to send out modulated light and measure the phase delay of the received light. This is the principle used in most laser range finders, such as “total stations” used by land surveyors. There is a wide range of laser range finders available, as well as laser scanners that use a laser range finder combined with a 1D or 2D scanner unit to measure the 3D geometry along a line or a surface.

The company MESA is selling a camera known as Swissranger. They use a detector array in their cameras where each pixel is capable of measure the phase of the received signal. The front of the camera contains multiple LED’s emitting at 850nm and modulated at ca 20 Mhz. Based on the measured phase shift in each pixel a full 3D image of the scene is captured in real time (> 25 images per second).

We have briefly tested this camera under water and although we think the principle may be promising our conclusion is that the camera can not be used as it is, since the usable range is very short, just 20-

30 cm, due to the low transmission of the infrared illumination in water. Light scattering and strong reflections is also a problem. The lens is fixed and has to small aperture. We think however it may be possible to reconfigure the camera for underwater applications.

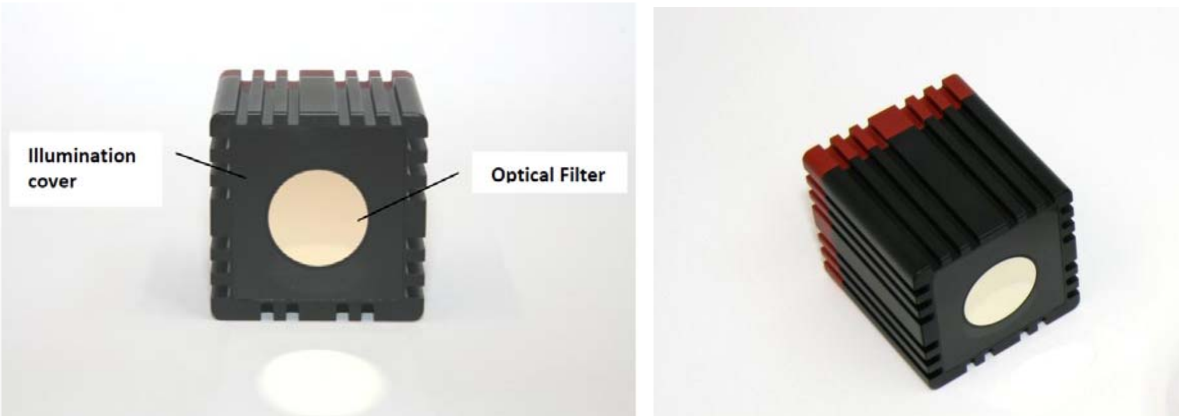


Figure 8. Pictures taken from MESA's web site. Dimensions are ca 80x80x80mm.

Another concept for range measurement is to send out a short pulse of light and measure the time between when the light pulse is emitted and when the returned reflection from the scene is detected. This is the principle used in LIDAR's (Light Detection And Ranging) and some laser range finders. To have a short light-pulse with less than 1 ns rise time, diode lasers are used. The companies Canesta has developed a camera chip witch precisely detects the time of arrival for the pulse in every pixel. This corresponds to one LIDAR per pixel. We expect underwater use to be a problem because backscatter is received continuously and there will be a less sharp difference between before and during the pulse.

Another company known as 3DV Systems has a camera called Z-cam. Their camera is range gated. This means that only light within a certain distance range is detected. They have developed an electronic shutter chip. This chip is mounted atop the sensor chip. They use diode lasers to generate short and well defined pulse with sub ns rise and fall times. Pulse signals are received on so called z-pixels. The camera chip has in addition to z-pixels also red, blue and green pixels. The ratio between neighbor color pixels and z-pixels will determine the distance.

Both Canesta and 3DV Systems is bought by Microsoft during the last year.

In general 3D cameras may have potential for biomass estimation. With the 3D information it should be easy to separate each fish in the image and easy to determine the size of the fish since the distance is known.

2.3.3 Quick and dirty experiments with the Kinect and the Swissranger

A short evaluation of the Kinect and the Swissranger concepts was done in our water-tank. Dimensions of the tank are 0,5x0,5x1,25 meter. A dead fish was mounted on a plate and put on the short side of the tank. We tried to image the fish from the opposite side.

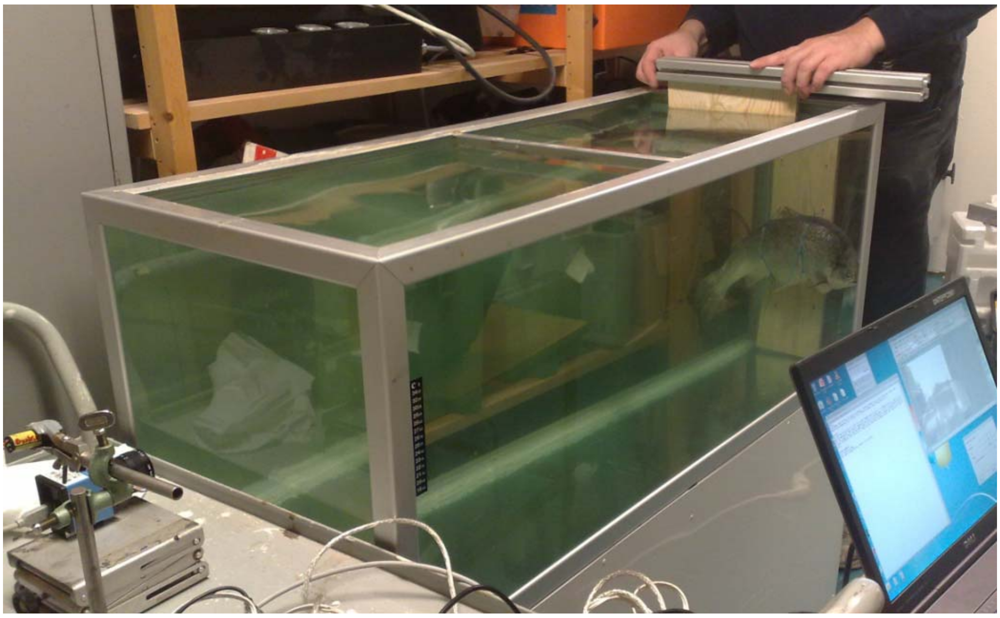


Figure 9. Watertank and fish. Imaging was done through the short side.

Both the Swissranger and the Kinect suffered from large absorption of the built in illumination. Both systems use a wavelength around 800 nm which is highly absorbed in water. The Swiss ranger camera also had problems with reflections from the glass in the water tank. The Swiss ranger gave pour images up to ca 30 cm and nothing above that. The Kinect camera is internaly blocked for short distances. Just above the block, that is 0.65 meter in water, we got a rather rough image of a label on a plastic soap container we held down in the water.

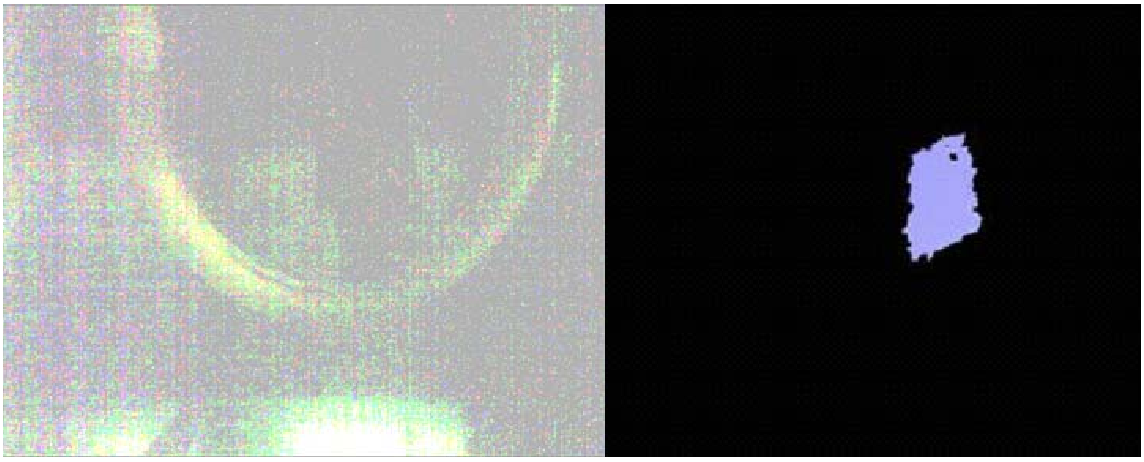


Figure 10. ***Images of a label on a plastic soap container at 0.65 meter distance in our water tank. Images are taken with the Kinect (X-box) camera. Color image to the left and false color dept image to the right.***

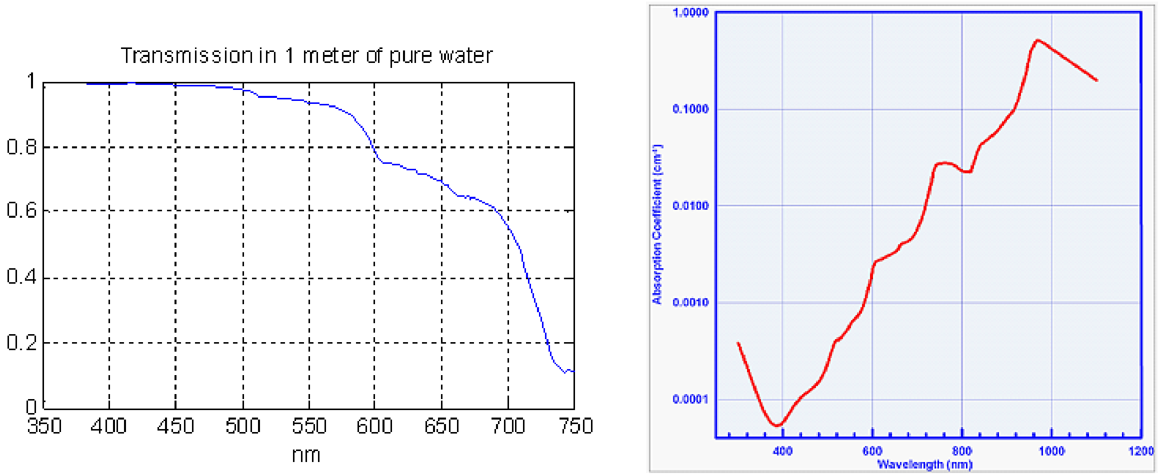


Figure 11. Transmission and absorbance curves for pure water. We should use a wavelength that is invisible for the fishes. But, if also shorter wavelengths than 800 nm is invisible for the fishes we can improve range and image quality by go to shorter wavelengths.

We think both the time of flight camera and the dot pattern camera can be rebuilt for under water applications. The time of flight camera might have problems with forward scattering from direct reflections from the fish skin.

Our conclusion is that we should investigate what is the shortest wavelength invisible for the fishes. A shorter wavelength will increase the range of a camera system. Direct reflections and scattering are unwanted and should be reduced. We want to look at ways to do this.

2.3.4 Sonars and echosounders

Acoustic echo integration is a well-proven and highly important tool for marine resource management. Stock assessment cruises are performed with calibrated echosounders that record acoustic backscatter from fish and plankton. Trawl samples and multi-frequency acoustic data are employed to discriminate between species. The accumulated acoustic backscatter is converted to a biomass estimates for the region being surveyed. During the last 10-15 years similar methods, based on the strength of acoustic echo energy backscattered from fish, have been applied a number of times to the problem of biomass estimation in aquaculture fish cages. The strength of backscattered acoustic signals strongly depends on aspect angles (dorsal, ventral, and side aspect).

“The fisheries acoustics approach”
Many research and development projects on quantitative use of echosounders for biomass estimation in aquaculture have been run, without reaching a state where the technology is commercialized, with the exception of Simrad FCM 160. All the major fisheries echosounder producers have been involved in such projects Furuno (pers. comm.), Biosonics (pers. comm.), Simrad (pers. comm.) on either Atlantic salmon or other species. Commercially available echosounders from all of the listed producers and others have been and is being used for research and development within aquaculture. Simrad FMC 160 was marketed and sold by Simrad as a commercial echosounder for use in aquaculture. However, very few units were sold and Simrad withdrew the product from the marked because it did not live up to expectations (Simrad, pers. com.).

In fisheries, biomass is found by integrating the echoes from fish in the water column (s_A; area scattering coefficient). Several steps must be taken in order to convert this quant to biomass. First a relationship between fish length and target strength (TS) needs to be established for the species in question, then the mean size of the fish surveyed needs to be found by other sampling methods to use the TS-length relationship to convert from s_A to biomass.

Alternatively, fish size may be found directly by either its TS or direct measurement of fish size (see 2.3.5 Imaging sonars and 2.2.1 AquaSonar (Aqua-DRUMS)). TS vary with the size of fish but may also vary with time of year (season, biological factors), depth, swimming angle, aspect, and species. There are also individual differences between fish of the same species and size, so several hundreds measurements are usually required in order to obtain a precise measurement of TS. Measuring single fish for sizing is difficult due to the high density, and is limited to measuring single fish in the outskirts of the aggregation. These fish may not be representative for the entire population. In order to size individual fish echosounders must be lowered close or into the fish aggregation (AquaSonar, Herring: Ona, al., 2003; Handegard et al., 2009, Pedersen et al., 2009). Salmon TS has been measured by Knudsen et al. (2008) and others (for example Lilja et al., 2000), but mostly in the side-aspect as the application usually is river monitoring.

Another option is to monitor growth as a function of increased backscatter in the fish cage, and loosely relate this to biomass i.e. only look at trends. This is the common method in fisheries, as “absolute acoustic abundance estimates” are not available for most species. However, extinction effects also prevent this from being a practical method unless correction factors for salmon are developed.

Echosounders have however proven to be a valuable tool for monitoring both the distribution and behavior of fish in aquaculture cages (see e.g. Juell, 1995; Oppedal *et al*., 2010)

General issues with the fisheries acoustics approach in sea cages

The main problems with these methods are the high density of fish in commercial fish farming. Extinction will always occur, which is loss of energy as the sound wave penetrates the layers of fish due to the high densities. Empirical models for extinction have been developed for some schooling fish such as Norwegian spring spawning herring (Toresen, 1991; Foote and One, 1993, Foote, 1999, Zhao and Ona, 2003). Other complicating factors include forward scattering and multiple scattering. Multiple scattering is caused by echo energy retained in dense fish layers by repeated scattering inside the layer, leading to a prolonged echo. Multiple scattering is observed in the ocean with dense schools, and is definitely an issue with the high fish densities in aquaculture. Fisheries echosounders are also designed to operate under conditions where the fish is far from the transducer where the fish are small compared to the range (point-source requirement). This requirement is not fulfilled at short ranges. Reliable measurements are only available in the sonar’s far-field, where the acoustic beam is properly formed and typical echosounders have a near-field of several meters (depending on dimensions and frequency). Fish also have a near-field (Dawson *et al*., 2000) and the combination of the near-fields of the echosounder and fish limits how close the sonar can be in order to achieve proper measurements of fish (potentially a substantial portion of the depth of a cage). Mounting an echosounder near the surface (dorsal aspect measurements) is not ideal for quantitative measurements since fish are lost in the blind zone of the sonar (fish near the surface), the near-field limit, surface movement, and back radiation/scattering from the surface. Noise due to interference from the sidelobes (signals from cage, rope, hard structures) is also reported in cage environments.

SIMRAD / Institute of Marine Research

SIMRAD has worked for several years to develop acoustic methods and a system for biomass estimation in aquaculture (SIMRAD, 2002; Knudsen *et al*., 2008) with the Institute of Marine Research and EWOS Innovation. The objective of the Research Council of Norway project ”Overvåkning av laks i merd med ekkolodd” was to develop a low cost echosounder to monitor growth and biomass in addition to feed waste, escapement, behaviour, and dead fish. The project was split in three parts to fulfil the objectives of the project: establishing a TS-length relationship for Atlantic salmon, a methodology for single-fish detection, and for measuring total echo-energy in cages.

Knudsen *et al*. (2008) measured target strength (TS) of salmon in several size groups in sea cages at Austevoll aquaculture station (low fish densities, 6-17 fish per length group in a 12x12x20 m cage). Measurements were performed with two echosounders (120 and 200 kHz) mounted at the surface (dorsal aspect) and bottom (ventral aspect) of the cage. Dorsal TS to length relationship was poor due to bi and trimodal TS distributions found in the smallest size groups (20, 25, 55 cm mean total length) but not in the largest (67 and 78 cm mean total length). All size groups showed unimodal TS distributions in the ventral case, leading to a good correlation between TS and mean total length. A bi- and tri-modal TS distribution was found in dorsal recordings of the smallest size-groups (20, 25 and 50 cm), but this was not evident for the two largest groups (67 and 78 cm). As a result, the TS-to-length relationship for dorsal recordings was rather poor. However, when the recording was made ventrally, the groups showed a predominantly unimodal TS distribution. A good correlation was then found between TS and fish length, both for 120 and 200 kHz. No depth effect was shown in this study, i.e. changes in target strength as the swimbladder is compressed with increasing depth. Salmon are and have the ability to compensate for increasing pressure by inflating its swimbladder. This is however a slow process (refilling the swimbladder), and rapid migration up or down in the water column will influence the TS.

SIMRAD used two echosounders (120 and 200 kHz), mounted beneath a cage to measure biomass. At the start of the experiments the weight of the fish was 100 g and the experiments ended when the fish had reached 2 kg. The echosounders managed to track the growth of the fish until it reached approximately 500 g, then the echo-energy started to level off due to extinction. Correction factors were applied to the acoustic data in an attempt to correct for extinction effects, using factors for herring and other species. This resulted however in a higher measured biomass than expected, possibly due to multiple/forward scattering.

Plans exists to commercialize an aquaculture echosounder system, but not as a tool for biomass estimation (SIMRAD, pers. comm.) but for behavior monitoring and for feed detection / control. This system will be a low cost single beam system, but with the possibility of extracting s_A values.

Universidad Politécnica de Valencia
The University of Valencia have worked to replicate earlier efforts at the Norwegian Institute of Marine Research and SIMRAD with echosounders in fish cages but with Mediterranean species, mostly gilt head sea bream (Espinosa, pers. comm.; Espinosa *et al*., 2006; Solvieres *et al*., 2007; Espinosa *et al*., 2008).

Their main results can be summarized as:

- Vertical movement during the feeding process is possible and straightforward to integrate in automatic feeding systems.
- TS-length relationship for sea bream varies monotonically with length in the ventral aspect, but not in the dorsal aspect.
- Positioning the echosounder beneath the cage allows for detection of uneaten pellets, providing a stop-feeding criterion

The research group is working to implement and test algorithms for single-beam data to exploit in a low-cost echosounder prototype. The goal of quantitative biomass estimates from echosounders has not been reached, and the research group is having problems getting funding to continue development due to the economic situation in Spain. They will however continue to work with these topics using own funding and are working to secure external funding.

BioSonics Inc.
BioSonics, a US based echosounder company, worked from 2002-2005 on a multi-phase USDA sponsored R&D project to develop a hydroacoustic biomass monitoring system for aquaculture (BioSonics, pers. comm.). The project was quite successful and provided much insight into the requirements and considerations in developing such a system according to BioSonics. However funding at the time was insufficient to advance the project to commercialization and therefore BioSonics does currently not have an "off-the-shelf" system for biomass estimation and they have not sold any such system to date. BioSonics has an US patent (US 2006/0018197 A1) for an acoustic biomass monitoring system for measuring fish size, quantity, and total biomass. The unique aspect of this patent is that the transducer is mounted on a moving platform. Either moving on the surface and "scanning" the contents of the cage, or being submerged and measuring from the side or from under the cage. BioSonics main product is the DT-X automated hydroacoustic monitoring systems with a wide range of acoustic frequencies available (38, 70, 120, 200, 420, and 1000 kHz) witch is the technology used in the biomass project. The DT-X is at present mostly used for monitoring of fish passage in rivers in addition to lakes and nearshore marine environments.

Swimbladder resonance for fish sizing
The spectrum of low-frequency echoes from fish can in principle be used to size fish (Løvik and Hovem, 1979), based on the assumption that peaks in the scattering spectrum corresponds to the resonance frequencies of the fishes swimbladder (Hawkins, 1977). This method is difficult to apply in practice because of the strong dependency of the resonance frequency on both depth and size of fish. Løvik (1987) used low-frequency sound (0.1-10 kHz), in the resonance frequency region of fish with swimbladder, to estimate the size of salmon in an aquaculture cage. The results are not that well documented, probably because the fish were not slaughtered at the time the paper was written and that only a few fish were manually sized. Løvik writes that "the mean fish length was found to be around 35 cm, well in agreement with the acoustically determined histogram"

Broadband acoustics for fish sizing
Scientific Fishery Systems, Inc. (SciFish) produce and sell four different models of its SchiFish 2100 sonar system, 2100-A (split-beam), 2100-B (broadband), 2100-C (multifrequency), and 2100-D

(combined). The company works mainly with fish identification in river systems. Scientific Fisheries Systems applied for funding from the U.S. Department of Commerce to develop a SciFish model specifically for fish-length assessment for optimizing aquaculture feeding rates. The basic idea was to develop low-cost narrow-beam broadband sonar that exploits the relationship between fish target strength and length over a range of frequencies in the near-side aspect of the fish, motivated by McKeever (1998) who looked at the pulse-compression aspects of the target backscatter to produce an estimate of fish length from side-aspect ensonification (SciFish, pers. comm.). By utilizing spectral estimation, the target strength can be estimated for a given frequency range. In this way, SciFish theorizes that the relative differences between the frequencies become signatures that correspond to a given length of fish of a given species. SciFish conducted some preliminary experiences on tethered smelt in Lake Michigan (dorsal aspect). The company reports that the results from this experiment were "encouraging". When processed to produce spectral features that are then classified using a neural network, the sonar produced over 90% correct classifications. Meaning that 90% of the fish echoes where correctly assigned to a length-class that had either 10 or 20 mm resolution.

SIMRAD is also developing its broadband system, WBT (Wide Band Tranciever) for use with their composite transducers, which is also under testing in the IMR project "Exploiting New Wideband Echo Sounder Technology for Zooplankton Characterization ".

Multiple scattering

Several papers in recent years have dealt with multiple scattering as a tool for estimates of fish growth and size in fish tanks where conventional echo-integration theory is invalid, such as De Rosney Roux (2001), Conti and Demer (2003), Conti et al. (2006). Solvieres et al. (2007). Conti et al (2006) further developed this concept to monitor fish density and growth (sea bass, sardines, and rockfish) in tanks (4-1 m3) using a single transmitter, and receivers to record the reverberation time series (scattering from fish and reverberation from the boundaries of the tank). The experiments were performed at the experimental aquaculture facility of Ifremer, Palavas les Flots, France (realistic Signal-to-noise ratio conditions). Good correlation between number of fish, growth rate and total scattering cross section was found by the authors. The accuracy of the measurements depends on the swimming activity and the number of fish in the tanks, and these experiments were performed with densities far below typical commercial densities, and research is needed to potentially develop this method into a usable tool for aquaculture. These methods also require reflective boundaries, and are therefore not suitable for sea cages.

Acoustic tags

HTI systems portable echosounders are mainly used for freshwater research and monitoring, such as counting migrating fish in river systems. HTIs other main line of products is there acoustic telemetry systems, also mainly used for research and monitoring of wild fish. Lately theses systems have also been incorporated in aquaculture cages to study fish behaviour. Rilahan *et al*. 2009 constructed an automated telemetry (HTI model 291 acoustic telemetry systems) and video system for observing and quantifying behavior of Atlantic cod. The telemetry system uses small high frequency tags and four hydrophones hard wired to a receiver. The authors were able to obtain positional fixes from juvenile fish every 2 s and plot these positions with an accuracy of approximately 10 cm, and thus obtain accurate information on fish swimming behavior such as feeding activity. Juell and Westerberg (1993) used a different acoustic telemetry to study the behavior of farmed fish (salmon). The authors were also able to track fish and found that the tracked salmon did not participate in 74.9 % of the feeding bouts.

Tags are without question a useful tool for aquaculture research, it is more questionable if this has the potential to become a useful tool for fish farmers. Tags may however also be used to also record both environmental parameters and the "welfare" parameters of the fish with is useful parameters in both research and operational fish farming.

2.3.5 Imaging sonars

Several imaging sonars are available on the marked from different producers (Sound Metrics, CodaOctopus, Reson, Norbit, Blueview). With the exception of DIDSON few are widely used for fisheries applications.

DIDSON

DIDSON (Dual-Frequency Identification Sonar), developed and distributed by Sound Metrics Corp, is a dual-frequency sonar imaging system. It produces high quality images from acoustic signals and has been tried out, and is still being tried out, for different fish farm/marine applications, e.g. fish counting and sizing. A huge benefit by use of such kind of acoustical system is the possibility to "see" through muddy waters.

The DIDSON system utilizes a transducer array that can operate at two frequencies, 1.1 MHz and 1.8 MHz. In the 1.1 MHz mode the system uses 48 sound beams with beam widths of 0.4 °H x 14 °V, and in 1.8 MHz mode it uses 96 beams with beam widths of 0.3 °H x 14 °V. The frame rate varies from 4-21 Frames/sec, depending on maximum range. The system has a remote focus from 1m to approximately 30m and has a field of view of 29°. Also, a long range version of the system is available, using 0.7 MHz and 1.2 MHz as operating frequencies. But this will be of less interest as the resolution is lower.

The DIDSON imaging system has for instance been tried out for counting and sizing salmon in rivers (Holmes, 2006; Burwen *et al*. 2007; Burwen *et al*., 2010) and counting and sizing yellow fish in a fish farm (Han *et al*., 2009). The DIDSON system is claimed to produce near-video quality images up to 15m and 40m for high-frequency mode (1,8MHz) and low-frequency mode (1,1MHz) respectively. A drawback with this system is that when the measurement volume gets too inhabited, the split-beam system gets saturated because of multiple targets in the pulse volume, defined by the pulse length and the effective beam cross-section at a given range, and is not able to distinguish between individuals (Holmes, 2006). The DIDSON system was tried out in fish size measurements of yellow-tail fish during transfer from a net cage to another (Han *et al*., 2009). Dedicated software utilizing the DIDSON system was developed. The system comprises software modules for image stabilizing, background subtracting and fish detector, tracker, counter and sizer. In an experiment, eighteen fishes, ranging from 75 to 90 cm (fork length 69-84) and having mean length of 83 cm, were transferred four times between two net cages while measured by the system. They were counted correctly, and the mean errors of the length measurements ranged from 0.0-2.4 cm. Adding a three-dimensional function to the system has been suggested in enhancing the accuracy of the fish sizing, but no information of the pursuing or progression of this idea has been obtained.

Echoscope 3D sonar
Echoscope is a sonar device made by CodaOctopus. The system delivers high resolution genuine 3D underwater images in real-time. It utilizes phased array technology and generates over 16000 beams simultaneously, producing 3D sonar images of moving and stationary objects. It is capable of up to 12 updates per second. The addition of motion sensor inputs enables the data to be positioned accurately in space. The Echoscope is claimed to outperform all other sonar imaging systems.

The operation frequency for this sonar device is 375 kHz, giving it a far lower resolution than the DIDSON system that can operate on 1800 kHz. The system is therefore considered to be less suitable for fish sizing compared to the DIDSON system. The major pro for this system is the possibility for 3D view in real-time, making it a system that has to be considered if a device for fish behavior is needed. The EchoScope has been used for fisheries research, for instance for measuring fish caught in demersal trawls by mounting the EchoScope on the headline of the trawl (Pedersen, personal experience).

2.3.6 Electrical, electromagnetic

The differences between the electrical properties of fish and saltwater are in practice zero, and is not likely a practical technology for fish sizing in cages. This is best suited for freshwater counting (see Section 3.3 Other systems). Electrical interferences in the form of waterborne AC currents are also an issue, and cages are a noisy environment in this respect (electrical equipment, pumps etc.). Other approaches have been discussed such as electromagnetic waveguide and radar (Mulligan, 1985), but these technologies have not been developed further for fish farming applications.

3 Review of technologies for fish counting

As there at present exists no reliable method to estimate the number of fish in a cage without any a priori knowledge, the counting strategy must be basted on keeping track of the number of fish from the moment they are let into the cage and do a meticulous accounting of the fish that are remove from the cage either as take-out for slaughter or test, by splitting and counting of the cage, or by death from disease.

The dominating types of counters today is table counters, mainly used for fry in hatcheries and smolt upon delivery to the fish farms, and pipeline counters, used for larger fish e.g. fish ready for slaughter. Pipeline counters come in a variety for dry counting, for semi filled pipes or as full water counters.

The counters may use different imaging technique as areal cameras, line scanning cameras or just a light path broken by the passing fish in the outlet of the counter

Line scanning camera counters have become increasingly popular for fish counting with hatcheries and such systems has a high accuracy and count capacity. Another advantage is that images are stored and the count may be verified, for instance if there are discrepancies between the numbers of fish counted and the delivered number. The camera records images as fish passes over the counting surface. These systems can also deliver size estimates of counted fish.

Relatively few counters utilize differences in electrical properties between water and fish to count and/or size fish. These types of counters are mainly based on measuring conductivity (e.g. Smith-Root), although there are several other possible measurables such as electromagnetic induction and time domain reflectometry. These methods are best suitable for measuring in pipelines or ducts and measures the differences in electrical properties between fish and water and are thus not practical in seawater (when passively measuring conductivity changes). There are also natural limitations to how large the dimensions of counting tunnels may be. Conductivity counters have show high accuracy when compared to manual counts.

Basic information provided by the producers are summarized in Table 2 in Appendix A 1.1

3.1 Sliding counters

Vaki Bioscanner Fish Counter

The Bioscanner counts individual fish that slides past a double row of infrared light emitting diodes in a V-shaped channel (one row of diodes on each side). The V-channel with flowing water ensures that single fish pass the sensor; software algorithms in the Bioscanner can however distinguish and count two fish at the same time. If used in conjunction with a fish grader, the Bioscanner can also count numbers in size groups. Vaki states an accuracy of 99 -100 % (percentage of fish counted), and a capacity of over 60 000 fish per hour. The counter can be configured to count fish with sizes between 3 g and 12 kg. Different sliding configurations are available. The Bioscanner is not developed further by Vaki, and the higher capacity micro/macro counters have taken over the salmon farming marked (Vaki, pers. comm.). The Bioscanner is now mainly sold to smaller farming plants, e.g for arctic char, and sea bass and sea bream farming in the Mediterranean Sea.

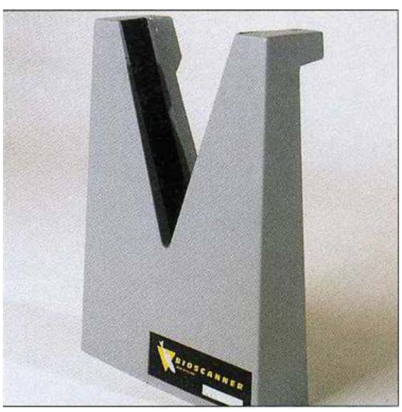


Figure 12 The Bioscanner sensor unit (Photo: Vaki).

Vaki Micro and Macro counters
Both the Micro and Macro counters are based on scanning cameras and computer vision to count individual fish. The Macro counter counts fish between 0.2 – 400 g, has a 100 cm wide opening and a capacity of 200 000 smolt per hour or 1 million 1 g fry per hour. This counter is also available in a wellboat configuration counting fish up to 2 kg. The Micro is designed for hatcheries and counting small fish between 0.2 - 200g. The counting area is 50 cm wide and has a capacity of 500 000 1 g fish per hour. Both counters can be supplied for counting directly from graders. Vaki states that the Micro and Macro counter has an accuracy of over 98 % (percentage of fish counted). The images of the fish passing through the counter are automatically stored and may be used to validate the count and accuracy of the system.

Figure 13. Vaki fish counter (Photo: Vaki).

Vaki Nano fry counter
Vaki Nano Fry counter is based on using line scanning camera and computer vision to count individual fry. Outlines of fish carried in water in a 40 cm broad channel with light underneath and the line scanning camera above are recorded. Images are stored on a computer so that the count may be verified if needed. The counter has a capacity of over 200 000 1 g fish per hour, and can count fish from 0.05 to 20 g with an accuracy higher than 98 % (percentage of fish counted) according to Vaki.

Figure 14. Vaki Nano fry counter (Photo: Vaki).

Vaki Wellboat counter
The Wellboat counter uses the same principles as the above mentioned counters, but is specifically designed for use on wellboats with large vacuum pumps. This is a high capacity counter which can measure more than 300 000 smolt per hour with an accuracy higher than 98 % (percentage of fish counted) according to Vaki.

Faivre PescaVision
PescaVision fish counters uses light emitting diodes. When individual fish pass the light beam a count is registered. Sizing sleeves are installed prior to the light beam to ensure that individual fish pass the counter. Two models, in two different configurations depending on target species, are available and designed for different fish sizes. Pescavision 30 has four channels and is designed for salmon/trout between 80 - 800 g with a capacity of 3 tonnes per hour. Pescavision 50 has two channels and is designed for salmon/trout between 500 g and 4.5 kg with a capacity of 4 tonnes per hour. Faivre states the accuracy of these counters as 98-100%.

Figure 15. Faivre Pesca Vision counters (Photo: Faivre).

Lumic AS fish counter LC 14/28
Lumic fish counters use laser light beams to detect fish passing the sensor. The fish are fed into the counter by hand, pump or directly from the grading machine. LC 14 has 14 counting channels and is designed to handle fish between 25 and 180 g, and has an advised capacity of approximately 30000 fish/hour. The producer stated accuracy of the counter is better than +/- 0.5 %.

Figure 16. Lumic LC 14 fish counter

3.2 Pipeline counters

Pipeline counter are usually compact and are easily adapted to the infrastructure of barges and vessels. Dry pipeline counters are the most reliable pipeline counter, but can not be used on full sized fish due to injuries to the fish. The full water counter is reliable when used with siphon pumps, but tend to fail when used with vacuum pumps where the large occurrence of air bubbles introduce a large number of miscounts

Flatsetsund(FLS 350 and FLS 500) can be used as either dry, semi filled or full water counter according to the manufacturer. Capacity is up to 350 ton/hour at +/- 1 % accuracy also according to the manufacturer. Fish size up to 25 kg.

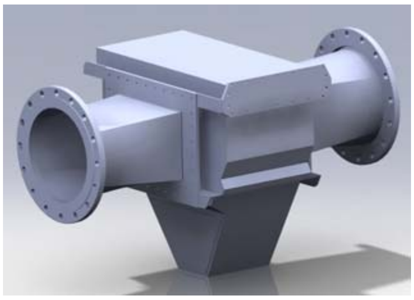


Figure 17. Flatsetsund pipeline counter (Illustration: Flatsetsund).

Vaki Bioscanner PLC(pipeline counter)
The Vaki counter is in effect a frame scanner inserted in fitting tube and can be used in full water and dry mode. Capacity is up to 40 tons per hour with an accuracy over 98%. Fish size should be between 300 g and 12 kg.

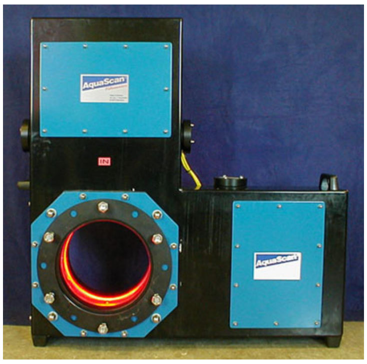
Figure 18. Vaki Bioscanner Pipeline Counter (Photo: Vaki).

3.2.1 Dry

Aquascan CSE series.
This is a dry counter an comes in the size range of 1g- 1 kg to 0.5 kg – 18 kg with corresponding capacity 10ton/hour to 175 ton/hour

3.2.2 Full water

Aquascan CSF series.
This is a full water counter series with a size range of 1g- 1 kg to 0.5 kg – 18 kg with corresponding capacity 20000 to 30000 fish/hour.



3.3 Other systems

Smith-Root SR 1101/1601 Fish Counters

Smith-Root has currently two fish counters on the marked using potentiometric bridge tunnels to measure conductivity changes as the fish swim through the counters. Both systems are intended for use in fresh water (water conductivities between 20 and 500 µS/cc).

SR-1101 consists of a single counting tunnel with three electrodes (measuring both upstream and downstream fish passage). The system can handle at least five counts per second and 18 000 counts per hour. With a correct tunnel-size to fish-size ratio, count accuracy is typically better than 95% according to Smith-Root.

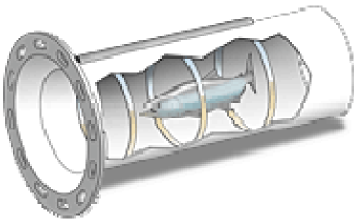


Figure 19. Smith-Root SR-1101 fish counter (Photo: Smith-Root).

The SR-1601 is a 16-channel fish counter with separate potentiometric bridges in each counting tunnel, designed for hatchery fry, migrating smolt, fish eggs and other organisms. The system can handle at least 10 counts per second and 576 000 counts per hour and with a proper tunnel to fish-size ratio count accuracy is typically better than 98% according to Smith-Root. The counting tunnels are submerged and arranged to produce a velocity through the tunnels so that fish in the vicinity of the tunnel entrances are pulled through by the water flow.

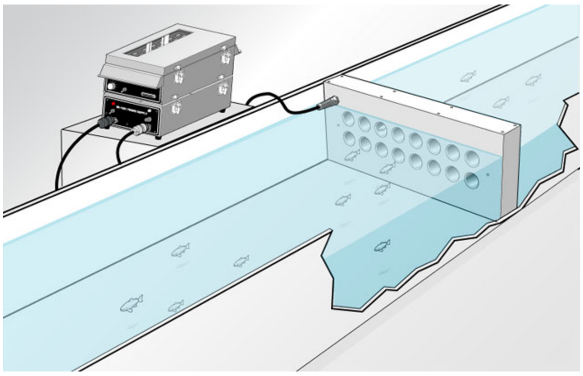


Figure 20. Smith-Root SR-1601 fish counter (Photo: Smith-Root)

Smith-Root counters are used at hatcheries and major river systems throughout North America as well as many other locations. The accuracy of these counters have also been verified in several research projects (freshwater/river biological research). Appelby and Tipping (1991) used a SR-1600 to count steelhead and sea-run cutthroat trout and found the accuracy to be within 1.5% of hand counts. Osborne and Rhine (1999() tested the accuracy of SR-1601 by forcing a known number of steelhead through the sensor, and by installing to sensors in series, although the results are not presented.

IchtyoS counter

The IchtyoS system counts fish but is also able classify the fish passing the counter into size categories, and determine swimming direction. The counter consists of three sensing strips connected with Plexiglas panels. Each strip consists of a series of laser transmitters and receivers, the transmitters are located at the bottom and the receiver at the top, forming three vertical beam curtains. IchtyoS claims the system records over 95% of the target population.

Northwest Marine Technology - Individual fish counter

The individual fish counter (IFC) is a conductivity bridge based system design for counting when processing fish by hand, for example during vaccination. The system was evaluated in a grey paper by Phillipson and Conrad, showing an expected difference of one fish between the two Individual fish counter and the reference method for every 5,000 fish that are counted by IFC.

Northwest Marine Technology has also introduced an Adult Fish Counter in 2010. The Adult Fish Counter is designed to be installed in fishways and ladders to provide counts of fish migrating upstream or entering a hatchery.

Wingtech (WingVax vaccination / anaesthetic lines WingVax 3000)
WingVax vaccination / anaesthetic lines include counters for vaccinated fish. This works by personnel manually dropping vaccinated fish through a slit with a photo-detector. This is a simple and most likely very accurate count. These results also have a high confidence with fish producers.

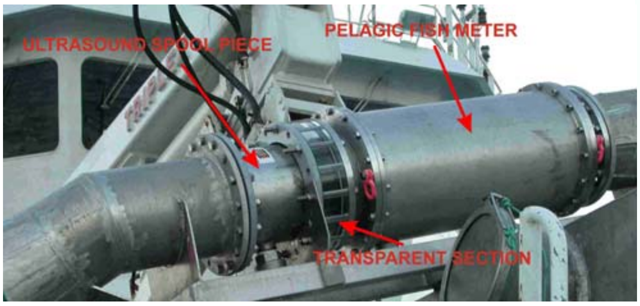
3.4 Existing technologies in other fields

3.4.1 X-ray

X-ray are used in virtually every branch of material detection, although it has been considered technically complicated and expensive the use has found its way into an increasing number of industrial processes ranging from waste sorting to quality control of food.(TU2010). As more inexpensive and more material specific detectors are finding its way into the marked, we propose to conduct some preliminary investigation on the feasibility in using x-ray detectors in two specific fish counting applications. One is to find if x-rays is a way to overcome problems connected to air mixing in full water pipe line counters, the other is to find if it is feasible to find the number of dead fish after incidents when mass deaths of small fish has occurred.

3.4.2 Conductivity (biomass/pipeline)

The fish flow meter (FFM-350) is developed at CMR to measure fish biomass and pump flow for seiners and trawlers in the pelagic and costal fisheries. The FFM is based on multiphase flow metering technology from the oil and gas industry, and measures fish biomass, density, and fish flow rate, in addition to real-time information on pumping processes. The approach is different than in for instance the Smith-Root counters and allows for measurement of fish in salt water. The Fish Flow Meter is based on an electromagnetic measurement principle where fish volume is found through the electrical conductivities of fish and water. This measured volume is converted to mass through the mass density of the fish. The technology is particularly well suited for pumping of large quantities of fish, as it tolerates high flow rates and large fish fractions. Typically hydraulically-driven submersible centrifugal pumps based on a 12 to 18 inch pipe diameter have the capability of delivering in excess of 1000 m^3/hour. Measurement results from more than 100 catches gathered through a four-year testing period indicate stable performance and reliable measurement results, in particular for fish with open swimbladder and without swimbladder (CMR, 2009). The FFM does not provide fish count or sizes, and must be combined with other technologies to provide such measurements. Initial projects to combine the FFM with an acoustic based flow meter have been run and trialed on mackerel and herring. However, the FFM technology may not be able to achieve the accuracy that the aquaculture industry desire.



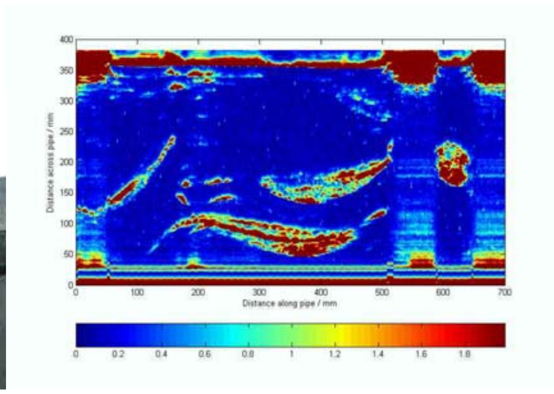


Figure 21. The CMR Fish FlowMeter with an ultrasound spool piece (left) and ultrasonic registrations of mackerel (right) (Photo: CMR Instrumentation).

3.4.3 Ultrasound (counting/pipeline)

Ultrasound is used for many applications involving flow in pipelines such as fiscal flow metering. CMR has developed an acoustic spool piece for measurement of fish size in pipelines, providing supplementary data to the Fish Flow Meter. For this reason the ultrasound spool piece projects focus on pelagic species such as herring and mackerel, and it has been shown that ultrasound can be used to generate detailed images of fish as they are pumped on board (Figure 21).

4 Review of technologies for feed spill and mort registration

Feed spill results in an unnecessary increased production cost to the fish farming industry and may produce negative environmental impacts. If the fish is underfed it will not be able to take out its full growth potential or the production cycle will be prolonged. Feed generally constitute more than 50 % of the total production costs in salmon farming. Better control with biomass also has significance for optimization of feeding. There are two technological approaches for controlling feeding; either to detect uneaten pellets or to quantify fish behaviour in connection with feeding. The first approach is most likely the simplest.

4.1 Optical systems

Optical systems are a simple and potential effective method for optimizing feeding based on visual detection of feeding behavior and uneaten pellets, although there are potential problems related to high fish density and water turbidity. Existing technology marketed for aquaculture is generally based on manual observation (except IR sensors), and requires an operator to visually detect pellets and behavior. This approach is widely used today, and may also be used for inspection of the net itself. Several aquaculture technology vendors sell subsea cameras for fish and cage monitoring. Methods based on automatic detection of pellets and behavior using machine vision has shown potential to automate this process.

4.1.1 IR Pellet sensors

AKVA group IR Pellet Sensor uses infrared single light beam to detect uneaten pellets. The sensor is typically suspended 5-8 m beneath the main eating area of the fish in small cages. Pellets are funneled through the opening of the IR Pellet Sensor by a pellet collector with a 1.5 m diameter opening. This system is integrated with the Akvasmart Feed System for automatic feed control.

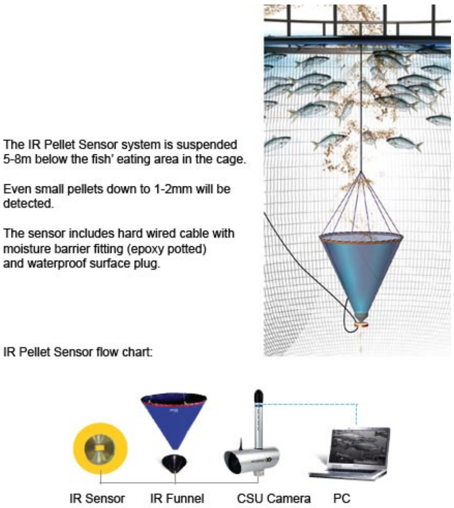


Figure 22. AKVA group IR pellet sensor system (Illustration; AKVA group).

Figure 23. AKVA group IR pellet sensor (Photo: AKVA group)

AQ1 Systems AQ-300 Adaptive feeding system for caged fish from AQ1 Systems uses the same principles as AKVA group IR pellet sensor. Pellets are funneled through the IR sensor by a pellet collector. The sensor enclosure is either made of bronze or Delrin and the sensor detect pellets ranging from 1 – 25 mm. The feeding system also measures water flow, oxygen saturation, temperature in addition to the amount of uneaten pellets. These measurements are fed to the control system with adaptive feeding algorithms.

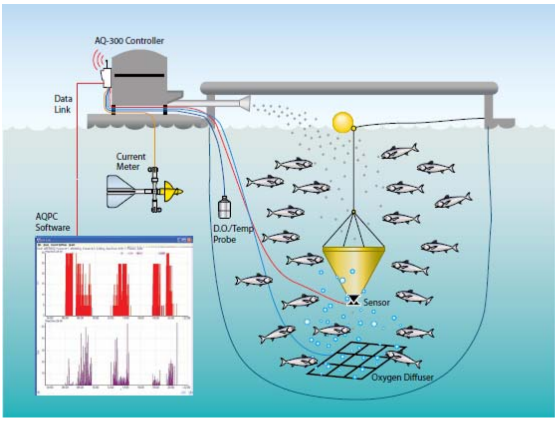


Figure 24. AQ1 Systems AS-300 (Illustration: AQ1 systems).

Figure 25. AQ1 Systems IR pellet sensor (Photo: AQ1 Systems).

4.1.2 Feeding cameras

AKVA group basic/super HR feeding cameras are monochrome underwater video cameras for manual feed monitoring. These cameras are designed to hang stationary just underneath the fish' eating area (typically at 5 – 8 m), looking up towards the surface. The images are transferred in real time via the internet and the operator needs to manually look for uneaten pellets sinking towards the camera.

AQ1 Systems AQTV-Digital is a video feeding control system operated either on site or remotely. The system can use up to two cameras per cage including one pan/tilt camera for manual observations of pellets.

The *Orbit 3000* is a subsea camera system widely used in aquaculture. This is reported to be a flexible system with possibilities of 360 degrees coverage, black and white or color sensors, and high brilliance. Another system based on the 3000 includes integrated sensors for measurement of temperature, depth, and direction of view. Orbit also sells a camera system for permanent installation (Orbit 1000).

Proteus Pro CAM is a subsea camera with the ability to rotate 360 degrees, lights, depth and direction indicator. The camera is easy to deploy and using “virtual vision glasses” or an external monitor to display video. Pro-F wireless monitoring system for feeding control uses a number of subsea cameras in combination with manual or automatic feeding systems

Feeding Systems Canada supplies stationary wireless black and white and colour cameras with pan/tilt possibilities for fish feeding and behaviour monitoring. The cameras can be integrated in a centralized camera and feeding system.

A significant amount of energy has gone in to developing routines for automatic detection of both feed and behavior using optical methods (e.g. Foster et al., 1995, Ang et al., 1997, Dunn, 2008), but to our knowledge such methods are not implemented in any of these camera systems..

4.2 Acoustic systems

Acoustic methods are in theory suitable for feed spill detection, as the acoustic properties of pellets and the way pellets sink through water differs from fish. Target strength, sinking speed and direction (Doppler shift or direct measurements) are the most common measurements for pellet detection. Acoustics may also be used to monitor behavior of fish in a large area of the pen including before, after, and during feeding. Passive acoustic methods for feeding behavior monitoring include tagging and measurement and analysis of feeding sounds (e. g. AQ1 systems sound feeding systems).

4.2.1 AKVA group Doppler sensor

AKVA groups Doppler Pellet Sensor (DPS) is, to our knowledge, at present the only acoustic system on the marked for monitoring feed spill in sea cages. It uses the Doppler shift effect to distinguish between fish and feed, measuring changes in frequency of the acoustic signal as the target (fish or pellet) moves relative to the sensor. The DPS is designed to be suspended in the pen underneath the main eating area of the fish, where it measures pellets in a 2.5 x 2.5 m vertical cone. The sensor includes a video camera for visual control, and is integrated with the Akvasmart CCS feed system. This allows for control over the sensor and automatic feeding control based on the amount of pellets passing the sensing area. This system is reported to work well in areas with low current. The sensor has however a rater limited volume of observation.

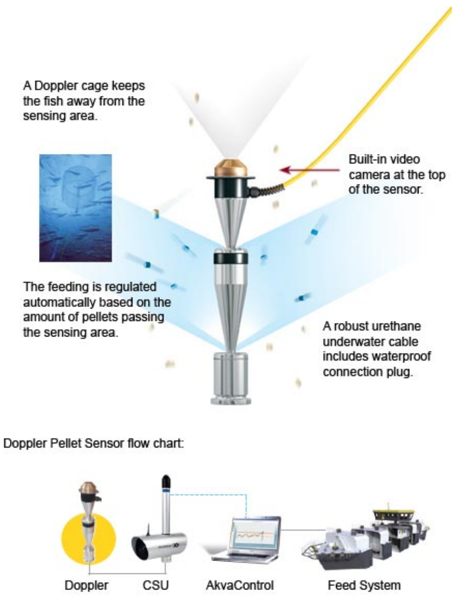


Figure 26. AKVA group Doppler pellet sensor (Illustration: AKVA Group).

4.2.2 AQ1 Systems

The sensor in the SF100 feeding system for finfish in ponds is based on passive acoustics using a single hydrophone to measure feeding sounds in ponds. Recorded sounds are processed by an adaptive feeding algorithm and feeding rates are adjusted automatically. This system has not been used for salmon farming, and a considerable R&D effort is most likely required before this method can be used on salmon.

AQ1 systems also offer an acoustic feed waste monitor for tanks (Summerfelt *et al*., 1995). A 1 MHz transducer is permanently mounted at the top of the stand pipe or particle trap detecting pellet larger than 1 mm, and discriminating pellets from faeces, scales etc. The sensor can be integrated with feeding systems for automatic feed control.

4.2.3 Research and development in acoustic feed monitoring

Echosounders have been explored as a tool for monitoring pellets and feeding by several companies and research institutions. These methods started to get more attention from the 1990s where methods for detection of pellets from the bottom of the cage using echosounders were developed.

Institute of Marine Research
Bjordal *et al*. (1993) used an upward facing echosounder transducer mounted under a cage to monitor changes in fish density with depth. Prior to feeding the highest fish densities was found at medium depths, after feeding started the fish density close to the surface increased and remained high as long as the appetite remained high. An automatic feeding system was implemented, shutting down feeding when the density of the surface layer decreased beneath a certain preset limit.

Juell et al. (1993) developed another acoustic method for automatic feeding control using an acoustic pellet detector at 2.5 m. A 360º acoustic beam detected sinking pellets, and feeding was stopped when the echo energy from sinking pellets exceeded a certain preset limit. Juell had earlier (Juell, 1991) worked on establishing relationships between salmon feed and echo energy. This method was trialed in an 83-day full-scale test where one group of salmon was fed using the automatic feeding control system, and a control group was fed using growth rate estimates. The specific growth rates were 1.01 (automatic feed control group) and 0.71 (control group).

Simrad
Simrad reported to distinguish feed from fish using a 308 kHz echosounder/transducer with an elliptical beam cross-section, and that this transducer is a suitable tool for monitoring feed as well as the distribution and behavior of fish in cages (Simrad, pers. comm.). Feed was identified by its echo strength and sinking velocity. Based on experiments on acoustic properties and sinking velocity of different sizes of fish feed. There was however some initial problems with this approach as the echosounder had problems distinguishing small fish in the periphery of the acoustic beam from feed, this problem may be solved by placing the transducer in a cage. The echosounder will be commercialized in the future and sold as a fish monitoring and feed waste detector.

BioSonics Inc
BioSonic Inc. is another echosounder producer that has worked to develop both acoustic biomass and feed spill sensors. The company has had several R&D projects (“Integrated acoustic system for monitoring fish feed and waste in aquaculture pens”, “Digital scanning sonar for fish feeding monitoring”) and patents (“Acoustic biomass monitor” US patent no. 2006/0018197 A1, “Aquaculture feed monitor” US patent no. 6 317 385 B1).

A computerize system (the “Fish Feed Monitor”) was developed for monitoring, assessment and optimization of feeding using BioSonics DE and later the DT-X digital echosounder and a current meter (Falmouth ACM-CBP-S two component acoustic Doppler current meter). The current meter and echosounder transducer was mounted in a scanning head with rotary motors, scanning a 360º sector beneath fish cages. An algorithm was developed for detection and quantification of pellets using data from the echosounder and current meter.

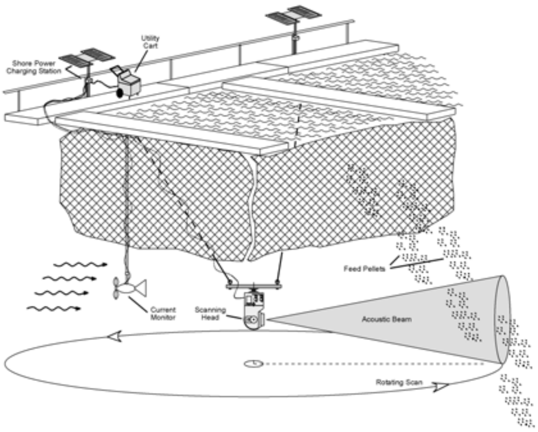


Figure 27. Illustration of the Fish Feed Monitor concept (from Acker et al,. 2002).

Acker *et al.* (2002) reported that the Fish Feed Monitor “performed well” with high signal-to-noise ratio and no interference from the rotator motors. Sinking pellets could successfully be monitored and quantified under optimal conditions. However, small fish was attracted to the wasted pellets and gathered beneath the pen during the trials, making quantitative measurements of pellets impossible. A research project addressing these issues was planned, but we have not been able to obtain information on the results from this project. Another issue with the Fish Feed Monitor is that by the time the pellets have reached the echosounder beam a considerable amount of feed has already been wasted, it is desirable to detect uneaten pellets at an earlier time that what the Fish Feed Monitor is able to do. Interference from wild fish beneath the cage is also a problem for this technology. These efforts have not led to commercial products specifically for either biomass monitoring or feed spill detection due to insufficient funds to advance previous projects to commercialization (BioSonics, pers. comm.).

4.3 Lift Up Akva - LiftUp feed/mort collector

The LiftUp system for circle cages is an automatic system for collection and retrieval of dead fish by high pressure air. The system consists of a china-hat collector cone lowered to the bottom of the net; the size of the collector is chosen based on the size of the fish in the cage. Compressed air is delivered to the collector cone, lifting feed, feces, and dead fish through a hose to a dewatering bin on the surface. After dewatering the number of dead fish can be recorded manually or transported through a Vaki counter. A sensor system is also available for automatic feed control, with a sensor scanning the content of the collector cone. The compressor may be controlled by a timer or by the sensor mounted in the collector, so that dead fish is retrieved once it is registered by the sensor.

The LiftUp system has a high capacity for retrieving dead fish and is not labor demanding. It is though to have little effect on the cage environment (for instance disturbing the fish in the cages), and can be tailored to specific cages/plants. On the negative side this is a costly system and live fish may be sucked into the system. The pressure needs to be balanced to avoid this, and the dewatering bin should be inspected for live fish.

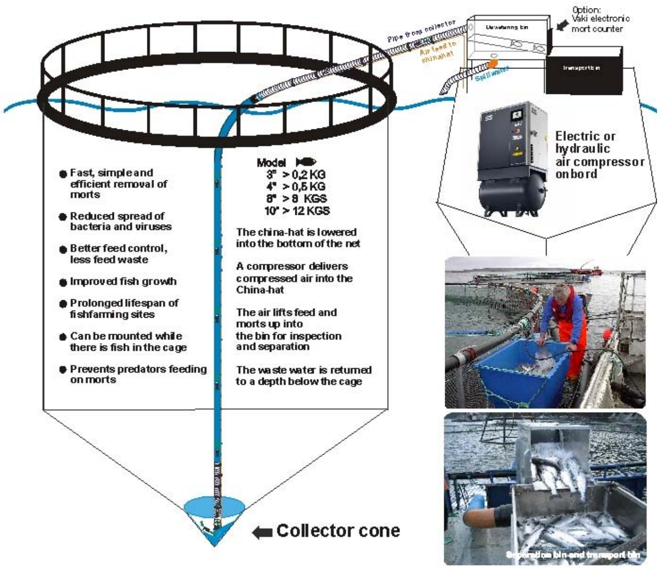


Figure 28. LiftUp for circle cages (Illustration: LiftUP Akva AS)

There are general issues with feed waste and dead fish collectors installed at the bottom of the net. Dead fish might not fall into the collector either because the slope of the net is not steep enough or it is caught in creases in the net. If it does not fall into the collector it may disintegrate and either be eaten by predators or fall out of the pen. It may also be difficult to quantify the amount of dead fish if it is kept in the collector for long before being removed, in these cases it is an advantage with sensors mounted in the collector itself. Ultrasound and X-ray are potential technologies for scanning the content of mort collectors. Another issue is how much feed does fall in to the collector, and how much is carried out of the pen with the current before reaching the collector. A current meter should potentially be included in such systems to quantify this. Acoustic and echosounders are potentially effective feed monitors as they have the ability to cover a large area of the cage, however mounting a horizontal scanning sonar under the cage (such as the ***BioSonics Fish Feed Monitor***) seems like a poor idea for several reasons.

5 Concluding remarks

This survey has not revealed any new technology or research that is foreseen to have an immediate large impact on the methods to estimate biomass or do fish counting in cages. Our view is that on a short time scale the way to improve the precision will be in combination of present detector technologies and in improving protocol to perform the measurement so as to have optimal condition for the method in use. Feasibility studies, both theoretical and experimental, of new and existing basic technologies and their potential to contribute to accurate fish counting and sizing is the objective of RA1 research task T1.2 which is in progress.

The most immediate task we will like to perform will be to ensure that basic premises for the methods are clearly understood. We therefore suggest the following subjects to further investigated:

- The basic reasons for the uncertainties in the measurement procedure is analysed
- The range of intensities and wavelengths for optical, acoustical and other source/detectors is decided
- Find whether changes in the operation procedures of the systems can improve precision and reliability of counters and biomass estimators.

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Appendix A Appendix

A 1 Tables

Table 1. Summary biomass / size estimators. † on average weights, †† typical deviation from harvesting report, if used correctly, ††† of measured length up to 8m from the cameras, * 300-500 pictures at three depths in one cage, X – no information

	Stated accuracy	Fish size min	Fish size max	Recommended sample size	Time measuring	Principle
AquaSonar	96%†	X	X	>2000	60 m	Acoustic
Vaki Biomass Counter	>98%†	~100 g	X	1000-1500	~24 h	IR Frame
Storvik Biomass Estimator	2% or less††	X	X	X	X	IR Frame
Vicass HD Biomass Estimator	"High"	X	X	300-500*	20-30 m	Stereographic photograpy
AQ1 Systems AM100	1-2 %†††	X	X	100	X	Stereographic photograpy

Table 2. Summary fish counters. † records over x % of the target population, * depends on model, ** flow rates, X – no information.

	Stated accuracy	Fish size min	Fish size max	Capacity	Type	Principle
Vaci Bioscanner Counter	99-100 %	3 g	12 kg	Up to 60 000 fish/hour	Sliding	Light
Vaki Pipeline Counter	98 %†	300 g	12 kg	Up to 40 tones / hour	->Full water	Light
Vaki Nano Fry Counter	98 %†	0.05 g	20 g	Over 200 000 fish/hour (1 g)	Sliding	Scanning camera
Vaki Micro Counter	98%†	0.2 g	200 g	500 000 fish/hour (1 g)	Sliding	Scanning camera
Vaki Macro Counter	98 %†	0.2 g	400 g	200 000/100 0000 fish/hour (smolt/1g fry)	Sliding	Scanning camera
Vaki Wellboat Counter	98 %†	30 g	X	Up to 300 000 smolt/hour	Sliding	Scanning camera
Faivre Pescavision 30/50	98-100 %	80 g / 500 g*	1 kg / 4.5 kg*	3 tones/hour / 5 tones/hour**	Sliding	Light
Lumic LC14/28	X	25 g	180 g	30 000 fish/hour	Sliding	Light
Aquascan CSE	98-100 %	1 g / 0.5 kg*	1 kg / 18 kg*	10 tones/hour / 175 tones/hour	Pipeline Dry	Camera
Aquascan CSF	98-100%	1 g / 0.5 kg*	1 kg / 18 kg*	20 000 – 30 000 fish/hour	Pipeline Fullwater	Camera
Flatsetsund	+/- 1 %	1 kg	25 kg	350 tones/hour	Pipeline Dry/semi filled/fullwater	Camera
Smith-Root SR-1101 Fish Counter	95 %†	X	X	Over 18 000 counts/hour	Full water (freshwater)	Conductivity
Smith-Root SR-1601 Fish Counter	98 %†	X	X	Over 576 000 counts/hour	Full water (freshwater)	Conductivity
IchtyoS counter	95 %†	10 cm	X	X	Full water	Light