University of Twente

EEMCS / Electrical Engineering
Control Engineering

Towards a detection and recognition system for freshwater fish

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MSc report

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Samenvatting

FishFlow Innovations is een bedrijf dat onder andere vispassages ontwerpt en produceert. Om er achter te komen hoeveel en welke soorten vissen gebruik maken van deze vispassages moeten deze geteld en herkend worden. Om de vissen te tellen en te classificeren per soort wordt tegenwoordig meestal gebruik gemaakt van een fuik om vissen te vangen, en later te tellen. Omdat dit erg arbeidsintensief is, zou het nuttig zijn als dit geautomatiseerd kan worden. Dit onderzoek is erop gericht om uit te zoeken wat de mogelijkheden zijn voor een automatisch systeem dat vissen kan tellen en het soort vis kan herkennen.

Om een methode voor het herkennen en tellen van vissen te vinden, is uitgebreid gekeken naar de verschillende mogelijkheden om vissen te detecteren, en te herkennen per soort. Er is gekeken naar vele methoden waaronder sonar, elektrische metingen, optische detectie, straling en temperatuur metingen.
Met name elektrische metingen, en optische meetmethoden kwamen hierbij positief uit de bus, en zijn daarom ook verder onderzocht.

Bij de elektrische methoden zijn resistief en capacitief verder onderzocht. Simulaties en experimenten toonden aan dat capacitief niet handig is voor in de praktijk. De resistieve methode daarentegen, die werkt door het verschil in geleidbaarheid van water en vis maakt blijkt wel mogelijkheden te hebben om vissen te tellen.

Soort herkenning op basis van resistieve tomografie is ook onderzocht met simulaties en experimenten. Hieruit bleek dat het niet haalbaar is om kleine details zoals stekels te herkennen met behulp van tomografie. Daarom is tomografie niet geschikt voor soort herkenning.

Bij de optische methoden is met name gekeken naar het gebruik van camera's. Hiervoor is in Enschede bij de Universiteit met een camera gekeken hoe goed het mogelijk is om in door water te kijken, en overgangen tussen licht en donker te zien. Verder is er in Roermond bij een bestaande vispassage een opstelling met camera's geplaatst waarbij gekeken is of het mogelijk is om vissen te detecteren. Uit deze experimenten is gebleken dat het mogelijk is om onder water een silhouet te zien. De opstelling in Roermond heeft helaas weinig resultaten opgeleverd in de vorm van zichtbare vissen. Wel heeft de test in Roermond inzicht opgeleverd in de belichting, en de benodigde framerate.

Voor verder onderzoek wordt geadviseerd om uit te zoeken of andere belichtingsmethoden bij cameratesten betere resultaten opleveren. Ook is het verstandig om voor water van verschillende bronnen te kijken hoe goed het mogelijk is met een camera te kijken.
Het verder onderzoeken van tomografische methoden, met name door meer elektroden te gebruiken, en zo een hogere resolutie te verkrijgen wordt aangeraden.

Abstract

FishFlow Innovations is a company that invents and produces among other things fish passages. To determine the effectiveness of such passages, it is necessary to continually count and recognize passing fish. Up to now, counting and classification of fish is mainly done by using a fyke net. Because this process is very labour-intensive, possibilities for electronic counting and recognition are investigated.

In this project, various methods for automatically counting and recognising passing fish has been studied, such as sonar, vision, impedance measurements, optical fish detection and temperature measurements. Especially optical and electrical impedance measurement methods appeared to have good prospectives and have, therefore, been investigated in more detail.

Two electrical measurement methods have been studied in detail: capacitive and resistive. Simulations and experiments showed that capacitive measurement are not feasible in practice. The resistive method, which works by using the difference in conductivity between fish and water proves to be useful to detect fish.

Fish species recognition using impedance tomography is also studied. An experiment and simulations showed that detection of fish species by tomographic measurements is not feasible. Small details, such as prickles are almost impossible to detect using these measurements. However, the presence of a fish can be detected using this resistive method.

For optical methods, especially the use of cameras is studied. In order to test these optical methods, an experiment is carried out in Enschede at the University. The goal of this experiment was to find out if it is possible to get enough detail for fish species recognition when looking through a layer of water. Furthermore a test setup is built in a real fish passage from FishFlow Innovations in Roermond. This setup has unfortunately produced little results in counted fish. However, this setup has brought some insight in the lighting, and the necessary frame rate.

For further research, it is recommended to investigate different setups of light sources for the camera setup. It is also recommended to research the effects of water for more sources (e.g. other rivers).
For tomographic methods, it is advised to test setups with more electrodes to get a higher resolution resistance map.

Preface

In front of you is the MSc report of Jeroen Broersen. This report is the result of my master's project about fish counting. The project is carried out in cooperation with Witteveen+Bos, FishFlow Innovations, and the University of Twente.

I would like to thank my supervisors Paul Regtien, Marcel Wijnberger, and Guus Kruitwagen for their support. Also thanks go to Alfred de Vries for help with the setups at the University.

Furthermore thanks to my fellow students at Control Engineering for the nice times and useful discussions. I would also like to thank the people from Witteveen+Bos and Fishflow that I have met for the nice times, and useful conversations.

Jeroen
Enschede, August 2009

Contents

1 Introduction

1.1 Background

In the Netherlands there are around ten thousand weirs and more than 3000 pumping stations to manage the water level and keep the polders dry. For a fish it is often not possible to pass such an obstacle. A weir can be too high to pass, and a pumping station can cut a fish into pieces. To give the fish the possibility to get to the other side of the pumping station or weir, sometimes alternative routes for a fish are constructed. One of the companies that makes fish passages is FishFlow Innovations, which is a cooperation between Witteveen+Bos and Gerard Manshanden. FishFlow Innovations is a company that invents and build products for bottlenecks in fish migration. For example fish guidance systems to let the fish pass a factory that gets cooling water from a river, or a fish passage to let fish pass a pumping station without getting through the moving parts of the pump that would kill the fish.

Because building such a fish passage is expensive, it is important to know if such alternative route is actually used by fishes. Therefore the number of fish passing a passage should be monitored.

In the Netherlands the most common method for determining how many fish use a fish passage is to place a fyke at the end of the passage. Every day the fykes are lifted and the length and species of the caught fish is determined.
This way of determining the number of passing fish and detecting their species and length is a very labour-intensive way of counting fish.

Therefore a lot of labour could be saved if there was a way to automatically count the number of passing fish, and recognise which fish species it is and what size the fish has.

1.2 Goals of the assignment

The goal of this assignment is to find out which measurement methods can be used to detect a passing fish and recognise the species of the passing fish. Therefore some literature study to currently used and possible other methods should be carried out. This should be followed by some experiments to verify if a chosen measurement method can work in practice.

1.3 Report outline

There are already some methods used for counting fish. These are described in chapter 2. After these currently used methods are described, chapter 3 continues with other methods that can be used to count fish and a selection of methods that are further investigated. Chapter 4 describes the optical method in more detail and also describes some experiments. The electrical measurement methods are described in more detail in chapter 5. After that, the conclusions and recommendations follow in chapter 6.

2 Currently used methods

2.1 Introduction

In order to know how many fish pass a fish passage, it is necessary to count the fish. There are already some methods used for counting the number of passing fish. This chapter describes the methods that are currently in use.

2.2 Fyke

A method that is currently used to count how many fish are passing a passage is to place a fyke at one end of the passage. The net is emptied every day and the number of fish, the fish species, and the length are documented. Using this method it is possible to get information about the number and species of the caught fish, but it is not possible to get information about the exact time a fish was caught in the fyke. It also makes it impossible for fish to pass a passage in two directions, because one of the entries is blocked by the fyke.

2.3 Vaki Riverwatcher Fish Counter

The Vaki fish counter is a fish counter from the Icelandic company Vaki. It can count fish by a light valve. If a fish passes the counter, the light is blocked, which indicates that there is a fish. This way of detecting fish is schematically drawn in figure 2.1. The Vaki fish counter has two rows of sensors next to each other, each row has 96 sensors. This type of fish counter is used in different countries, for example Iceland, Sweden, Denmark, and the USA.
However this method is not used in the Netherlands. This is because in the Netherlands the water is often too turbid to let the counter function correctly. Another problem is that the fish counter is most used for counting salmons, while in the Netherlands the fish are often a little smaller, which makes them more difficult to be detected by the fish counter.
The Vaki fish counter can only count fish, and get a rough silhouette of the fish, however it has no automatically species recognition.

2.4 Fish counter

The resistive fish counter is a method that is already used in the Netherlands. It consists of 3 metal strips placed underwater parallel to each other. The outer two strips are driven by an out of phase sinusoidal voltage at 3 kHz. The voltage on the center electrode is measured. If a fish (with lower resistance than the water) passes the passage in upstream direction, first the resistance between the downstream and center electrode is lower, a little later the resistance between the upper and center electrode is lower.

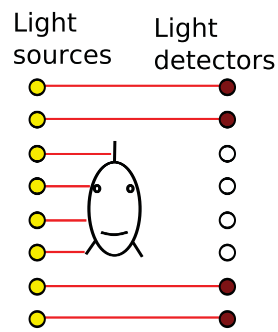


Figure 2.1: The detection of a fish by the Vaki fish counter works like a light valve. For the Vaki 2 lines of 96 receivers and 2 lines of transmitters are placed. In this figure a schematic view of how a light valve works for detecting fish. The fish blocks the light of the center 4 light sources. Therefore it is possible to get a silhouette of the fish shape.

Because the voltages at the two outer electrodes are out of phase, it can be detected between which electrodes the resistance is lowering.
With this fish counter it is not possible to recognise the fish species, but it is possible to count the fishes, and estimate the length.

2.5 Didson

The Didson is an acoustic underwater camera. With a Didson it is possible to create images underwater with relative high quality. It has already software for counting fish. However, it is mainly for counting longer fishes. It is difficult to detect fishes that are only around 10 centimetre or less in length.

3 Possible fish counting methods

3.1 Introduction

In order to develop a fish counting device, it is necessary that fish can be detected. The fact that there are already fish counting devices, as described in chapter 2, indicates that it is possible to detect fish.
Because not all methods that could possibly be used for fish counting are described in the previous chapter, this chapter describes different methods that could possibly be used for counting fish.
The measurement methods are divided in a number of categories based on the physical properties of the fish that are used. Every category is written in its own section, which is for most of the categories divided in different subsections describing multiple methods for counting fish using the same physical property.

3.2 Ways to detect or recognise fish

3.2.1 Acoustical

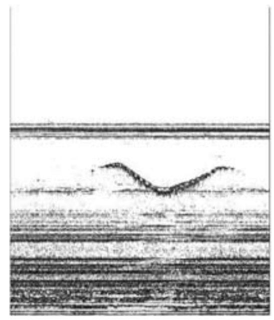
When measuring acoustically, a sound pulse is emitted to the water. Sound travels at approximately $1500\,\mathrm{m\,s^{-1}}$ through the water. When the sound wave hits a fish or some other object, it will be partly reflected. A part of the reflected wave will return to the transducer. This part is then recorded and analysed. The time the sound is on its way to the fish and back to the transducer gives information about the distance from the transducer to the fish. When there are multiple receivers close to each other, the phase difference between the received signals gives information about the direction in which the fish is located.

Sonar

Fish detection using sonar is already used in some experiments [2] [37].
With sonar it is possible to find the distance from the fish to the sonar. If multiple receivers are used, it is also possible to find the direction where the fish is positioned. This is done by emitting a pulse and analysing the reflected signal. The phase difference between the different receivers gives information about the direction in which the fish is positioned in comparison to the receiver. It is also possible to estimate the size of the fish by measuring the strength of the returned signal [18].
When the speed of the fish is also important to measure,this can be measured at two different methods. It is possible to detect the speed by measuring the time between two measurements, and the change in fish location at these two measurements, but it is also possible to use the Doppler effect to determine the fish speed.
When the transducer can be repositioned automatically, it is also possible to get a 3D

image of some object[54], [40]. Unfortunately this last method is only possible if the object to detect does not move.
When there are multiple fish close to each other, detecting individual fish can be impossible because the echoes will (partly) overlap. Other difficulties can be caused by echos that are not from fish but for example from the bottom, the water surface, or the wall of a pipe .

Figure 3.1: This image shows a fish moving in front of the sonar (the curved path), along with some reflections (horizontal lines)from the side, and bottom of the river. The horizontal axis represents the ping (number of the emitted pulses, and is linear with time). The vertical axis represents the distance from the sonar device. It can be seen that the fish does not follow a straight path. Image taken from [18].



Pros:

- Fish detection possible in turbid water.
- Possible in environments without light.

Cons:

- When fish are close to each other the echos can overlap making it difficult to distinguish individual fish.
- Echos from the pipe can interfere with echos from the fish.
- When there are a lot of air bubbles, the image will be blurred.
- The noise depends a lot on uncontrollable variables like rain and waves. [2]

Dual-frequency identification sonar (DIDSON)

The Didson is a Dual-frequency identification sonar produced by the company Sound Metrics.
The Didson has a system with acoustic lenses which is described in [3]. One of the lenses can be automatically repositioned in order to focus the ultrasonic sound waves. The Didson module with the lens housing removed is shown in figure 3.2. The ultrasonic sound is received and transmitted by a transducer array which has 96 different transducers. The combination of the transducer array and the lenses system makes it possible to detect from which angle the reflected sound is coming. The sound direction can be measured in 96 steps of 0.3° in horizontal direction if the 1.8 MHz frequency is

used, or in 48 steps of 0.6° if the 1.0 MHz wave is used. This means that the total viewing angle in horizontal direction is 28.8°, the vertical angle is not divided in different steps and is 14°. With a Didson it is possible to get high quality images in turbid water. The Didson has also software to count fish, track fish, and estimate the length of a fish [35]. An example of an image taken with a Didson is shown in figure 3.3, in this image the fish are clearly visible. However the shown fish are relatively large with lengths of over 50 cm. For fish detection in the Netherlands also the small fish of 10 centimetre needs to be counted. It is possible to detect objects of 5 cm [1], but the resolution of the image is probably too low for species recognition.

Figure 3.2: A Didson module with the lens housing removed. The centre lens can be moved to change focus. Image from an article about the Didson lenses system. [3] .

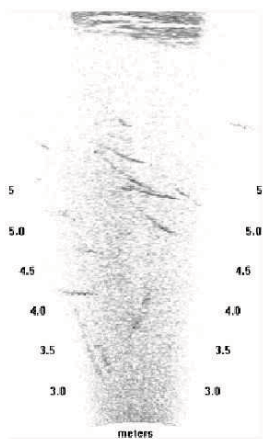


Figure 3.3: An image of a couple of gar taken by a Didson system. The darker area on the top is the surface of the water. The noise is caused by bubbles and suspended particles. The fish are visible as the darker stripes. The image is from the Didson site.

Pros:

- Good image quality for large fish.
- Information can easily be interpreted by human (nice for testing an automatic counter).
- Didson software can already count fish as good as visual observation for salmon-sized fish.[23]

Cons:

- Rather expensive ($75.000 [32] - $140.000 [19] for each unit).

- Maybe problems from echos when used inside a metal pipe. [34].
- No color information (color can be useful for species recognition).
- Length estimates give very disparate results [11].

3.2.2 Optical

By optical measuring, measurement methods are meant that use some kind of light in order to detect or recognise fish. This can for example be light that is coming from the sun, reflected by a fish, and captured by a camera. This is of course not possible during night, but it is also possible to use a light bulb or other light source. In this case the fish is detected because it reflects light. Another possibility for optically detecting fish is to use an array of LEDs and an array of receivers and check if there is something blocking the path between the LED and the receiver. In this case the fish is detected because it blocks light.

Camera

With a camera it is possible to take a lot of pictures from swimming fish after each other. After the pictures are stored, some computer algorithm can be used to analyse the images, and decide if there are fish in the images or not. The camera can only capture images of the fish if the fish is affecting light. Therefore the area in which the fish is swimming should be illuminated. The light source can for example be the sun, a light bulb or some infra-red light source. If the light is placed on the wall opposite to the camera, the silhouette of a fish can be detected because the fish blocks the light. If the light source is placed on the same side as the camera, the fish can be detected because it reflects light.
Unfortunately the light is not only reflected or blocked by the fish, but may also be affected by the sand grains or other turbid objects in the water. Therefore it is not possible to look very far into the water. So the fish should always be relatively close to the camera.
Cameras are often used for surveillance purposes, for example in stores, streets, for traffic safety etc, or for product inspection in industry. Therefore there is already a lot of research carried out for detecting moving [38] [48] [50], or stationary[46] [47] [55] objects.
Cameras are also used for experiments concerning detecting or recognising fish species. Some systems are more based on the shape of fish [28] [57] [29] [12] [56] where other systems are more interested in patterns of the fish (such as stripes, or spots) [8] [44]. However the experiments are not carried out in riverine water, but only in laboratory setups, or fish farms, where the water quality is more controllable.

Pros:

- A lot of cameras are readily available.

- Easy to manually check the results (a human is used to look at optical images).

Cons:

- Difficult to estimate the size when distance to the fish is unknown.
- Not much color-information because of the water.
- No clear image in turbid water
- No imaging possible without proper lighting.

Stereo camera

With two cameras it is possible to get some 3D information about the fish. The biggest problem is that in order to get 3D information, some spots must be recognised on both images. This can be difficult if the water is very turbid. There is already some research carried out about fish detection and size estimation using stereo vision [43] [9] showing that it is often (73% success rate) possible to detect fish in images from both camera's when the water is clear.

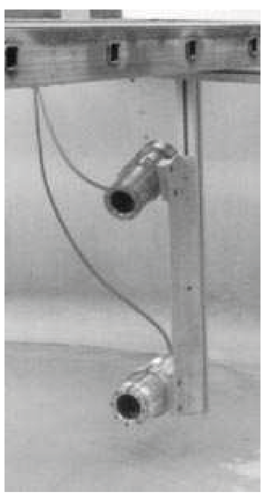


Figure 3.4: The stereo camera setup as used in [43]. With the 2 cameras it is possible (if the water is clear enough) to detect the 3D position of the fish. It is also possible to detect some of the 3D direction of the fish.

Pros:

- 3D information about the fish position
- Possible to get the fish size.

Cons:

- Problems when the water is very turbid, because the images will be too different to find corresponding spots in the image.
- More processing power needed

- Not each point is suitable for template matching or cross correlation. In areas with little contrast stereo matching is unreliable or even impossible[13].

TOF camera

A TOF (time of flight) camera is an optical camera which uses the time of flight from the camera to the fish and back to the camera to obtain depth information about an image. In order to get this information there are light sources (mostly infra-red) placed around the camera which transmit light modulated at a high frequency (e.g. 20 MHz). The camera receives the light that is reflected by some object, but because there is some distance between the object and the camera and the light is travelling at approximately 300 000 $\mathrm{km\,s^{-1}}$, a phase difference exists. This phase difference is used to calculate the distance to the object. In air there are some experiments carried out with good results [16].
However, there is not much information about using these cameras in underwater situations. This is probably caused by the short time 2D optical TOF cameras exists and are used . The first report about the building of an TOF camera found dates from 2001 [27].
Mesa-imaging, the manufacturer of the SR3000 TOF camera, has carried out some experiments, and concluded that it is possible to measure in very clear water, but as soon as there are some particles in the water, the measurement of the more distant objects gets drown by the strong reflections of the nearby particles. Because there are almost always some particles between the camera and the fish, it will be almost impossible to get 3D information about the fish.

Figure 3.5: This camera is a SR3000 TOF camera. The LEDs that are visible around the lens are used to create the light modulated at 20 MHz. The camera compares the phase of the reflected light for every pixel with the phase of the emitted light. Based on the phase difference the distance is calculated. This can be done to a distance of 7.5 metre, further away the measured distance becomes ambiguous.

Pros:

- Easy to obtain 3D information about an object.
- Fast method to obtain 3D information. (up to 54 fps for SR4000 camera)
- Low processing power needed for gathering 3D information.

Cons:

- Not possible to measure distance in turbid water.

- Cameras have low resolution.
- Relativly new technique, therefore not much information available.

Light valve

A light valve can be used to get information about the shape of the fish. This can be done by placing an array of LEDs on one side of the sensor and an array of receivers on the other side of the fish sensor. When there is a fish between the receivers and the transmitters, some receivers can not receive the emitted light. This indicates that there is a fish between the LED and the receiver. In figure 3.6 an example of a fish passing a light valve is showed. The outline of the fish can be detected by using the information about the light blocked by the fish when the fish swims through.
There is already a system available that can detect and count fish using a light valve. This system is called the "Riverwatcher Fish Counter" and is produced by the Icelandic company Vaki. This Fish Counter is used for research [5]. With different fish species recognition algorithms this counter was accurate in fish species recognition in approximately 70% of the cases.

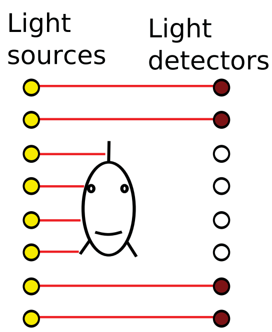


Figure 3.6: Detecting fish using a light valve. When the fish swims through the light valve, some receivers can see the light that is emitted (in the figure the top and bottom two receivers). Some other receivers can not receive the light, because the fish is blocking the light (4 receivers in the centre).

Pros:

- Measured size of fish does not depend on fish location in sensor because the scan lines are horizontal. (closer to or from the sensor does not give larger or smaller images)
- Infra red light can be used, which does not scare the fishes.

Cons:

- Length of fish measurement is difficult when swimming speed is unknown. (Can be solved by also placing a row of sensors and LEDs in horizontal direction)
- When the water is too turbid no information is obtained. (This is probably only the case when there is a large distance between the transmitter and receiver array.)

Ring sensor

With a ring sensor it is possible to detect some 3D information of the fish. It is possible to get the outline just as was the case with the light valve, but now there is more information about the 3D shape of the fish. Concave spaces can not be detected, which is a pity, because information about the position and location of the fins of fish can give useful information about the fish species. The global outline of the fish can be measured. This type of sensor has not been used in fish counting solutions before, but it is used for counting and measuring the shape of potatoes and apples [17].

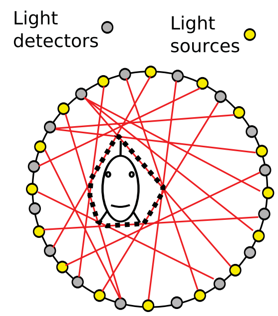


Figure 3.7: Detecting fish using a ring sensor. The global shape of the fish is detected, but it is not possible to detect for example the concave areas on the bottom between the fins and the body of the fish.

Pros:

- 3D information about the fish
- Swimming direction in 3D can be distinguished (Maybe some fish species have another swimming pattern than others)
- Infra red light can be used, which does not influence the fish.

Cons:

- Length of fish measurement is difficult when swimming speed is unknown.(Can be solved by placing some horizontal LEDs for measuring the speed)
- When the water is too turbid no information can be obtained.
- Can not detect concave spots, this can give problems with fish fins. (See figure 3.7), the shape of the fish will be seen as the bold outline, while the shape of the fish is different. This can make species detection more difficult.
- The sensor can not detect more than one fish at a time in the sensor.

3.2.3 Resistive

Resistive measurement is based on the difference between the resistance of fish, and the resistance of water. The measurement can for example be carried out by placing two conductive plates underwater facing each other. Because the resistance of a fish differs from the resistance of water, a passing fish can be detecting by measuring the resistance between the two plates.

According to information from the company Aquantic, the conductivity of riverine water varies between 30 µS cm^{-1} and 450 µS cm^{-1}.
The conductivity of fish is according to the information of Aquantic higher than the conductivity of water. Some conductivity values for fish that are published [24] indicate that for carp (787 µS cm^{-1} - 1085 µS cm^{-1}) the conductivity is indeed higher than for water. For 'various species' the conductivity is (280 µS cm^{-1} - 3130 µS cm^{-1}), which partly overlaps the conductivity of water. Unfortunately 'various species' is not specified further in this article.
Because the fish counter is tested with success in the Netherlands, it is very likely that almost all fish that needs to be counted have a resistance differing from the resistance of water. Therefore it should be possible to detect fish using resistive measurements.

Fish resistance between two plates

With a resistive measurement system consisting of two plates, the resistance between the plates is continuously measured. When a fish passes the sensor, the resistance is likely to lower, because the resistance of fish is lower than the resistance of water.

Pros:

- Only the measurement elements need to be waterproof, the largest part can be outside the water.
- Light is not needed for the measurement

Cons:

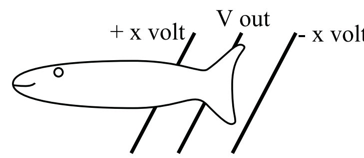
- When the diameter of the pipe / passage is large with respect to the diameter of the fish, resistance change is low.
- Not possible to distinguish species.
- The resistance of water can be varying, which can give false fish counts.
- The differences in resistance caused by the fish can be small in comparison to the measured resistance, which makes it difficult to detect fish.

Fish resistance using three metal strips

Resistive measurement using three metal strips is already used in the Netherlands [10]. This fish counter works by putting a 3 kHz sine wave with amplitude of approximately 8 volt, at the outer two electrodes (the voltage on the electrodes is in counter phase, and one of the electrodes has a lower amplitude than the other, in order to generate an offset). By measuring the voltage at the centre electrode it is possible to detect if there is an object between two of the strips that reduces the resistance or there is none.
Because this method measures the difference in resistance between the upstream and centre, and downstream and centre electrode, it is relatively insensitive to changes in water resistance. This is because when the water resistance changes, the resistance

between upstream and centre electrode, and downstream and centre electrode both change with the same factor. Therefore the difference between the two resistances does not change.

Figure 3.8: Schematic view of detecting fish using three metal strips. The upstream and downstream electrode have a voltage that is in counter phase, therefore the measured voltage at the center electrode is 0 V if no fish is present. If a fish is present, the measured voltage will change.



Pros:

- Method works and is tested in a real situation.
- Independent of environmental light.
- Direction of swimming can be detected.
- Because of differential setup, relative insensitive to changes of water conductivity.

Cons:

- Not possible to distinguish species.
- Not possible to count fish correctly when multiple fish are passing simultaneously.

Impedance based tomography

Impedance tomography is a measurement method that can be used in order to measure the impedance of objects inside a ring of sensor elements. A ring with a number of metal plates can be used to measure the resistivity of the material inside the ring. In figure 3.9 there is some current put onto two of the plates, and the voltage is measured at two other plates. This measurement is carried out with the current on different plates, and the voltage measured on the different plates. When there are a lot of measurements carried out, some reconstruction algorithm can than be used to create an image which shows a map of the resistivity inside the ring. This technique has not been used in fish detection before, but there is research for using this system in medical environments [7], An example of such a measurement for measuring a body with a hearth and lungs is shown in figure 3.10. Because the resistance of fish differs from the water resistance, the location of the fish can be detected this way. Because the resistance inside the fish will also differ, it can be possible to detect the location of some of the organs of the fish, which can be used to detect the species.

Pros:

- Environmental light does not influence the measurement.

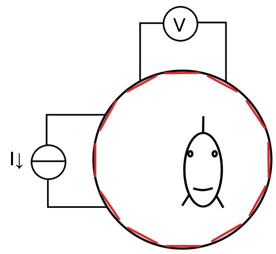


Figure 3.9: A schematic view of a setup for detecting fish using impedance tomography. In this figure, there is a current flowing through two of the electrodes, where the voltage is measured on two of the other electrodes. The measured voltage is dependent on the distribution of conductivity in the pipe. When enough of these measurements are carried out, it is possible to reconstruct a map of the resistivities.

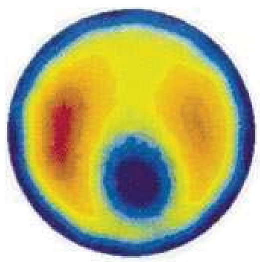


Figure 3.10: An example of a reconstructed image of two lungs, and a heart. It can be seen that the lungs (left and right) and the heart have a different resistance than the area between them(if you look at this image in color, you can also see that the lungs tend to red, meaning higher resistance, where the heart is blue, and thus has a lower resistance). This image is from an article about ways applications, and reconstructions of impedance tomography [7].

- If the fish are large enough, information about the location of some organs may be obtained.

Cons:

- Reconstruction algorithm will be difficult and computational intensive

3.2.4 Capacitance

Capacitive mnethods are based on differences in permittivity between fish and water. When two plates are placed in parallel, the capacity can be calculated by:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

In which C = capacity, ε_0 = permittivity in vacuum ($\approx 8.8510^{-12}$), ε_r = relative permittivity, A = surface of a plate, d = distance between two plates.
The relative permittivity of water is approximately 80, this value differs for changing temperatures and frequencies, but for frequencies below 1 GHz, and temperatures that seems reasonable for water in rivers (0 °C to 25°C)[31] the relative permittivity is between 78 and 86. This is mostly influenced by temperature, and almost not by frequency.
The relative permittivity for fish is not found in literature, but the relative permittivity for some organic materials like muscles are published. The permittivity for these organic materials is strongly dependent on the frequency, but for a lot of organic materials the relative permittivity is at frequencies up to 1 MHz higher than the permittivity

of water. Muscle for example has a relative permittivity of approximately 1800[15] for a frequency of 1 MHz.
Because there are differences in the permittivity of water and organic materials like blood and muscle, it is assumed that the permittivity of fish also differs from the water permittivity. Therefore it seems to be possible to detect fish using capacitive measurements.

Capacitance

Counting fish based on capacitance can be done by placing a metal plate on the bottom, and a metal plate on the top of the fish passage (both underwater). When a fish swims between the plates, the water is partly replaced by fish, which changes the permittivity between the plates. Therefore the capacity changes, which can be measured.

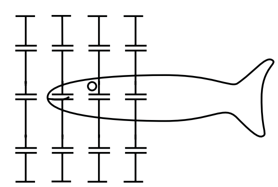


Figure 3.11: Illustration of counting fish using the capacity of a fish. Because the permittivity of the water differs from the permittivity of fish, the measured capacitance between the plates on the left (only water) differs from the measured capacitance between the plates on the right (fish and water). When measuring the capacitance, it is therefore likely that a fish can be detected.

Pros:

- Light is not needed for the measurement.

Cons:

- Not possible to distinguish species
- Not much research about capacitive fish detection

Capacity based tomography

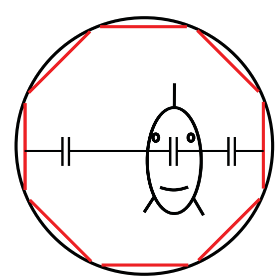


Figure 3.12: Capacitive tomography. When the measurement electrodes are placed inside the tube, and the capacitances between all electrodes are measured, some reconstruction algorithm can calculate the capacitances of a 'slice' of water with fish between the electrodes.

Capacitive based tomography uses a ring of (generally 8 or 12) metal plates. The capacity between each of these plates is measured. When the permittivity is not homogeneous (for example because there is a fish in the water), this can be detected. This can be used to make an image of the location of the fish. Capacitive tomography is used for example to measure the filling of a pipe [22]. The biggest problem when using tomography is the reconstruction. Because the measured values need to be converted to an image, some reconstruction algorithm is needed. There is already some research carried out about reconstruction images [52] [51] indicate that capacitive tomography reconstruction is possible. There is also some research carried out about capacitive tomography for fish detection, however the results are not made public.

Pros:

- Information about the shape of the fish.
- Maybe even information about the location of some organs of the fish that give information about the species.

Cons:

- Changes in the water capacity will greatly influence the measurement.
- Reconstruction is a computationally heavy process.
- Reconstruction is a mathematical difficulty, and will probably be not very accurate.

3.2.5 Inductive

Inductive measurement is based on the change in permeability inside a coil, or between multiple coils. For a coil the inductance can be calculated with the following formula.

$$L = n^2 \mu_0 \mu_r \frac{l}{A}$$

With L = inductance, n = number of windings, μ_0 = magnetic constant ($4\pi 10^{-7}$, μ_r = relative permeability, l = length of the coil, A = area of the coil.
The idea is that when the coil is placed around a tunnel filled with water, and an object with a relative permeability different from the relative permeability of water passes through the tunnel, the inductance will change. The change in inductance can be detected.
Unfortunately the relative permeability of water is probably almost the same as the relative permeability of fish. This assumption is made because most non-metallic materials have a relative permeability that is almost equal to 1. Therefore fish detection by measuring the permeability will probably not work very well.

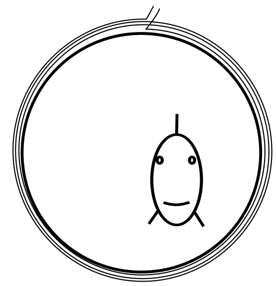


Figure 3.13: Counting fish using a coil around the fish tube, and measure changes of relative permeability.

Inductive

Placing a coil around a non-conductive pipe through which a fish swims, can detect changes in the permeability inside the coil. This probably changes when a fish passes through the sensor.

Pros:

- No need for light or sound.

Cons:

- Probably not possible to distinguish fish from water
- Not possible to distinguish species.
- Not possible when the fish passage is made from metal.
- Not much information available about inductive fish detection.

Induction based tomography

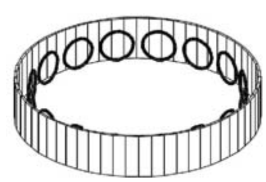


Figure 3.14: A schematic view of the localisation of the coils inside a ring. Each time one of the excitation coils is activated, while the receiving coils are measuring. This measurement gives information about the conduction of the materials inside the ring. This image is from a report about an experimental setup for magnetic induction tomography [25].

For magnetic induction tomography, coils are placed inside a tube. A schematic view of such a setup can be seen in figure 3.14. For a measurement, each excitation coil is activated one after another, while the detection coils are measuring the phase of the received signal. The oscillating magnetic field interacts with the conductive material, which generates eddy currents. Because of these eddy currents, the field is influenced by the conductivity of the material. This method has been used previously in experiments [25] [45]. In these experiments conductivities were used that are larger than the conductivity of fish probably will be, so it is not clear if this method will work for fish. However, the biggest problem is the time it takes to get an accurate measurement. In order to get a complete measurement, the setup takes approximately 1 second. In the situation with a fish, it is unlikely that the fish will stay at a location for 1 second. Therefore the reconstruction will be impossible, because the fish has changed location between the different measurements, which makes the measurement results incomparable.

Pros:

- No need for light or sound.

Cons:

- Image is probably not clear enough to detect shape of fish
- Measurement as described by [25] takes too much time to detect a fish

3.2.6 Radiation

Electromagnetic radiation can be divided in a lot of different categories. Some examples of these categories are radio transmission, visible light and ionizing radiation (e.g. x-rays). Methods using X-rays, and radio frequencies are described in this chapter. Methods using light (both visible and invisible (e.g. IR and UV) have been discussed in section 3.2.2.

X-Ray

This kind of radiation can pass through the most soft tissues, and is blocked by most hard tissue such as bones. Therefore this method can be used to look through the skin and see the bones of a human. This method is often used in medical imaging. Another sector where the x-rays are used is the food industry, where it is used to check contaminants in the food.
This method can be used by placing an x-ray source on one side, and a detector on the other side of a pipe. When a fish swims through the pipe, the fish bones can be detected. Unfortunately this kind of radiation can be dangerous if people or animals are exposed for a longer time to this kind of ionizing radiation. Therefore there are a lot of regulations for using this kind of radiation [39], which makes using this method very time consuming because of the permissions that must been granted.

Figure 3.15: An x-ray image of a fish. This image was probably not taken underwater. In underwater situations the fish will have probably less contrast on the background. However it will be possible to detect the fish bones. This image is from a report about x-ray sources[53].

pros

- Can detect shape of bones, which can give information about the fish species.

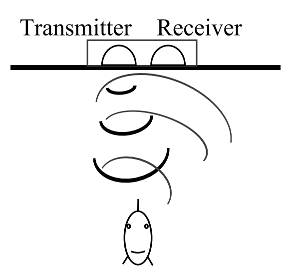
Cons

- X-rays can be dangerous if people or fish are exposed to this radiation too long.
- Strict regulations for ionising radiation.[39]

Radar

Radar (Radio detection and ranging) is a method which can be used for detecting aircrafts[36], ships[14], but also for level measurements in reservoirs[21] and detecting buried objects[4]. There are 2 types of radar, primary and secondary.
Primary radar emits a pulse, and waits to receive an echo. By calculating the time between the emitted pulse, and the reflected signal, the distance to an object can be measured.
Secondary radar does not emit a pulse, but waits for a pulse that is emitted by another object (for example an air plane). Because fish have usually no transmitter for emitting these pulses, only primary radar can be used.
Radio waves can be strongly damped by conducting material. Tin foil for example can almost block radio waves, but also salt water which is a bit conductive can strongly attenuate the radio waves. Pure freshwater does not attenuate the radio waves as fast as salt water, however also freshwater attenuates the radio waves more than air. But with a strong enough transmitter it should be possible to measure half a metre to detect fish.

Figure 3.16: A schematic view of how to detect a fish using radar. The transmitter transmits a pulse. This pulse is reflected by the fish, and received by the receiver. By calculating how long the pulse is on its way from the transmitter via the fish to the receiver, the distance can be calculated. Unfortunately the bottom of the water (not drawn here) also reflects a part of the signal, which makes it difficult to find the fish in the reflected pulses.



Pros

- Can work without influencing the fish behaviour.

Cons

- Difficult to measure at close distance, because the waves travel very fast.

3.2.7 Magnetic

There are various measurement methods using magnetic fields. One of these methods is to measure the magnetic field around some object. Another way uses a magnetic field and radio waves to detect the hydrogen molecule density (nuclear magnetic resonance).

Determining the magnetic field

This method is based on detecting the magnetic field around a magnetic object. This field can be detected by for example a Hall sensor, or a fluxgate sensor. Unfortunately, fish are not magnetic. Therefore this measurement method will not be able to detect fish.

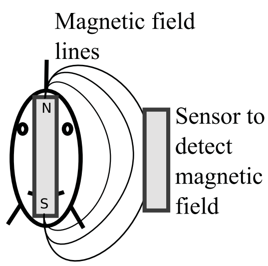


Figure 3.17: This figure shows how a fish could be detected if it was actually magnetic. The sensor on the right side could detect the magnetic field that the fish creates. Unfortunately the fish does not have such magnetic field.

pros

- Can be used in situations without light, or sound

Cons

- Fish are not magnetic, and therefore not detectable using this technique.

Nuclear magnetic resonance

This method is also known as MRI (magnetic resonance imaging). This method works just like an MRI scanner. A strong magnetic field sets the spin of the atoms to be either with, or against the direction of the magnetic field. Most of the spins are cancelled out by each other (a spin in the direction of the field cancels a spin in the counter direction). Only a couple atoms out of a million are not cancelled out. These atoms can change spin when there is a radio wave transmitted of the correct frequency. When the radio field is turned off, the spin will restore to its original direction. By going back to the original direction, the atom releases some energy in the form of a photon, with a frequency depending on the magnetic field at the location of the atom.
By applying a gradient magnetic field, it is possible to select a slice of the object to detect the hydrogen atom density.
Because the magnetic field is very strong, some precautions need to be taken, there may for example be no ferromagnetic material in the area of the scanner, or it will be pulled in the scanner with a high speed, and become a deadly projectile. An example of an object pulled into an MRI scanner is an oxygen tank[6].

Figure 3.18: An image of a MRI scanner that can be used for scanning humans.

pros

- Can be used in situations independent of environmental light.
- Can look inside the fish to detect location of organs.

Cons

- Very strong magnets needed.
- Absolutely no ferromagnetic parts are allowed in the area of the sensor.
- Scanning is not very fast, the fish needs to stop moving during the scan, which is very improbable.
- The gradient magnets make a lot of noise, which is uncomfortable for humans, and very likely also for fish.
- These scanning devices are very expensive(in the order of millions of euros) [20], [49].

3.2.8 Thermal

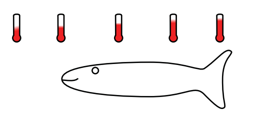


Figure 3.19: This image shows a fish passing some thermometers. The thermometer before the fish is not yet warmed up. As the fish passes, the thermometers show increasing temperatures. When the fish is passed, the temperature decreases again.

To measure the temperature, it is possible to use for example an infra red thermometer or a thermocouple. This could detect the fish if the temperature of a fish differs considerably from the temperature of water and the fish were swimming close to the sensor. Unfortunately, this is not the case because all fish are cold blooded. Therefore they have approximately the same temperature as the water. The other problem is that fish are swimming in the water and not always at the same distance from the sensor, which would make it difficult to measure the temperature of the fish.
This is a problem because measuring at a distance from a hot object, using for example a thermocouple would measure the temperature of the water, not the temperature of the object. Temperature measurement using infra red radiation would also give troubles because the water attenuates the amount of infra red radiation. Therefore it would

be necessary to know the exact distance from the object to the sensor to calculate the real temperature of the object.

pros

- Can be used in situations without light.

Cons

- Fish can probably not be detected because they are cold blooded.
- The water spreads the temperature relatively well, therefore it is only possible to measure the fish temperature if the fish is close to the sensor and this (small) distance is known.

3.3 The methods compared

During a meeting in Deventer with Marcel Wijnberger, Marcel Klinge, Guus Kruitwagen, Paul Regtien and Jeroen Broersen the pros and cons of the different methods were compared, and each property has been given a weight. The values as assigned in this meeting are showed in table 3.1.
Not each method mentioned in this chapter is placed in the table, because some methods like magnetic and temperature have that small chance of success that they were not discussed any further, and therefore have no values assigned.
The score in the table varies between +2 and -2, where +2 is indicated by two plus signs, and -2 by two minus signs. The score for each property is multiplied by the weighing factor, and summed. It can be seen in the column with the total score that the optical stereo vision, and electrical (resistive and capacitive) tomography methods have the highest score. This is because these methods are expected to be the best in recognising the fish species. The other methods have often the possibility to detect a fish, but for determining the species, not enough information can be gathered.

	Information available	Expected costs	Computational power required	annoying for fish	Can detect objects	Can distinguish fish and other objects	Can distinguish multiple fish	Can approximate fish size	Can determine fish shape	Can detect color of fish	automatize-ability species recognition	Total score
Sonar	++	-	0	++	++	+	+	0	- -	- -	- -	4
Didson	+	- -	0	++	++	++	++	+	+	- -	0	22
Camera	++	0	-	+	+	++	+	+	+	0	+	21
Stereo vision	0	0	-	+	+	++	++	++	++	0	+	27
Light valve	0	0	+	+	++	+	+	+	+	- -	0	17
Ring sensor	-	0	0	+	++	+	++	++	+	- -	0	20
2 metal plates	-	0	+	++	+	+	0	0	- -	- -	- -	- 2
3 metal strips	+	0	+	++	++	+	+	+	- -	- -	- -	8
Impedance tomography	-	-	- -	++	++	++	++	++	+	- -	+	24
Capacitive	-	0	+	++	++	+	+	0	- -	- -	- -	3
Capacitive tomography	-	-	- -	++	++	++	++	++	+	- -	+	24
Radar	0	- -	-	++	+	0	- -	- -	- -	- -	-	-15
Weighting factor	1	1	1	3	3	2	2	3	3	1.5	2	

Table 3.1: The methods with the values that are assigned to the methods in a meeting. The weighing factors are shown on the underside. The sum is shown on the right. For this sum, the values assigned are: ++: +2; +: +1; 0: 0; -: -1; –: -2. These values are multiplied by the weighing factor and summed.

3.4 Conclusions about the possible measurement methods.

As already shown in table 3.1, the tomography (resistive and capacitive) and camera methods have the highest score. Therefore the choice was made to further investigate these measurement methods.
Some experiments will be carried out in order to verify if the methods that are chosen are in real situations as good as they seem to be on the theoretical investigation.

4 Optical methods

4.1 Introduction

This chapter is about optical fish detection and recognition. The chapter starts with some information about what will happen to the light when it passes through riverine water. After this part an experiment that is carried out in the lab at the university, and a test with camera's in a real fish passage will be described.

4.2 Background

When a light beam travels through riverine water, the beam is affected by the water. Water can have the following effects on a beam of light:

absorption When light travels through water, a part of it will be transformed to other forms of energy, like heat.

scattering When light hits a particle (e.g. a grain of sand), it can be scattered into different directions depending on the shape of the grain and the angle of incident.

refraction Because most cameras are intended for use above water, a camera has probably to be placed in an area without water. Because this creates a transition from air to water, the angles at which the light travels will change.

The amount of absorption is mainly dependent on how turbid the water is, and what kind of matter causes the turbidity. It is also dependent on the color(wavelength) of the light. Humic acid for example absorbs the blue side of the spectrum more than the red side [26], leading to a brown color of the water.
Green alga on the other hand mainly absorb red and blue, while not absorbing green [41]. This makes these alga look green, and therefore affects an other part of the spectrum.
The amount of scattering depends strongly on the water. If there are a lot of particles (sand, clay, alga) more light will be reflected by these particles.

The refraction is caused by the transition from water to air. When the light goes from air to water, or from water to air, the light beam will be refracted. The angle of refraction can be calculated by Snell's law

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

In this formula θ_1 is the angle the light from medium 1 to the boundary between medium 1 and medium 2 (angle of incidence). θ_2 is the angle of refraction. n_1 and n_2 are the refractive indexes for the different mediums. In the case of air to water, the refractive indexes are respectively 1 and 1.33 .

If for example a circular tube is used, and a camera is placed to the side of the tube, the refraction of the water will make a part at the top and bottom of the tube 'invisible' to the camera, while another part of the tube is seen twice, which can give strange views when analysing the images. Figure 4.1 shows the light beams for different angles. It can be seen that the beam of light at the top side of the tube (red in the figure) crosses other light beams inside the tube. This makes it very difficult to look at the top and bottom side of the tube. Therefore another shape for the tube is preferred. In case of a square tube (figure 4.2), the whole tube can be seen by the camera.

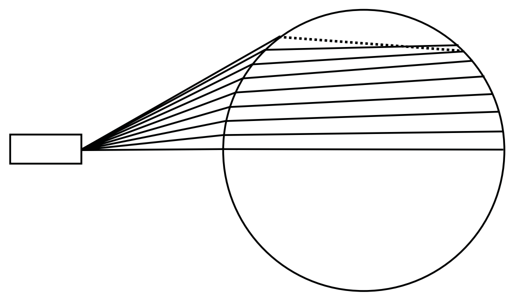


Figure 4.1: Illustration of some light rays when a circular tube is used. The rays partly cross each other (top 2 lines) which makes it impossible to see the top of the tube by using only 1 camera.

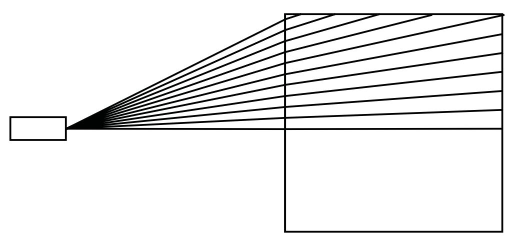


Figure 4.2: A view of some light rays when a square tube is used. This tube has less problems caused by the refraction index than the case with the circular tube.

Fish can be chased away by intense light sources, or blinking lights. Because a fish passage is meant for letting the fish pass, it is not a good idea to use a very bright light source that the fish can see. Freshwater fish living in deep water often have only two color receptors, and can only see colors around 530 nm and 620 nm wavelength (green and orange). Fish living in shallow water often have also sensitive receptors for 430 nm (blue) light. Fish in very shallow water usually have also three color receptors, but the sensitivity is changed to a little lower wavelengths [42].
Because infrared light has larger wavelengths than red light (IR starts from from approximately 800 nm), it is very unlikely fish can see infrared light, therefore infrared light can be useful to detect fish without influencing the fish behaviour with the light.

4.3 Camera tests at the University of Twente

4.3.1 Introduction

When cameras are used to count and recognize fish underwater, the quality of the image is strongly affected by the water. The water contains alga, sand, and humic acid, which all add some noise to the image. Edges can become blurred and a grain of sand can block or reflect light, which adds more noise.

This experiment is carried out to find out if it is possible to look with a camera through turbid water and detect a fish or the edges of a fish. Furthermore this experiment is to find out which color can be used to look at the fish.Because the requirements state that a fish should be possible to recognise in a tube with a 30 to 50 centimetre diameter, it is necessary to see enough detail through 30 to 50 centimetre of water for recognition.

4.3.2 The setup

In order to measure how much the water influences the 'sharpness' of the edge, a barrel is used. On the bottom of the barrel a lamp is placed of which a part is covered. The camera is placed above the water level. The camera looks to the lamp. This means that a part of the image is dark, while another part emits light. Images are taken for different amounts of water between the camera and the lamp. This is done by taking 10 images every 5 centimeter of water level raise . In figure 4.3 a photo of the setup is shown. The camera is not visible in this photo, but the camera is placed above the barrel, facing the light source which is partly covered with the plate.
Because the water in rivers has much more turbidity than tap water, water from a pond near the Hogekamp building of the University of Twente is used for this experiment.

Figure 4.3: The setup used for obtaining images. A camera is placed above the barrel facing the partial covered light. At the moment of the picture there is no water in the barrel. During the experiment water is added to barrel. Every time 5 litre of water is added, this made a level raise of 5 cm, after this a new set of pictures is taken with the camera above the barrel.

4.3.3 Processing the images

It is difficult to compare the images objectively by only looking at them. Therefore a matlab script is developed to extract the needed information from the images.
For this script it is necessary to manually select the area in which the edge is visible. In figure 4.4 such an area is marked. After the selection, the edge between dark and light needs to be found. This is done by highlighting the edges using the canny edge detector. After this, the Hough transform is used to find the edge between the covered and not covered part.
When the edge is found, the image is rotated to get this edge vertical (see figure 4.5). After rotation the average of a column of pixels is taken in the area where more than 50 % of the rotated image contains infomation from the image. The thin vertical lines in figure 4.5 indicate the area where more than 50% of the pixels in a vertical row are from the original unrotated image.
Figure 4.6 contains graphs that are created from the rotated image. The left part shows the average value of the pixels for every column as well as the the minimum and maximum value. The derivative of the amplitude is shown in the graph on the right. This derivative is calculated by subtracting two values next to each other from the average graph.

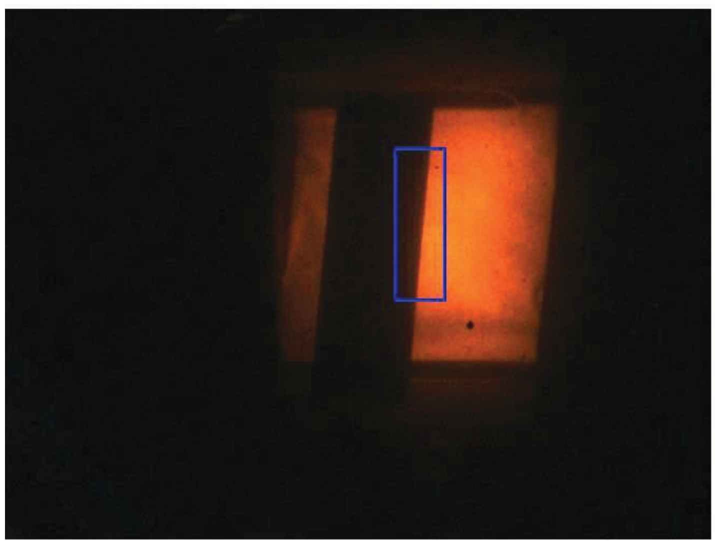


Figure 4.4: An image of the partly covered light source underwater, in which the area that is selected by hand is marked.

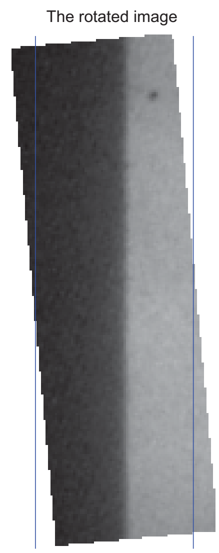


Figure 4.5: The selected area of the image is rotated. The area in which more than 50% of the vertical line is from the original image is marked with the two small vertical lines.

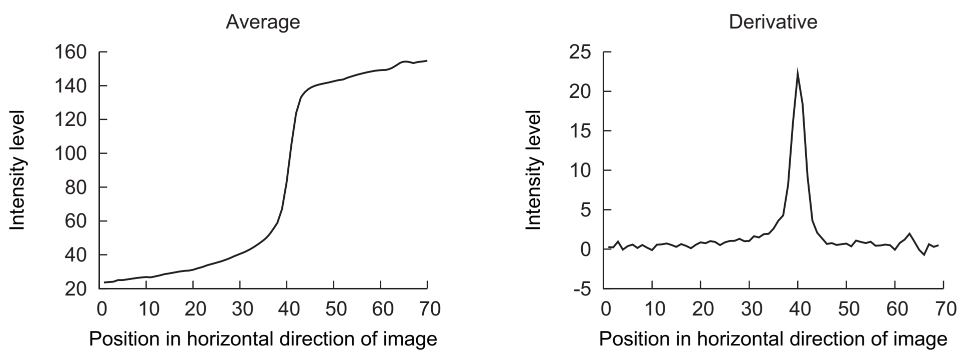


Figure 4.6: The graphs that are created based on the rotated image, from the gray image. In the left part, the average value is shown, it can be clearly seen that there is a transition from dark to light. In the right part, the derivative is showed. Here a peak can be seen at the location where the derivative is at it's maximum value.

4.3.4 Analysing the results

To determine which of the images will have enough quality to recognise fish species, a criterion is made. This section describes how this criterion is determined. First the noise of an image is analysed. Then an image with two stickles is created, and it is determined how much blurring is allowed in order to be able to detect the stickle in presence of noise. When the maximal blurring is determined, this blurring is transfered to a maximal derivative. This is because in the images obtained by the camera, the maximum derivative is measured.

Noise

The quality of the image is not only determined by blurring, but also by some noise caused by larger particles, for example sand grain. In order to get an idea of the level of this noise, the noise of some images with the highest water level used (38cm) is calculated. The noise is calculated by assuming that the average of an area of 5x5 pixels has the 'correct' value. By subtracting this value from the value in the centre of these five pixels, the noise is calculated.
Noise has a wide range of which low noise levels occur often and higher noise levels are rare(figure 4.7). The standard deviation of this noise is calculated using

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

The standard deviation is found to be 5.2 .
When 99.99 % of the noise should be within the specs, a 4 σ can be used. In this case, this is 21.
This value of 21 is on a scale of 0 to 255. This corresponds to a value of 0.082 on a scale from 0 to 1 (0=black; 1=white), as is used in the following section.

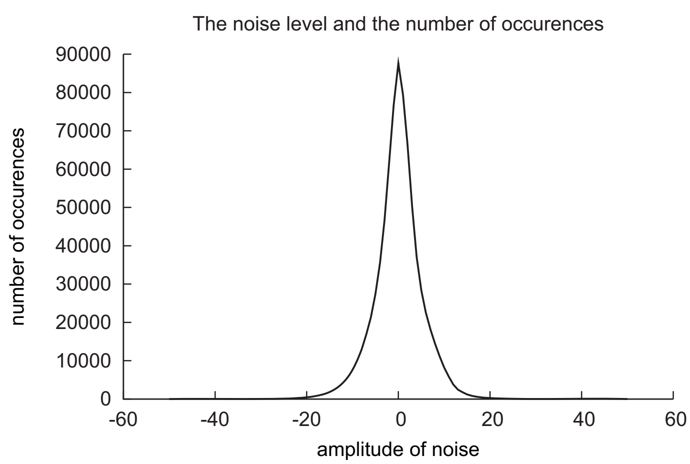


Figure 4.7: The noise level versus the number of occurrences for an image taken through a layer of 38 centimetres of turbid water.

Maximal blurring

For recognizing fish species, it is necessary to have the possibility to detect small details of a fish, such as the prickles of a stickleback. In order to find the maximum allowable

blur, a figure with two black stripes with a width of 3 pixels and a distance of 30 pixels is used (if 3 pixels per millimeter is assumed, this means that there are two prickles of 1 mm thick with a distance of 1 cm), see figure 4.8.
A Gaussian blur with different values for the scale(σ) is applied to this model. In figure 4.9 the result for different values of σ can be seen.
Obviously, as sigma increases, it becomes more difficult to detect the prickles. In order to make it more clear what pixel intensities are caused by blurring, the intensities at the centre of the prickle are plotted in figure 4.10.
In these cases no noise is present. In order to still be able to detect the stickle in presence of the noise, the change in intensity caused by the stickle should be more than the intensity difference caused by noise. Because the noise can work in both directions (light can be darker, and dark can be lighter by the noise), it is possible that a part without stickle is made darker, while a part with a stickle is lighter, leading to a difference two time as much as the noise that was found. Therefore the stickle should give an intensity more than 2 times the noise (for a better difference, 3 times the noise is chosen). Because the noise was found to be 0.082 , the minimum level change caused by a stickle should be $3 \times 0.082 = 0.25$. In the case of a σ=4.5, the level change caused by the prickle is 0.26 as can be seen in figure 4.10.
Therefore it is necessary to have a blurring level σ <4.5 in order to be able to detect details of a fish like prickles.

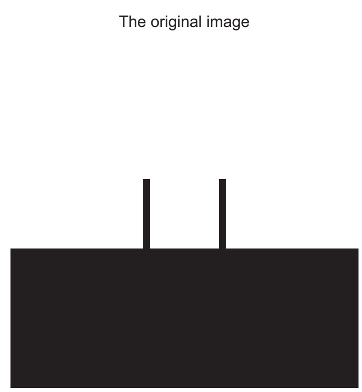


Figure 4.8: The model used to test how much blur is allowed. In figure 4.9 this image can be seen blurred with different values for σ

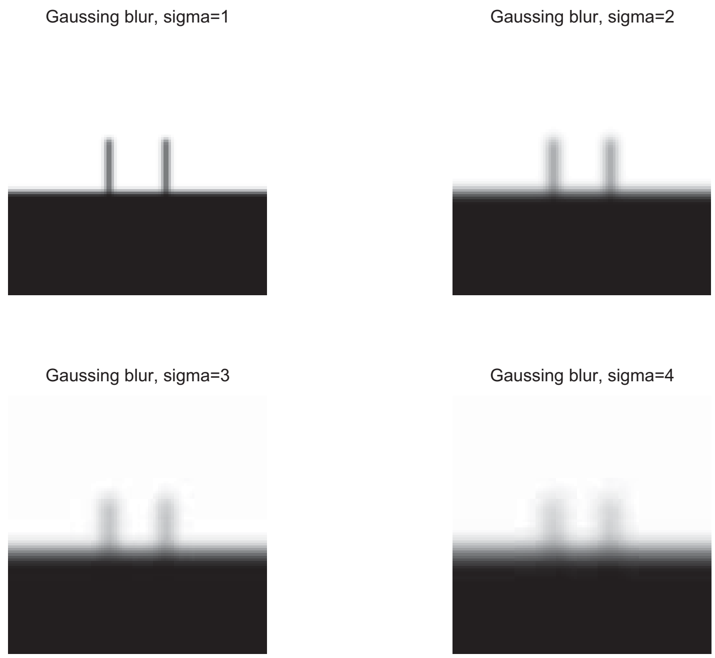


Figure 4.9: The stickle, but now blurred with different values for σ

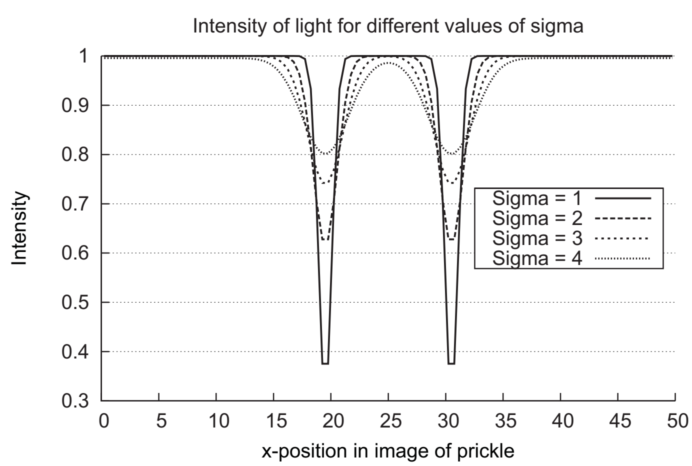


Figure 4.10: The values for every pixel at the centre of the prickle.

From sigma to derivative

Because in the experiments the values for the derivative are obtained, and not the blurring factor σ, this blurring should be converted to a derivative.
Because the transition from dark to light behaves like a step, a step is used to simulate

this.
For the standard Gaussian blur, the following formula can be used.

$$h(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Because the image is rotated, we can consider only the 1-dimensional case. This can be written as:

$$h(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}}$$

The blurred edge is found by convolution of h(x) and the step function. This results in:

$$f(x) = \int_0^{\inf} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-t)^2}{2\sigma^2}} dt$$

The maximum derivative is at x=0, and is dependend of σ by:

$$\dot{f}(x) = \frac{1}{\sqrt{2\pi}\sigma}$$

So with the maximum allowable sigma of 4.5, this leads to a minimum derivative of 0.09 .

Results

For every color channel (Red, Green and Blue), the derivative and average values are obtained from the image. Unfortunately the red channel has clipped in a lot of the images taken (clipped means the intensity applied to the camera is higher than the maximum detectable intensity). Therefore it becomes difficult to find the amplitude for the red channel for all water distances .
To get the amplitude for the water levels where the images clipped, the other color channels are studied. It seems that the intensity of the blue channel divided by the intensity of the green channel is a linear function dependent on the water level. For the not overexposed values of the red channel, it is also possible to calculate such a ratio between the red and green or blue channel.
By calculating the ratio between the red and green channel, the expected amplitude of the red channel is calculated. The amplitude for the different color channels can be found in figure 4.11.

The maximum derivative is also detected in the images. For the derivative the clipping of the red channel also gives some problems. Therefore not every water level has a data point in the graph. The derivative is divided by the amplitude, resulting in the graph of figure 4.12.
It can be seen that the signals of the different color channels are close to each other, and are decreasing when the water level increases.
In the previous part, it was concluded that the derivative divided by the amplitude

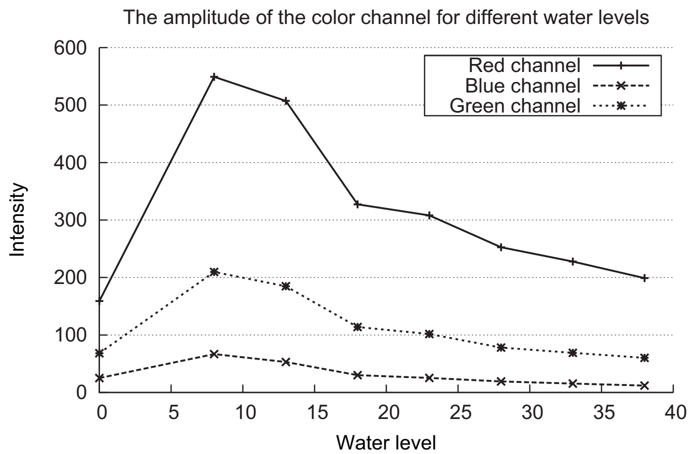


Figure 4.11: The amplitude for the different color channels.

should be no more than 0.09. It can be seen in figure 4.12 that in this case the levels are above this value. Therefore it should be possible see enough detail to distinguish prickles of 1 mm wide, and 1 cm long in 38 centimetre water. However, when extrapolating the graph, it is probable that at 50 centimetre the derivative becomes lower than 0.09. Therefore at 50 centimetre the requirement for detecting these prickles is not met.

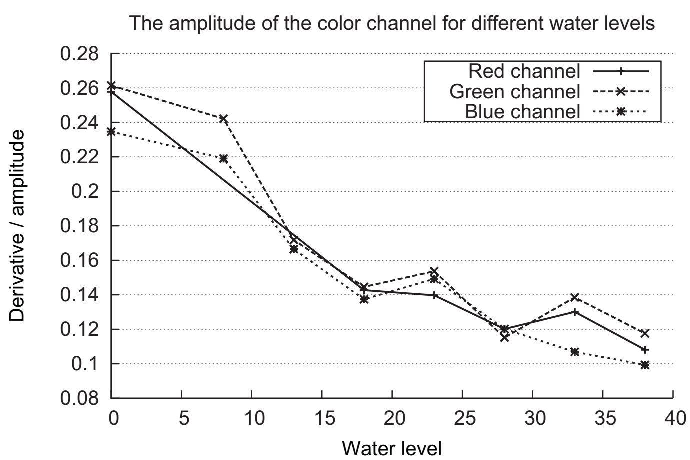


Figure 4.12: The derivative of each color compensated for the amplitude for the different color channels.

4.3.5 Conclusions about the camera experiments at the University of Twente

The experiments in the laboratory at the University of Twente have shown that it is possible to look with a camera through 38 centimetre of water, while still seeing enough details of a fish in order to detect fish species. When the results are extrapolated to a distance of 50 centimetre, the level of detail that is visible is not enough to achieve the requirements as discussed in section 4.3.4.
The red channel has stronger signal strength than the other channels. This is probably caused by the light source, since this is also the case in the situation without water. Because there are no big differences in the used spectrum, it is assumed that colors close to this spectrum (such as infra-red) will also satisfy. Because fish can not see infra-red light [42], and it is likely that infra-red is as good as the other colors to look underwater, Infra-red is recommended to use for fish recognition.

4.4 The camera setup in Roermond

4.4.1 Introduction

In Roermond there is an experiment where a siphon fish passage from FishFlow is compared with a basin fish passage from the Ministry of Waterways.
Every morning one of the two passages is turned on. The next morning the other passage is turned on. The two passages are compared by counting the number of fish caught in a fyke at the end of the passage. Unfortunately there are not many fish caught after the siphon passage. There are several theories why the fish are not caught. It is for example possible that the streams at the fyke could confuse the fish, which lets the fish turn around and go to the start, instead of entering the fyke. It is also possible that the fish hear the noise of a dam nearby, and decide to turn back.
In order to find out if the fish are actually passing the largest part of the passage, cameras are placed inside the passage. These cameras should be able to record fish, and can give information about the theory that fish are going to the end of the passage and return to the entry of the passage. If this is the case, the fish should pass the cameras twice. One time in upstream direction, and one time in downstream direction.
The experiment is carried out in two iterations. In the first iteration some cameras and infrared light sources were placed. After analysing the results, the choice was made to place more infrared light sources and a better camera. These additions are done in the second iteration.

4.4.2 The first setup

Cameras

For the first setup three cameras were placed inside the fish passage. One of them is placed above the water surface. Two of them are placed below the water surface. The location of the cameras can be seen in the schematic figure 4.13, or on the photo 4.14.

The tube of the fish passage is fairly large (2.4 meter diameter). Fortunately the part of the passage in which the fish can pass is a lot smaller, as can be seen in figure 4.13. This is because the goal of the fish passage is to change a large difference in water level to a lot smaller differences in water level. This is done by placing baffles in the tube with small differences in water level, which are all possible for the fish to pass.
The cameras are located near a baffle, because here the fish need to pass through a small part of the tube, which makes it more likely for the camera to detect passing fishes.

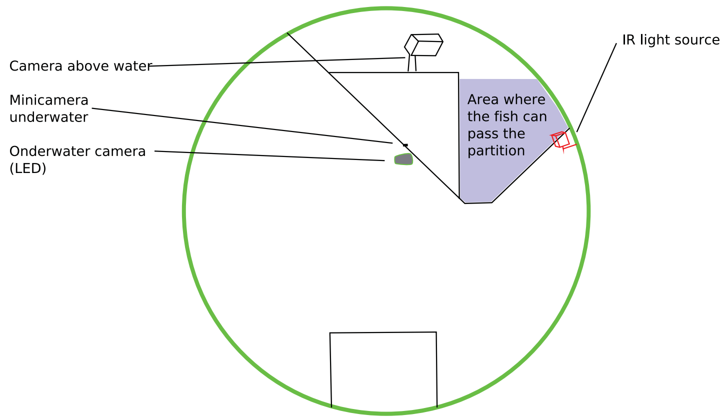


Figure 4.13: The schematic setup of the cameras in the fish passage. The tube has a diameter of 2.4 meter. But the fish can only pass through a small part of the tube. The cameras are directed to this part.

Figure 4.14: A photo of the camera placed in the tube, as used in the first setup.

The used cameras are different types. A list of the used cameras and their names and location can be found in table 4.1.

	Location	camera type	video Server
	Above water	Axis 207M	inside camera
	Below water (with LEDs)	VKC-1317/IR-3.8	Axis 247S
	Below water (mini-cam)	spycam from Axis M7001 kit	axis M7001

Table 4.1: The cameras that are placed inside the fish passage (first setup)

IR beamers

There were also several Infra-red (IR) sources used. The camera above the water had a source of IR light, one of the underwater cameras had an IR source and another IR source was placed facing the underwater cameras.

Data transfer

The cameras produce a lot of data. Because these data need to be analysed, and preferably not at the fish passage, but at another location, the data has to be transfered to another location. A few days after the camera-setup was placed, an UMTS-router was placed. Via this UMTS router it was possible to look at live images from the cameras, however playing forward and backward was not possible, which is difficult when analysing the images, because if there is something interesting it would be nice to take a second look at the images.
Therefore the data was also saved locally in Roermond. When the first setup was converted to the second setup, the images were copied to a NAS (Network attached storage) , and transported to Deventer.

4.4.3 Results from the first setup

After looking at the images generated by the cameras it was not very clear if there were fish present. In the camera positioned above the water surface it was possible to see

some waves at the water surface, that could be caused by fish, but it was not clear enough to be certain.
The underwater minicamera was not sensitive enough for the IR light to see clearly what was passing.
The underwater camera with IR beamer had problems with looking underwater because the light generated by the IR beamer on the camera was reflected very close to the camera by the turbidity of the water. This caused the image to be overexposed, however it was also possible to see the IR beamer that was mounted on the opposite side of the area where fish could pass.
This made it very likely that if the IR source at the camera is disabled and more IR beamers are placed on the opposite side, a kind of light valve setup is generated. This would make a passing fish block the IR light emitted by some of the LEDs, which causes the shape of the fish to be detected by the camera. This would create the silhouette of the fish to be detected.

4.4.4 The second setup

Cameras

Because the results from the first setup where unsatisfying, but showed that there were possibilities for improvements, changes were made to the setup. In this second setup a camera was added. The extra camera (a Mobotix D12) is chosen because this camera is much more adjustable to the situation. It is for example possible to select a region to which the brightness is adjusted.
This Mobotix camera has two lenses. One of them has a daylight sensor, and a sensor with a small angle. The other lens has a night (IR) sensor, and a wide angle lens. Because the daylight camera is not sensitive to IR light, and there is almost no non-IR light present in the tube, this camera gave no information, therefore the recording of this lens is stopped after a few days. The night vision camera with a 90° lens gives a better quality of images. Therefore these images are recorded.
Because the two underwater cameras from the first setup were blocking the ideal location of the Mobotix camera, these two cameras were moved. These two cameras are still placed underwater, but they are moved more to the top as can be seen in figure 4.15. The setup is also shown in figure 4.16a.

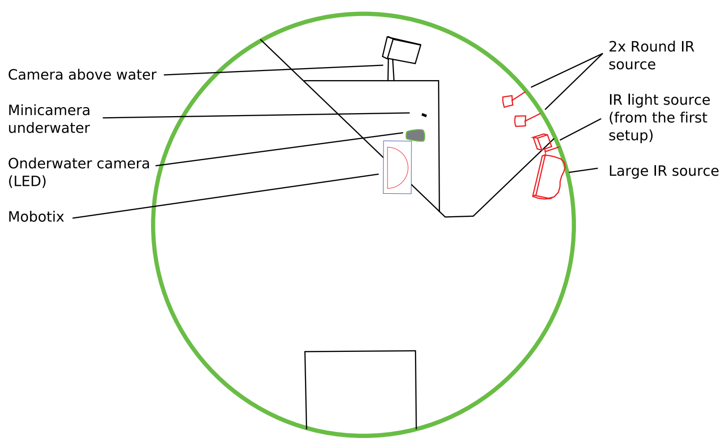


Figure 4.15: The location of the IR beamers, and the camera for the second setup.

IR beamers

The other change for the second setup was the addition of more IR beamers. A picture of the placed IR beamers can be found in figure 4.16b. This was done because in the first setup it was possible to see the IR beamer at the other side of the water stream. When using more IR beamers it would be possible to see all the IR beamers, except for the moments that a fish passes. At that moment the silhouette of the fish could be seen. Because it could be useful if some of the IR beamers are switched on or off, they are

(a) The cameras

(b) The IR beamers

Figure 4.16: The cameras and IR beamers as used in the second setup.

made switchable by the outputs that the different cameras have. The switching setup is described in table 4.3.

Data transfer

Shortly after adding the Mobotix camera, the live images from that camera were also available via the UMTS router.
To get the images to Deventer, at first an ftp server was established, so it would be possible to download the images. However, this connection was also over the UMTS network, which made it too slow to transport all the data. Therefore the data was locally stored on a NAS (network attached storage) in Roermond. After some time of recording the images, the NAS was replaced by another NAS and sent by mail to Deventer to analyse the captured images.

4.4.5 Results from the second setup

The new setup has an extra camera and more IR beamers. Especially the Mobotix camera combined with the IR beamers gives better images than the previous setup.
While looking at the live images, some images that are probably a fish were detected. When the complete recorded data from the time the fish was seen was downloaded

over FTP, the fish could not be found. This is probably caused by the frame rate of the recording. The Mobotix camera can take up to 25 fps. But there were less frames recorded. Manually counting of the frames showed that between 3 and 5 frames per second were recorded. Because of this low speed of recording images, and the independent process of viewing images by the live viewer, it is possible that fish are seen, that are not recorded. This is illustrated in figure 4.17

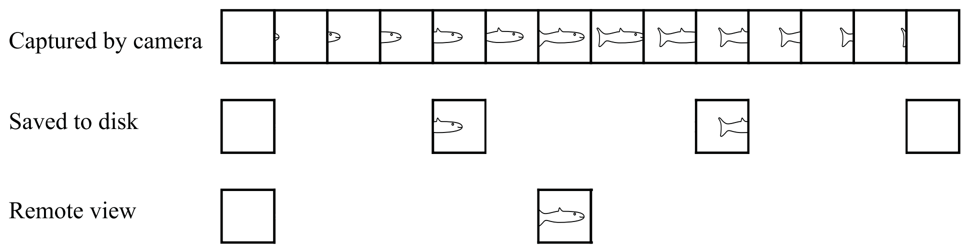


Figure 4.17: The images captured by the camera are not all saved. The images are also not all viewed by the live video stream. It is possible that different images are viewed by the live stream than are captured by the camera. Therefore it is possible to see a fish in the live images, while not seeing it in the saved video.

There are a lot of images found in which objects are detected that are likely to be a fish. However because of the low frame rate at which the recordings were made, the object is gone in the next frame. Therefore it is not possible to get information about the direction in which the object moves. If there are multiple frames with the object, and the object moves in upstream direction, it should be a fish, because other objects usually move downstream. Two of the pictures taken with the Mobotix camera are shown in figure 4.18.

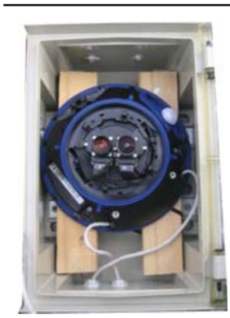
	Location	camera type	videoServer
	Below water	Mobotix D12D-Sec-D43N22	inside camera

Table 4.2: The camera that is added to the cameras of the first setup.

IR beamer	switched by camera
two round beamers at the top	Above water
beamer at the center (from setup1)	Mobotix camera
Large IR beamer	M7001 spycam

Table 4.3: The IR light sources and the camera which can be used to switch it

(a) On the left side of the white area a dark object that is likely to be a fish is detected.

(b) On the left side of the white area, the head of a fish could be seen.

Figure 4.18: Two pictures taken with the Mobotix camera which contain objects which are very likely to be a fish.

4.4.6 Conclusions about the camera setup in Roermond

The experiment in Roermond unfortunately did not give good results in finding fish, however the setup has given some useful results. With an camera it was possible to look through approximately 85 centimetre of turbid water while seeing the light source through the water. In order to get information about passing fish, it will be necessary to use a higher frame rate than the 5 fps that were used in this setup. The problem with the low frame rate is that when a fish like object appears, it is gone in the next frame, and it is not possible to be sure if it is really a fish.
Another important finding is that it is really necessary to use some kind of trigger in order to determine if there is a fish. When there are just images recorded and no information about the moment a possible fish passes the camera, it takes very much time to watch the images, it also takes very much disk space to save the images. If a trigger is used, it is possible to automatically save only images a few seconds around the trigger, which relieves the work of watching the images a lot.

4.5 Conclusions about optical fish detection

The cameras in Roermond have shown that the turbidity of the water is not constant. In order to get images of good quality it would therefore be useful if the sensitivity of the camera or the intensity of the light sources (or both) can be automatically adjusted to the changing situation.
There are different methods for the illumination of the fish. It is possible to place a light source next to the camera, or to place a light source in front of the camera. Placing a light source next to the camera can give overexposed images when the water is turbid. It is therefore not recommendable to place the light source close to the camera. Placing a light source opposite to the camera can give the silhouette of a fish, while the path of the light through the water is as short as possible.
When a camera that is normally not used for underwater use is placed in some transparent box underwater, it is necessary to keep in mind that the angle of refraction between water and air can cause the viewing angle to change. It is also possible that when the camera is placed outside a tube the shape of the tube influences the viewing angle in such a way that it is not possible to see the entire tube.

5 Electrical methods

5.1 Introduction

Electrical fish detection uses electrical signals in order to detect fish. Because a fish differs from water in the electrical domain (differences in conductivity and in permittivity), it should be possible to detect fish using an electrical measurement method. This chapter starts with the capacitive method for detecting fish. After that resistive fish detection will be described, followed by a description of tomographic measurements.

5.2 Capacitive

5.2.1 Background

Capacitive measurement methods are based on differences in permittivity of fish and water. The capacity for a flat plate capacitor is related to the dielectric constant by the following formula:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

In which C = capacity, ε_0 = permittivity of vacuum ($\approx 8.8510^{-12}$), ε_r = relative permittivity, A = surface of a plate, d = distance between two plates.
The relative permittivity of water is approximately 80. The relative permittivity of most other natural materials is lower. Air for example has a permittivity of approximately 1. The permittivity for fish was not found in literature, but for human body tissues the permittivity is very frequency dependent, but for example at 1 MHz the permittivity of muscle is approximately 1800 [15]. This is quite different from the permittivity of water. Because the permittivity of water differs from the permittivity of fish, it is very likely that fish can be detected using capacitive measurements. In order to get more certainty about the possibility of detecting fish using capacitive measurements, experiments and a simulation are carried out.

5.2.2 Experiments for capacitive measurement

In order to find out if it is possible to detect objects in water using capacitive measurement, an experiment is carried out in which the capacity between two plates is measured. In this experiment two sealed electrodes were placed underwater. The capacity was measured using a relaxation oscillator, which is described by [33]. This relaxation oscillator measures by transferring the charge of the capacitor that needs to be determined to a capacitor with a known capacity. This known capacitor is then discharged by a known current. The time it takes to discharge this known capacitor determines the amount of charge on the capacitor, which means the charge in the capacitor to be measured is also known. Because the voltage on the capacitor to measure is a predefined voltage, the capacity can be calculated.

The results of this measurement showed a capacity that was much larger than the expected capacity. This was probably caused by the fact that water has a conductivity as well as a permittivity. This leads to a more extended model of the measurement setup (see figure 5.1). To find out if the assumption about the reason for the false results are correct, the circuit was simulated using 20sim.

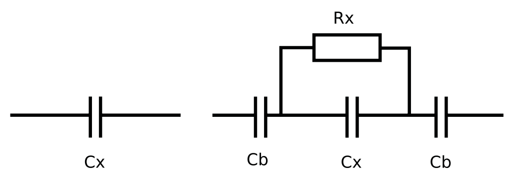


Figure 5.1: The model of the sensor as was assumed to be measured (left), and a model that better represents the real situation (right).

Because the relaxation oscillator charges the capacitor that needs to be measured, and drains it very quickly after some time, it is necessary that the capacitor that needs to be measured is not discharged very fast. Unfortunately the water has a resistance which relative quickly discharges the capacitance. Figure 5.2 shows a graph of the voltages when a step is applied to the circuit. It can be seen that the voltage over the capacitor that needs to be measured (C_x) diminishes quickly. This is caused by the resistance parallel to this capacitor. In the experiment the time between the charge and the discharge was approximately 70 µs, while in this figure, it can be seen that almost all charge is already gone after 2 µs. This explains why this measurement does not give correct measurement results. .

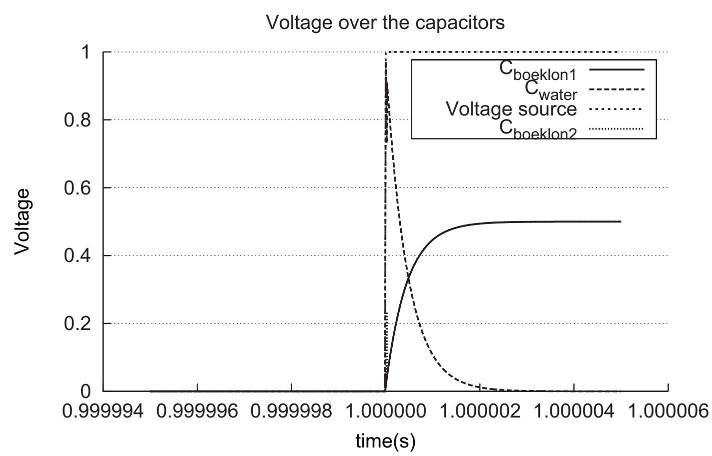


Figure 5.2: The behaviour of the measurement sensor when applying a step voltage. The voltage on the capacitor C_x that needs to be measured is almost gone after approximately 2 µs, due to the resistance that is parallel to the capacitor to be measured (figure 5.1)

5.2.3 Simulations to determine possibility of measuring capacity

Introduction

Because the results of the experiment described in section 5.2.2 did not give as good prospectives as expected, a simulation was carried out in order to find another way to measure the capacitance of water with a fish without measuring the effect of the resistivity of water.
The simulation tries to find a way of measuring the capacitance of the water C_x independent of the water resistance (R_x). There are different variables that can be changed for this measurement. The sensor is given, but the measurement frequency, and the reference impedance can vary. The simulations are carried out using matlab.

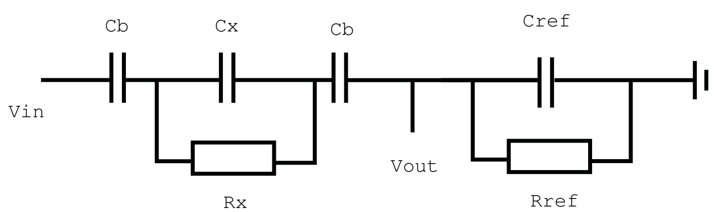


Figure 5.3: The model of the sensor setup (on the left), together with a reference circuit (between Vout and the ground). This document will describe some simulations with this circuit.

An approach for finding optimal parameters for measuring R_x

Another way to find the optimal values for ω, C_{ref}, and R_{ref} is to simulate the model with a lot of different values for all these parameters, and find the optimal combination. This is done by a matlab program. The program varies the values for C_{ref}, R_{ref} and ω. For each combination of these values, some values for C_x and R_x are chosen.
The specification for a good measurement is defined as:
-The change of C_x (from 1 fF to 100 pF) should have less influence on the output signal(Vout) than a change in resistance (R_x) of 2% from the average value of 1 kΩ. This should be the case for R_x from 100 Ω to 10 kΩ.
-The change of V_{out} for a changing R_x should be at least 1 mV per change of 20 Ω.
These ranges are chosen to be around the expected values.
Because there are 5 variables that change during the running of the program (ω, R_{ref}, C_{ref}, R_x, C_x), it is computationally very heavy (and unnecessary) to calculate for every variable with a lot of steps. Therefore the program is executed twice. The first time with a very wide range of variables, but with a large space between the values. The second time with the variables around the optimum values found the first time. When the simulation was executed, the values for ω, C_{ref} and R_{ref} which satisfy the specifications are selected. Among them, the highest value of $\frac{dR_x}{dC_x}$ is selected. This value is found to be:

parameter	value
frequency	15 kHz
R_{ref}	100 kΩ
C_{ref}	1×10^{-18} F

The value for C_{ref} indicates that this component can be neglected, and the capacitance should be just as low as possible. When this setup is built on a breadboard for example, care should be taken to avoid parasitic capacitances, for example between two adjacent rows on a breadboard.

The found solution for measuring R_x gives the situation as shown in figure 5.4. It can be seen that the influence of C_x on the output value is relatively small, while the influence of R_x is larger. A difference of 20 ohm gives a much larger change in output voltage than a difference from 3 fF to 50 pF.

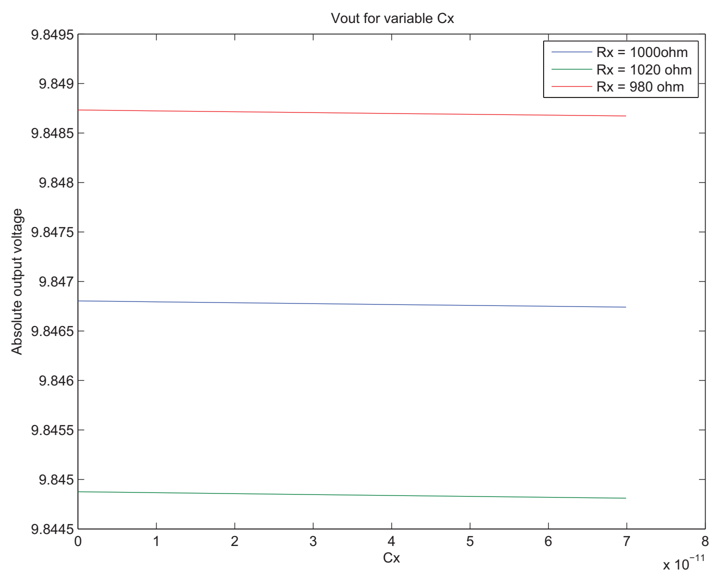


Figure 5.4: The simulation results for measuring R_x. Freq = 1 kHz, R_{ref} = 100 kΩ, C_{ref} = 1×10^{-18} F , C_x = on the x-axis

An approach for finding optimal parameters for measuring C_x

Measuring C_x without influence from R_x seems to be a lot more difficult. It was tried to find some values for ω, R_{ref}, and C_{ref} such that it is possible to measure:
-capacitance differences(C_x) of 50 fF in a range from 100 fF to 10 pF, without knowing the value of R_x when R_x is between 100 Ω and 10 kΩ.
-at least 1 mV output change per 50 fF capacitance change.

Variable	min	max	steps
Frequency	10 kHz	100 MHz	40
R_{ref}	10 Ω	1 TΩ	9
C_{ref}	10×10^{-21} F	1 F	20

Table 5.1: The range for the different variables in which is searched for the best combination. The number of steps is the number of values that is used between the maximum and minimum value.

This is tested for a lot of different situations (frequency from 10 kHz to 100 MHz, R_{ref} from 10 Ω to 1 TΩ).
The range of values in which is searched is shown in table 5.1. This gave no results that met all the specifications. Therefore the best result is chosen by searching for the result with the largest value of dC_x/dR_x. The values ω=628 000 rad s^{-1} (= 100 kHz) , C_{ref} = 10×10^{-21} F and R_{ref}=75 MΩ are used to simulate the results. This is shown in figure 5.5. It can be clearly seen that it will be impossible to determine the value of C_x with an R_x. Further, the output voltages for changing C_x are separated by approximately 16 nV, which makes it very difficult to measure C_x accurately.

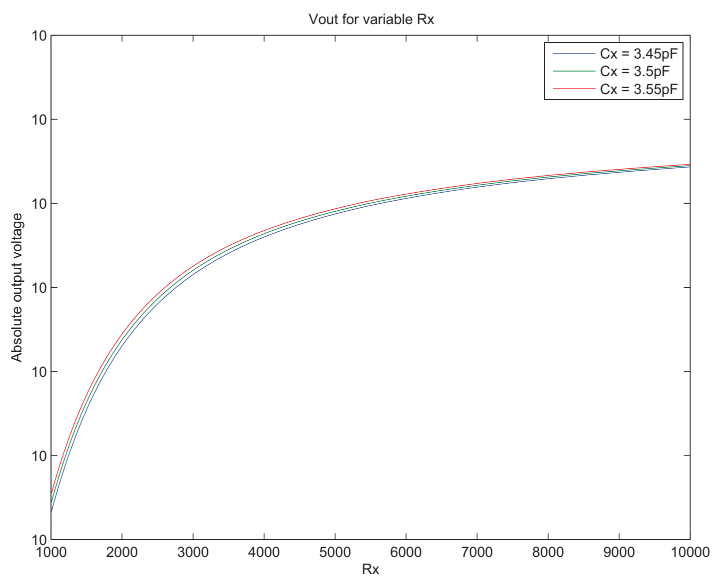


Figure 5.5: The simulation results for measuring C_x. Freq = 100 kHz, R_{ref} = 75 MΩ, C_{ref} = 10×10^{-21} F.

5.2.4 Conclusions for capacitive measurements

The resistive effect of the water and fish has a much larger influence than the capacitance. Since the resistivity of water also varies, it is very difficult to measure capacitance.

5.3 Resistive

5.3.1 Background

For a resistive measurement, it is necessary that the resistance of a fish is different from that of water. It is very likely that it is possible to detect fish using a resistive method, because there is already an instrument, the Logie Fish counter, that can count fish based on resistivity differences between fish and water.
There are various values found for the conductivity of river water. According to Aquantic, the company that produces the fish counter, the conductivity of riverine water is in the range of $30\,\mu S\,cm^{-1}$ to $450\,\mu S\,cm^{-1}$.
The conductivity of fish is dependent on a lot of variables such as the species of the fish and the temperature of the fish, but the found values are within the region of $300\,\mu S\,cm^{-1}$ to $3000\,\mu S\,cm^{-1}$. The fish conductivity overlaps the water conductivity partly, however according to information from Aquantic the fish conductivity is higher than the water conductivity. It is assumed that the fish conductivity can indeed always be higher that the water conductivity, because both fish and water have a temperature dependent conductivity. It is assumed that when the fish conductivity is on the low part of its conductivity range, the water will also be on the low side of its conductivity range, therefore still having a distinguishable same conductivity.

5.3.2 Simulations of a resistive fish counter

Introduction

Counting fish using resistance is a method that is already used in practice. It would be interesting to check if the results from the real fish counter are comparable to the measurements carried out in an FEA(finite elements analyses) program. There is no real fish counter at hand, which makes it difficult to compare the results. However, there are some graphs of the measured voltage created by a fish counter. By comparing these graphs with the simulation results, it is possible to compare the simulations with the real measurements.

setup

The setup for the finite elements simulation is a tank with a width of 3 meter, and a height of 40 cm. In this tank three electrodes are placed on the bottom. These electrodes are placed 30 cm apart from each other at the centre of the tank, as can be seen in figure 5.8. The width of the tank is chosen to be 3 metre, because this is a lot larger than the

Material	Conductivity(S/m)	Relative permittivity
Water	0.005	80
Fish	0.5	4
Copper plate	59600000	1

Table 5.2: The values used for the conductivity and permittivity of the different materials as used in the simulation for the resistive fish counter.

width of the part with the electrodes. Therefore the effect that the area is bounded in size is almost negligible. This can also be seen in the voltage plots. The voltages on the left and right sides are almost constant.

For the water level 40 centimetre is chosen, because this fits in the range of water level (30 to 50 centimetre) advised by the manufacturer of the resistive fish counter. The electrodes are driven by a voltage at 3 kHz, just as for the already existing fish counter. The voltages on the driver electrodes are 10 V (180° out of phase), so it could be considered as +10V and -10V. In table 5.2 the used values for conductivity are described.

The fish In order to get the shape of the fish, an image of a white bream is taken. This shape is outlined with a few straight lines. After this process, the lines are scaled in such a way that the length of the fish is 20 centimetre(not unusual for a white bream) when used in femm (the used finite elements program). The bream together with the created outline can be seen in figure 5.6.

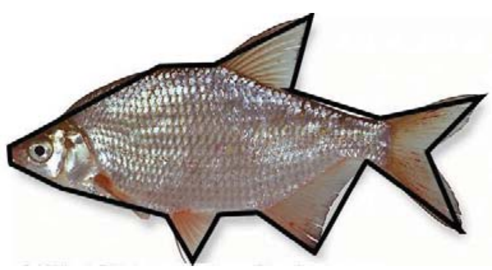


Figure 5.6: The fish used for the model, with the shape outline.

Results fish at different heights above the plates

The simulation is carried out for a fish moving from the left to the right side of the tank at different heights from the bottom. For every centimetre of movement from left to right, the voltage on the measurement electrode is measured. The x-axis of figure 5.7 represents the position of the fish. The values at the x-axis of the graph represent the fish position. The fish is at the left side at value 1, 90 represents the centre and 180 is at the right side. This last situation is shown in figure 5.8.
This experiment was also carried out in order to compare the simulations with the real fish counter. When the simulated signal from figure 5.7 is compared with the result

from a real measurement using the fish counter (figure 5.9), it can be seen that the shape is globally similar. The real fish counter has some more noise at the beginning and end of the graph, which can be expected because in real measurements there is almost always some noise present. The amplitudes of the graphs can unfortunately not be compared, because the voltages from the real fish counter are not known.
The amplitudes for the different heights above the plates can be compared. It can be seen that when a fish swims higher above the plate, the width of the signal is the same, but the amplitude is smaller. This can be explained because when the fish is further from the strips, there is more water between the fish and the strips resulting in a larger effect of the water conductivity. Because the influence of the water becomes larger, the changes caused by the fish become smaller, and so does the amplitude of the signal.

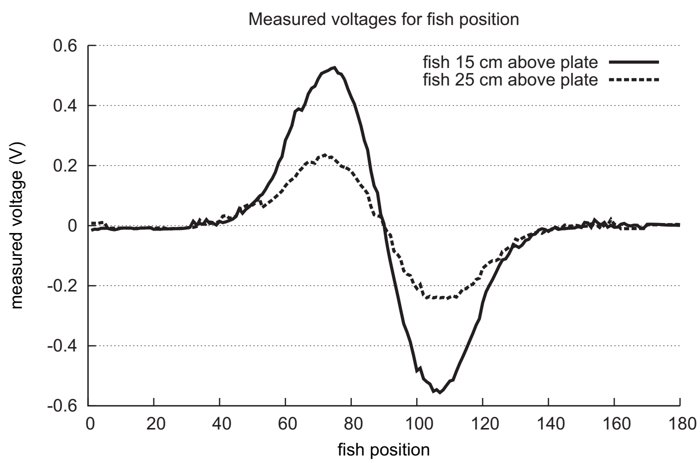


Figure 5.7: The measured voltage on the centre plate versus the position of the fish

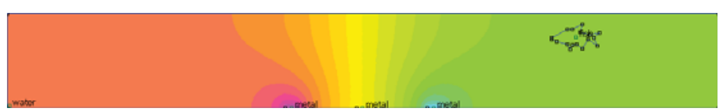


Figure 5.8: The simulation setup of the fish swimming 25 centimetre above the plates. Fish at the right (position 180 in graph)

Results for different fish conductivities

In order to get more insight in detecting fish using a resistive measurement, the simulation is also carried out in a situation where the conductivity of a fish is lower instead of higher than the conductivity of water. For this experiment two situations are compared. One in which the fish is swimming 15 centimeter above the electrodes, where all the settings are equal to the settings used in the previous experiment (shown in table 5.2). And another time, but now with the conductivity of the fish 100 times lower

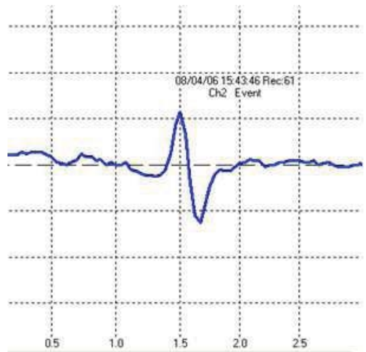


Figure 5.9: Measurement signal of a resistive fishcounter when a fish passes the counter (image taken from [10]).

instead of higher than the water (e.g. conductivity = 0.00005 S/m), where the other values are the same as in the previous simulation.

The assumption is that if the fish is less conductive than the water, the shape of the graph will be opposite to the shape of the graph with the conductivity higher. In figure 5.10 it is visible that indeed the shape of the lower conductivity is mainly the upside down variant of the case with the higher conductivity, with some differences. The amplitude is smaller. This is because when the resistance of the fish is a factor 100 higher or lower than the water resistance, the resistance between the measurement plates does not automatically change by the same factor.
This is caused by the water that is also conducting. The water and the fish can partly be seen as parallel resistors. If one of them increases or decreases by a factor 100, the resulting resistance will not change by a factor 100. This is also the case in the simulation, which causes the difference in signal amplitude.

Conclusions about the fish counter simulations

The simulations of a fish passing some strips create a graph similarly shaped to the graph created by a real fish counter. This indicates that the simulations are comparable to real world situations.
The simulations in the case were the fish conductivity was lower instead of higher than the water conductivity yielded a shape that was inverse to the shape of the graph with fish conductivity higher than the water conductivity.

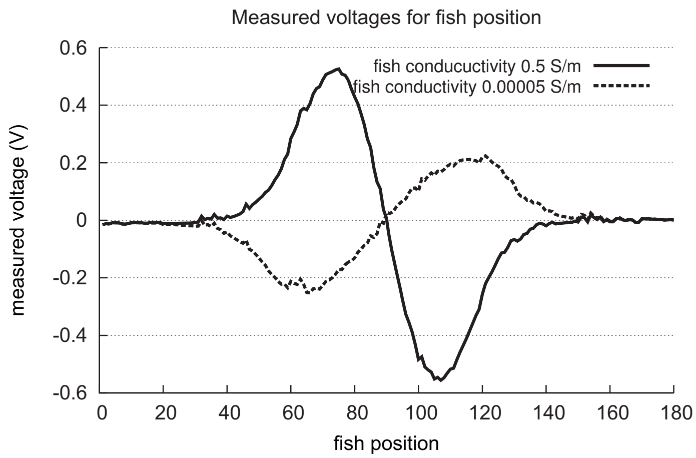


Figure 5.10: Measured voltages for the FEA experiment with different values for the conductivity of the fish.

5.3.3 Conclusions for resistive measurements

When measuring the resistance directly between two plates, the system is very sensitive to changes of the water resistance, which makes it difficult to be certain about a passing fish. A differential measurement setup can be used to determine fish even when the water conductivity changes, while being less sensitive to noise.

5.4 Tomography

5.4.1 Background

Tomography is an imaging method in which slices of the object to be imaged can be measured. When multiple slices are captured from an object (e.g. a fish) that moves through the measurement device, these slices can be put together in order to create an 3D image of the object.
One must keep in mind that the created slices and the created image does not necessarily show the same as the human eye should see. This chapter is mainly about resistive tomography, and therefore the simulations and measurements are carried out measuring the conductivity, and not the optical visibility. However, because the conductivity of a fish differs from the water conductivity, it should be possible to detect the shape of a fish when showing images representing the conductivities.
This section describes simulations and experiments that are carried out in order to find out if tomography can be used in practice for detecting fish and recognising the fish species.

5.4.2 Simulation to determine effects of electrode size

Introduction

When in a circular tube with large conductive plates measurements are carried out, the largest part of the current will probably not flow through the centre of the tube where the fish is, but through the shell of conductive plates.
In order to decrease the currents through the layer with conductors, the conductors can be made smaller. Unfortunately this will also reduce the area of contact between the plates and the water, which will possibly lower the sensitivity.
Because a wrongly chosen plate size can possibly give measurements not detecting a fish while measurements with another plate size can detect a fish simulations to find the optimal plate size are carried out.
The simulations are carried out using *femm 4.2*.

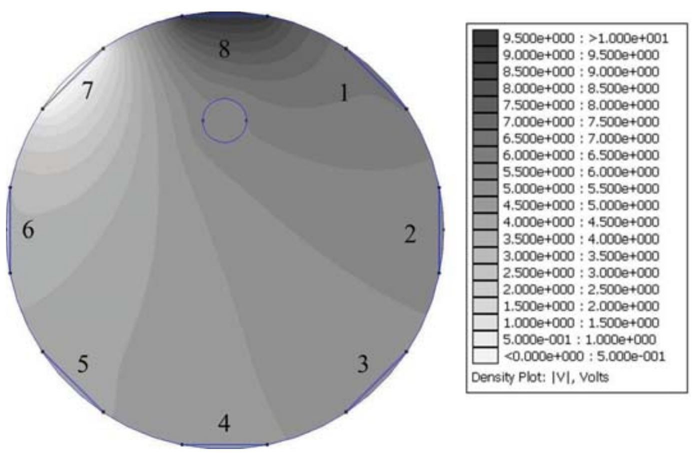


Figure 5.11: An overview of the tube as used in these simulations. The plate numbers are shown as used in the experiments.

The setup

In order to simulate this setup, the used materials (water, fish and copper plates) need to be assigned values for the conductivity and permittivity. The values as used in this setup are shown in table 5.3.

For water a conductivity of $0.005\,\mathrm{S\,m^{-1}}$ is chosen. This value is within the range that is usual for drinking water in the Netherlands ($30\,\mathrm{\mu S\,cm^{-1}}$ - $70\,\mathrm{\mu S\,cm^{-1}}$ [30]) and the usual values for electrical conductivity of riverine water ($30\,\mathrm{\mu S\,cm^{-1}}$ to $450\,\mathrm{\mu S\,cm^{-1}}$ according to Aquantic).
For fish a conductivity of $0.5\,\mathrm{S\,m^{-1}}$ is chosen. This value is chosen because the conductivity of fish is usually larger than the conductivity of water while a factor 100 difference between the water and fish conductivity seems to be possible.

Material	Conductivity(S/m)	Relative permittivity
Water	0.005	80
Fish	0.5	4
Copper plate	59600000	1

Table 5.3: The values for the different materials in the simulations in which the effect of the plate size is determined.

For the tube, a diameter of 50 centimetre is selected, because for real measurements a diameter of 30 to 50 centimetre is needed. A bigger tube has more water, which makes the influence of a present fish smaller, so the worst case is a tube with a 50 centimetre diameter.
For the fish diameter 5 cm is chosen. The position of the fish is chosen to be exactly between the centre and the top of the tube.

A voltage of 10 V is applied to a plate while another plate is connected to the ground. The other plates are electrically floating.
This measurement is carried out for each combination of plates, while the voltage on all the plates is measured. Therefore there are 28 combinations to connect the power supply to. For every combination, a simulation is carried out with, and one without fish.

These simulations are carried out for different sizes of the plates. The percentage as used in this report describes the percentage of the angle that is covered by a plate. If 8 plates are used, and the plate percentage is 50 %, then every plate has (seen from the centre of the tube) an angle of 22.5° (0.5*360/8).

The results

The results of the simulation are shown in figure 5.12. This graph shows only small differences for the different plate sizes, therefore it is not easy to say which of the plate sizes is the best.
During these experiments another difficulty with the simulations was also found. When the size of the mesh (the number of blocks that is calculated) changes, this has a large influence on the measured voltages. When the mesh size is made smaller (more smaller triangles), another plate size has the best results. The graphs in figure 5.13 show the differences for different mesh sizes. In the top figure it can be seen that for a small mesh size, it seems that a larger plate gives a bigger difference, while with a smaller mesh size as in the bottom figure, the plate size does have a smaller influence.
An example of the mesh sizes is shown in figure 5.14. This figure shows a small part of the tube (the wall of the tube and a piece of a plate) in combination with the mesh. The used mesh sizes are numerically represented in table 5.4.
Because the plate size seems to have only little effect, while the mesh size has a larger effect, it seems there are no plate sizes that are the 'best' in the range that is tested (25 %

- 85 %). Only the plate size of 25 % has a suspicious value at plate 7, and therefore is advised against, but the other values do not differ enough from each other to have a clear winner.

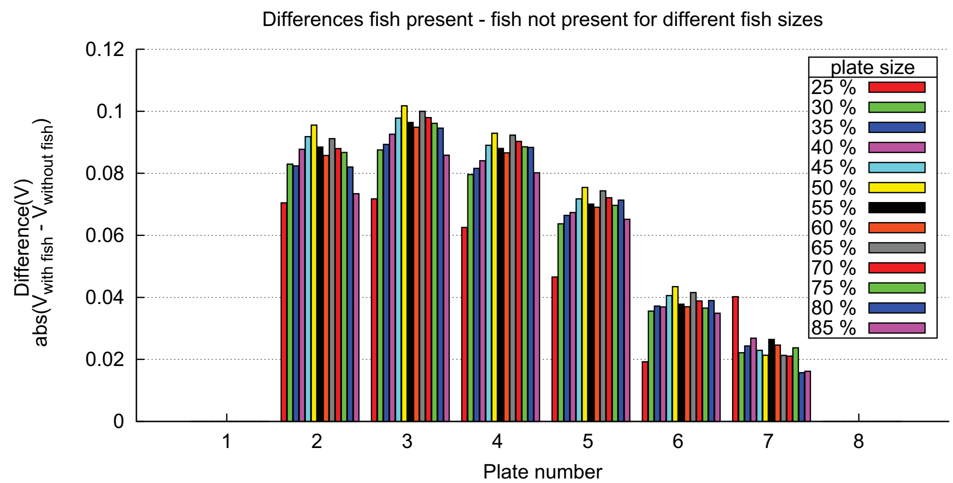


Figure 5.12: The differences in measured voltage with and without fish for different sizes of the plate. It can be seen that the differences do not clearly show a best plate size

Material	Higher mesh size	Lower mesh size
Copper	0.005	0.0005
Water (before the plate)	0.01	0.01
Water (behind the plate)	0.01	0.001
Fish	0.01	0.01

Table 5.4: The mesh sizes as used in the simulation for the different plate sizes.

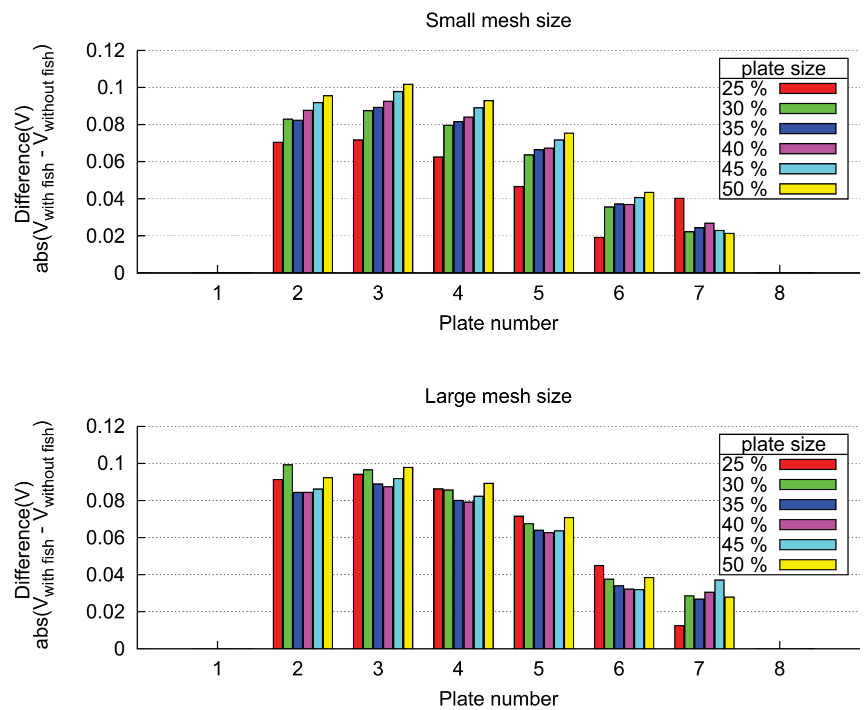


Figure 5.13: The differences in measured voltage with and without fish. A voltage of 10V is applied to plate 8, while plate 1 is connected to ground. Because these plates are actuated, on these plates the voltage does not change in presence of a fish. The different measurement results for the different mesh sizes show that the used mesh size has a large influence

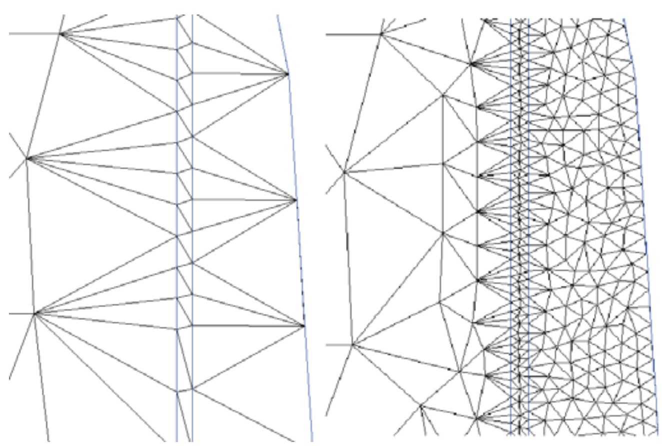


Figure 5.14: A very small part of one of the plates with the mesh shown. On the left side, there is a large mesh size (low mesh resolution), on the right side the mesh size is smaller (higher resolution).

Conclusions about the plate size simulations

This simulation shows that it is possible to detect fish, however, the measured voltages between the presence and absence of a fish are relatively small. So in practice the measurement will be relatively sensitive to small noise signals. The maximum difference is 0.1 V (3.9 V without fish, 3.8 V with fish). This is a difference of only 2.5 %.

The results of the FEA simulation are dependent on the used mesh size. Therefore it is difficult to determine the best plate size, because the small differences can be caused by the plate size, but also because of the mesh size. A smaller mesh size is preferable, but takes more time to simulate.
In the current situation the smallest practical mesh size has already taken almost a day to calculate the results for the different plate sizes. Using even smaller mesh sizes would be unpractical. Because the differences between the most measurement results are relatively small and only the 25 % plate size has a suspected measurement result at plate 7, there is not a very clear 'winner'. Because the 25 % plate size gives a different result than the other plate sizes, this size is advised against, however the other plate sizes do not have much differences. Therefore platesizes from 30 % to 85 % are advised.

5.4.3 Simulation to determine effects of fish size

Introduction

In order to use tomographic fish species recognition, detecting the size of a fish can be important. To see if there is a relation between the size of the fish, and the current flowing between two plates, experiments are carried out using the finite elements program *femm 4.2*.

Setup

Two different setups are used. In the first simulation the fish had a conductivity of $0.5\,\mathrm{S\,m^{-1}}$, and in the second $0.1\,\mathrm{S\,m^{-1}}$. The different conductivities are used because in real situations the conductivity of a fish is also not a constant. One of the plates has a voltage of 10 V applied, another plate is connected to ground. All other electrodes are (electrically) floating. The setup can be seen in figure 5.15, where also the plate numbers are indicated. Measurements are carried out for a voltage applied between plate:
1 and 7
1 and 8
4 and 8

For this simulation all the used materials need to have some values assigned to the different properties. The experiment is carried out twice, with different values for the fish conductivity. The values for the conductivity and dielectric constant for the plate, the water, and the fish are shown in table 5.5. There are also a lot of other properties

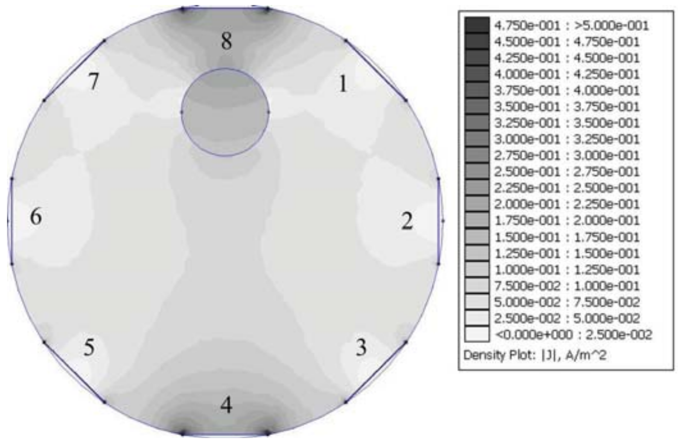


Figure 5.15: Results for a computer simulation of a fish in a tube. This figure shows the current density. In the simulation on this image a voltage of 10V is applied to plate 8 while plate 1 is connected to ground. The other plates are electrically floating.

that are used to create the setup. These are shown in table 5.6. In these simulations the fish is located between the top, and the centre of the tube.

Material	Conductivity(S/m)	Relative permittivity
Water	0.005	80
Fish (first test)	0.5	4
Fish (second test)	0.1	4
Copper plate	59600000	1

Table 5.5: Values for the material properties in the simulations for determining the effects of the fish size. There are simulations carried out with two different fish conductivities. Both are put in this table.

Property	value
Number op plates	8
width of each plate	0.098 m (9.8 cm)
Diameter of tube	0.5 m
Radius of fish	Variable (0 m–0.11 m)
Thickness of plates	0.001 m (1 mm)

Table 5.6: Other properties used in the simulation to determine the effect of the fish size.

Results

Figure 5.16 shows that when the radius of the fish increases, the current between the measurement electrodes also grows, but the larger the fish is, the faster it will grow

when the diameter of the fish is increased. This is probably for a large part caused by the changing area of the fish. When the diameter of the fish increases linearly, the area of the fish increases quadratically.
Therefore for the larger diameters of the fish, the current will increase faster than for smaller diameters.

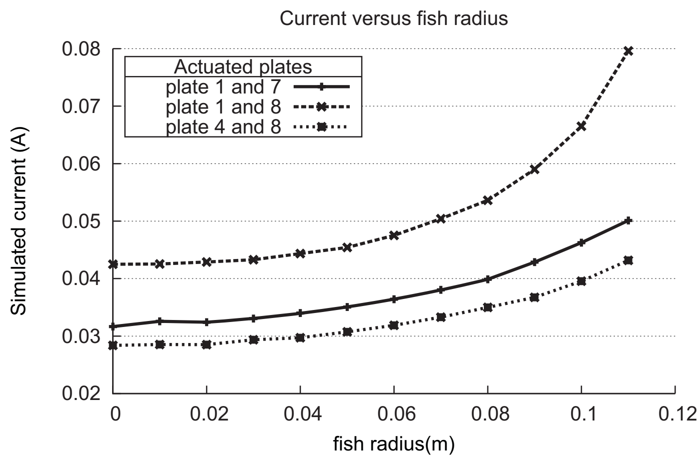


Figure 5.16: The radius of the fish compared to the current measured between two plates for a fish with a conductivity of 0.1 S/m. A voltage of 10V is applied between different plates.

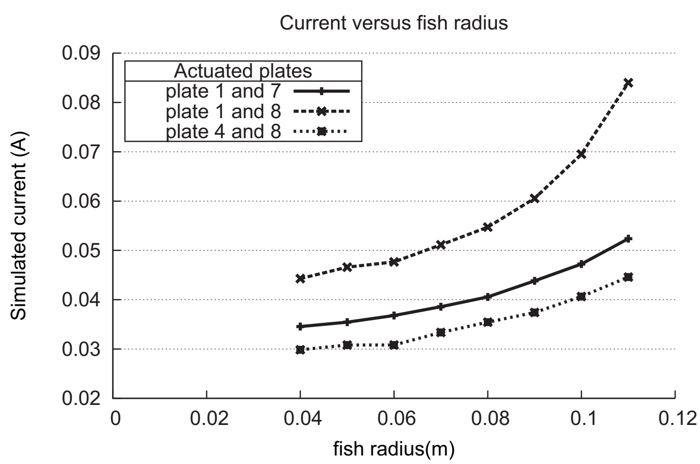


Figure 5.17: The radius of the fish compared to the current measured between two plates for a fish with a conductivity of 0.5 S/m. There are different combinations of plates used to put a voltage between.

When the experiment was carried out for a fish conductivity of $0.5\,\mathrm{S\,m^{-1}}$ it seems that the effect of the conductivity of the fish is not very large. This is probably because in this experiment the conductivity of the fish is 20(fish conductivity $0.1\,\mathrm{S\,m^{-1}}$), or 100 (fish conductivity $0.5\,\mathrm{S\,m^{-1}}$) times higher than the water conductivity. Because of this difference in conductivity between fish and water, the relatively small difference for conductivity between the two used fish conductivities is not very clearly visible in the graphs.

Conclusions about the fish size simulations

- The size of the fish has a large influence on the measured current through two plates when the fish is between them.
- For small fishes it is almost impossible to determine the size of the fish by measuring the conductivity
- For larger fishes it becomes possible to determine the size.
- The conductivity of the fish has a relatively small influence on the measured currents as long as the conductivity is much larger than the conductivity of the water.

5.4.4 Simulation to determine effect of fish position

Introduction

When tomography is used, it should be possible to detect the location of the fish in the tube. To see if it is possible to determine the fish position in the tube, this experiment simulated a fish at different positions in the tube. The experiments are carried out using the finite elements program femm 4.2.

setup

For this simulation a setup comparable to the setup in previous simulations, (where the effect of the fish size is determined, and where the size of the plates is determined) is used.
A voltage is applied between the different plates. For this experiment the voltage is applied between the plates:
1 and 8
2 and 8
3 and 8
1 and 7
2 and 7
3 and 7
1 and 2
These plates are chosen because the effects of the fish position is probably the largest when measuring on these plates.
There are two different measurements carried out. The current through the electrodes is measured. Besides the current, the voltage on a plate between the actuated plates is

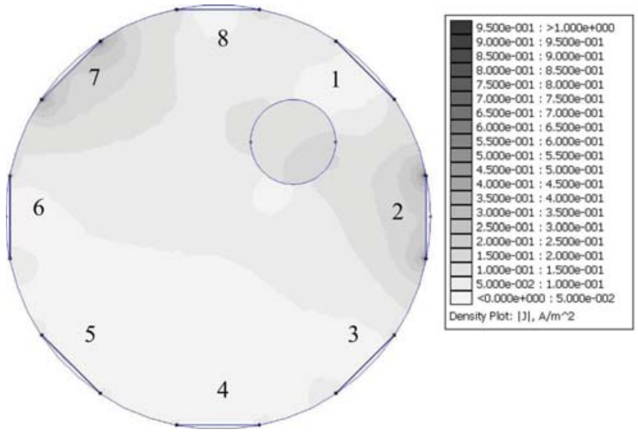


Figure 5.18: The results from a simulation where a fish is located between the centre of the tube and plate 1. A voltage is applied between plate 7 and plate 2. The results show the current density.

Material	Conductivity(S/m)	Relative permittivity
Water	0.005	80
Fish	0.1	4
Copper plate	59600000	1

Table 5.7: Values for the material properties (second test)

also measured. This is done because the resistive fish counter can detect fish, and uses a differential measurement method, therefore this differential measurement method is also tested in this experiment.

As in every simulation, some values need to be used for the different materials. Table 5.7 lists the properties of the used materials.

Results for circular changing fish position

There are simulations carried out for different positions of the fish. The fish is positioned at a constant distance of 12.5 cm from the centre of the tube, and the displaced is concentrically from plate 8 (0°) to plate 1 (45°). First the current through the plates was measured. In figure 5.19 it can be seen that the current does not depend very heavily on the position of the fish. Therefore it seems difficult to detect the fish position by measuring the current. (For this experiment a voltage of 10V is applied to a plate, the other plate is connected to ground)

When using a differential setup, and measuring the voltage at a plate between the actuating electrodes, it becomes better possible to detect the fish position. Figure 5.20 shows the results for this measurement. It can be clearly seen that with this differential measurement the position of a fish gives a huge effect on the measured voltage.

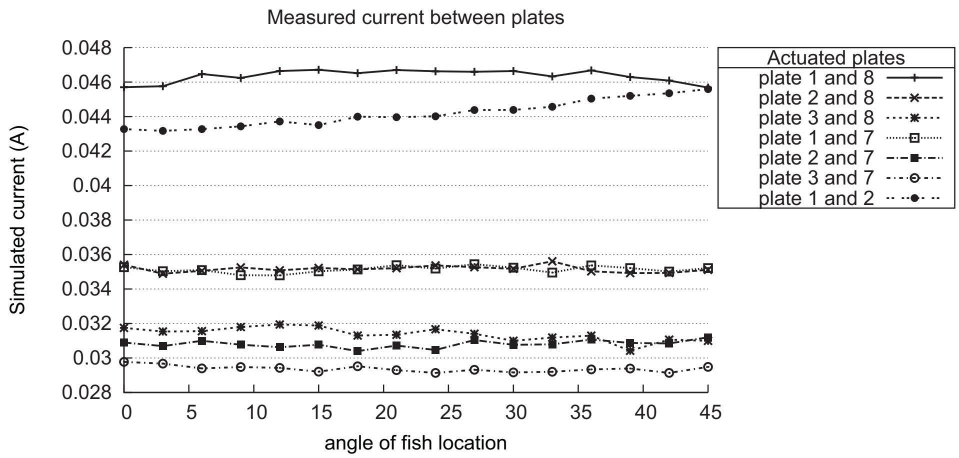


Figure 5.19: The currents at a voltage of 10 V applied between two plates. In this situation a voltage is applied between two plates, the current through these plates is measured. The position of the fish changes following a circular path, over 45 degree.

Therefore it is possible to detect the fish position using this method.

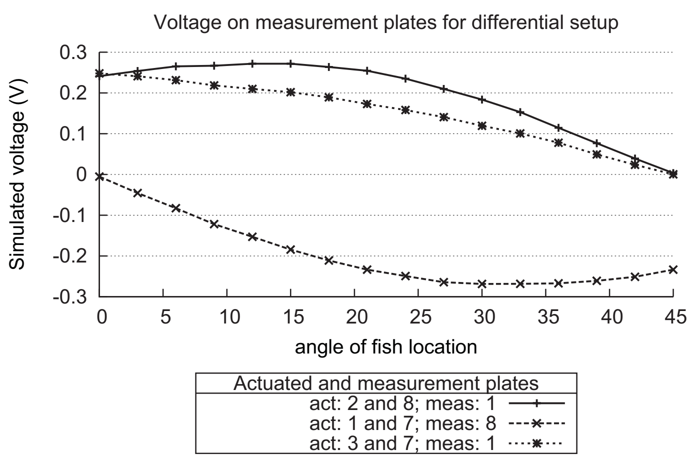


Figure 5.20: The voltage measured on a plate, when a voltage of +5 and a voltage of -5V is applied to the two adjacent plates for a circular changing position of the fish.

Results for vertical changing fish position

In another experiment with the same settings as in the previously described setup, the location of the fish was changed on the vertical axis between the centre of the tube, to the measurement electrode on top. Also in this case the current was first measured.

The results for the current measurements are shown in figure 5.21. In this case the current between plate 1 and plate 8 changes a little, while the other currents remain almost constant. Therefore it is almost impossible to detect the fish position by using a non-differential current measurement. For the linear case, also an experiment with a differential measurement setup is used. These results are shown in figure 5.22. In this figure it can be clearly seen that the effect of the fish position on the measured current is relatively large, and it is very likely that the fish position can be determined by this differential measurements.

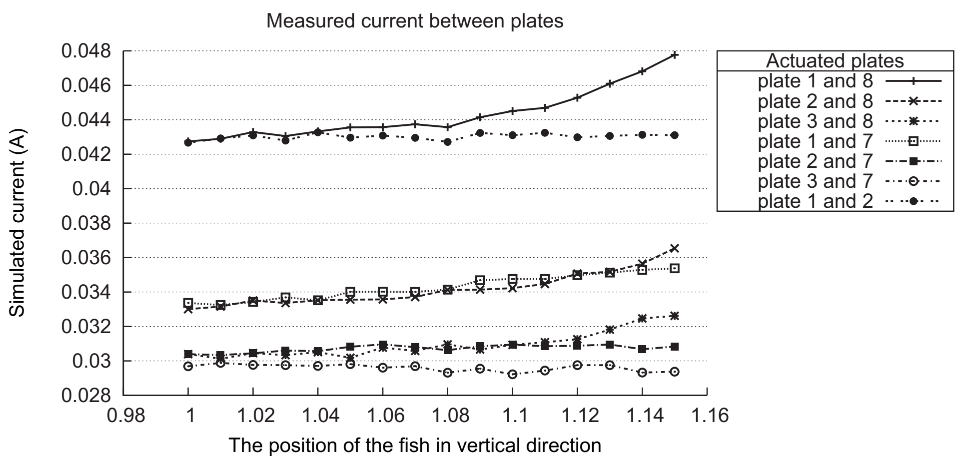


Figure 5.21: The measured currents when a voltage is applied between two plates. In this situation a voltage is applied between two plates, the current through these plates is measured. In this situation the position of the fish changes following a linear path between the centre of the tube, and the top plate.

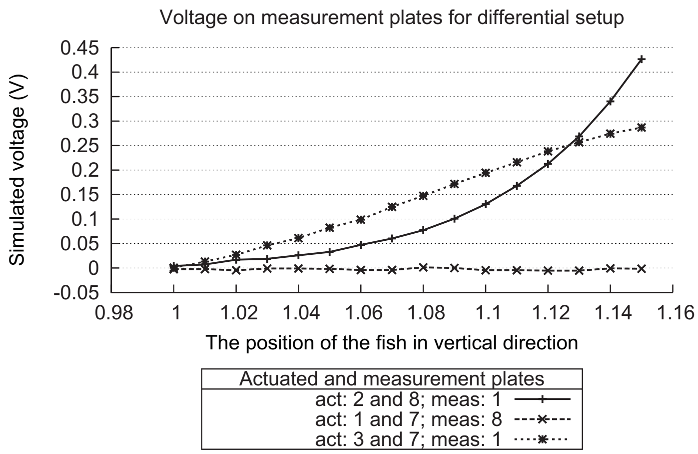


Figure 5.22: The voltage measured on a plate, when a voltage of +5 and a voltage of -5V is applied to two plates around this plate for a circular changing position of the fish.

Conclusions about the fish position simulations

When measuring the currents, the differences in fish position give only a very small difference in the measured current. Therefore it is difficult to detect the fish position based on a non-differential measurement of the current.
When a differential setup is used to detect the fish position, the changing fish position gives a rather large effect on the measured voltages. This indicates that it is possible to detect the position of a fish using differential measurements.

5.4.5 Experiments for electrical fish detection

Introduction

Because electrical fish detection is already used in practice, it should be possible to detect fish using this method. However, the information about the exact working, and the exact measured voltages is not available. In order to get more feeling about electrical fish detection, and in order to check if the simulations that are carried out and described in the previous sections are correct, experiments for tomographic measurements, a differential setup for a passing fish, and a conductivity measurement are carried out.

Setup

Setup of measurement tube For the measurement setup a PVC pipe with a diameter of 20 cm and a length of 63 cm is used. Four electrodes with a size of 6.1 cm $\times$ 6.1 cm $\times$ 0.5 mm are placed inside this tube.

The electrodes are placed in the centre (between top and bottom) to the walls inside the tube, located at 90° from each other, as can be seen in the left part of figure 5.23.

This tube is then placed inside a barrel for stability and to avoid problems when the pipe starts leaking for some reason. This can be seen in the right part of figure 5.23.

Figure 5.23: The tube with the electrodes as used for the experiment (left) with a closed bottom and placed inside a barrel (right)

Electrical setup Various measurements have been carried out. These measurements use the same tube, but the electrical part of the measurement setup is different. This section describes the electrical setup for the measurements.

Setup conductivity measurement In order to measure the conductivity between different plates, a 3 kHz sinusoidal voltage is applied to two opposite plates using an Agilent 33120A frequency generator. The current through these plates is measured using an Agilent 34401A multimeter. A schematic view of this setup is shown in figure 5.24.

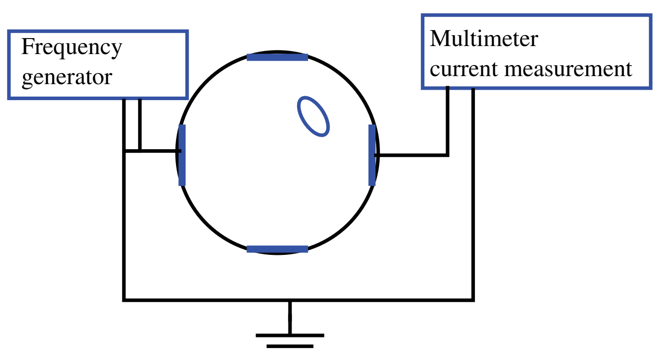


Figure 5.24: The measurement setup used for measuring the conductivity of the water.

Setup tomographic measurement In order to check if tomographic fish detection is a possibility, a measurement is carried out in which all the combinations of actuated and

measured plates are tried. To that end, a 3 kHz sinusoidal, 500 mV peak-peak voltage is applied to one of the plates, another plate is connected to the same signal, but in antiphase. The other two electrodes are then used to measure the voltage, using a lock-in amplifier (SR 830). The signal generation occurs by an Agilent 33120A frequency generator. The inverted signal is generated by applying the signal from the frequency generator to an OPA 2132 opamp. A schematic view of the measurement setup is shown in figure figure 5.25. In the situation shown in this image, the voltage is measured on the top plate, while the left plate is actuated with a sinusoidal signal, the right plate has the same signal in antiphase. In the real situation, the connected plates are cyclically changed until every combination of plates is measured. Therefore 24 measurements are carried out.
To approach a realistic situation, a dead mackerel of 20 centimetre length is placed between the plates.

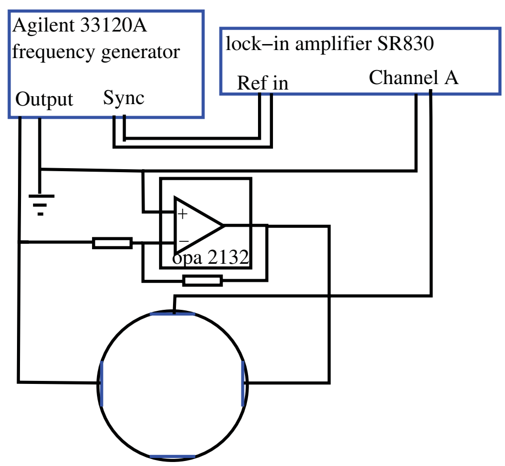


Figure 5.25: The measurement setup as used for the tomography experiments

Setup fish detection measurement In order to detect a fish, a 3 kHz signal is applied to one of the plates, while the same signal, in antiphase is applied to a plate opposite to this plate. A plate in between is then connected to the measurement device. The measurement setup is almost the same as the method for tomography described in the previous section. The only difference is that the measurement plates are not changed, but the fish passes through a set of fixed plates.
The fish is pulled through the plates, and hold in position during the measurements by some nylon rope.

Results

Conductivity In order to measure the conductivity of water, a 3 kHz sine voltage was applied on one of the plates while the plate opposite to the activated plate was connected to ground. The current through the plates was then measured. This same experiment is also carried out using a simulation. In this simulation the conductivity of the water was changed until the measured resistance in the simulation was approximately the same as the measured resistance in the real setup.

The measurement in the real setup was carried out by placing a sinusoidal voltage of 3 kHz at the two of the plates (using an Agilent 33120A function generator) , while measuring the current through the plates (using an Agilent 34401A multimeter).

Using this setup the measured resistance was approximately 400 Ω for both the drinking water and the water from the outside lake. When simulating with the same pipe diameter and the same plate size, a conductivity of 0.062 S m^{-1} gives a resistance of 400 Ω. Because the simulation only operates in the 2D plane, while the real measurement was carried out in a 3D plane, it is likely that in the real situation the conductivity will be lower, up to a factor 2, so the conductivity will be around 300 µS cm^{-1} to 600 µS cm^{-1}. The assumed conductivity was around 500 µS cm^{-1}, so this value seems to be in agreement.

Tomography For the tomography, a fish is placed in the tube, after which the voltage is measured for all possible combinations of actuated plates and measurement plates. Because all plates are connected to the signal in both phase and antiphase, half of the measurement results is independent, while the other half should be the inverse of the other signals. Therefore a check about the accuracy of the results is possible.
The measurement results in table 5.8 indicate that the values that should be inverse are almost the inverse. The small differences are up to approximately 0.35 mV in the case that the measured voltage was around 18 mV, so the difference is less than 2 %. This seems to be small differences, however for the lower voltages, a smaller voltage difference can have a larger difference in terms of percentage. The maximum difference is found to be around 9 %, here the measured voltages are approximately 2.2 mV and differ by 0.2 mV.
These differences can be caused by a lot of factors, such as noise effects, a not exactly -1 time amplification for the antiphase signal, a small measurement error, a little bit movement of the fish that is between the plates, or a readout error.
It is assumed that the differences in measured results are mostly caused by a small movement of the fish, since the fish was could move a little in all directions.

Lowering the fish in the water In this experiment the fish is lowered in the water in steps of 5 centimetre, after every step of lowering, the voltage is measured. The lowering of the fish can be seen in figure 5.26.

The differential measurement setup is shown in figure 5.27. When there is no fish present, the measured voltage will be approximately 0 V. This is because on the measurement plate, the two out of phase signals will compensate each other. When a fish is between the measurement plate and an actuated plate, the resistance between these plates will lower, while the resistance between the other actuated plate and the measurement plate is not changing. Therefore the measurement plate is more influenced

measure nr	antiphase plate	signal plate	measure plate	Voltage (mV)	Antiphase plate	signal plate	measure plate	Voltage (mV)
1	Top	Right	Bottom	23.06	Right	Top	Bottom	-22.96
2	Top	Right	Left	-17.03	Right	Top	Left	17.13
3	Top	Bottom	Right	-2.311	Bottom	Top	Right	2.115
4	Top	Bottom	Left	-1.2807	Bottom	Top	Left	1.33
5	Top	Left	Right	-22.42	Left	Top	Right	22.23
6	Top	Left	Bottom	18.07	Left	Top	Bottom	-18.404
7	Right	Bottom	Top	-25.33	Bottom	Right	Top	25.3
8	Right	Bottom	Left	15.62	Bottom	Right	Left	-15.755
9	Right	Left	Top	-5.32	Left	Right	Top	5.346
10	Right	Left	Bottom	-4.25	Left	Right	Bottom	4.25
11	Bottom	Left	Top	19.4	Left	Bottom	Top	-19.365
12	Bottom	Left	Right	-19.99	Left	Bottom	Right	20.06

Table 5.8: The measured voltages for a tomographic measurement. Clearly, the measurements give almost the same, but inverted results when the actuated electrodes are swapped.

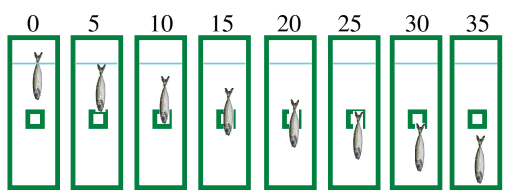


Figure 5.26: The fish at different heights in the tube as used for the experiment. Above the tube the height of the fish (in cm) as used in the graphs is indicated.

by the plate close to a fish, resulting in a voltage unequal to zero. When the fish is moved from above to the bottom through the tube as shown in figure 5.27, the voltages changes as indicated in figure 5.28. The passing fish can clearly be detected. In the first measurement series, the signal of the fish seems to be less clear than in the second and third series. This is because the fish was in another pose in this measurement. The pose of the fish for the measurements can be seen on the right side in this graph.

Simulations

In order to verify the results of the measurements, simulations are carried out. In the experiments the fish was posed in two directions. These directions are also simulated. In the left part of figure 5.29 the $+45^\circ$ pose of the fish is shown, and in the right part, the -45° pose.

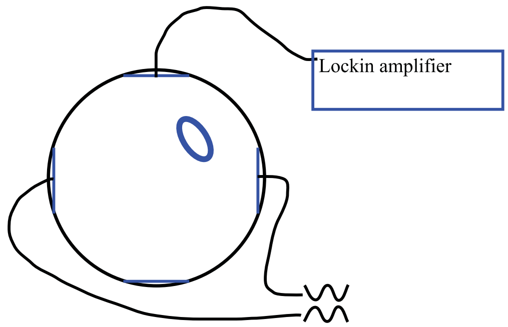


Figure 5.27: A global view of the measurement setup. The plates on the left and right side are connected to a sinusoidal wave with 180° phase difference. The voltage is measured on the third plate using a lock-in amplifier.

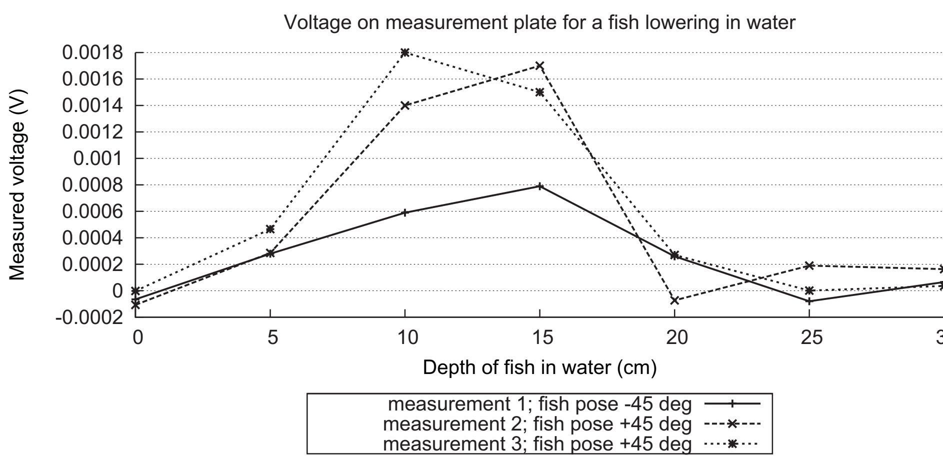


Figure 5.28: Measured voltage for a fish that is lowered into water. The measurement is carried out three times. Once with the fish in -45 degree pose, and twice with +45 degree pose (see figure 5.29). It can be seen that the fish in the -45 degree pose influences the measured voltage less than the +45 degree pose.

Each time a positive voltage was applied to one of the plates, while a negative voltage was applied to another plate. The other two plates were then used to measure the voltage. This results in 24 different measurements, of which 12 are the inverse of the other 12. Therefore only twelve of the measured voltages are shown in the graphs. The other twelve simulated voltages are the inverse of the shown voltages.

Setup for the simulation In the setup of this simulation, the tube diameter is set to 20 cm. The fish is assumed to be 4 cm×2.5 cm, which is approximately the same as the fish in the experiment. There are 4 plates in the tube with a width of 6.1 cm and a thickness of 0.5 cm, just as in the real measurement. The applied voltage on the plates

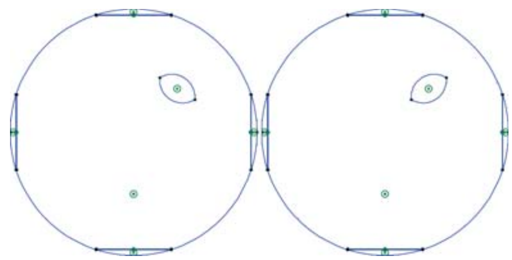


Figure 5.29: The two positions used for the fish. The left position is +45 degree. the right position is -45 degree

Object	Conductivity (S/m)	Relative permeability
Fish	0.1	4
Metal plate	59600000	1
Water	0.005	80

Table 5.9: The values used for the simulation

is a sinusoidal voltage at 3 kHz, with a peak voltage of 500 mV. The plate with the negative voltage has the same signal, but with 180° phase difference (inverted). The conductivities and permeabilities are shown in table 5.9.

Results for the simulation The measurement number on the x-axis of the graphs indicates which electrodes are connected to the in phase signal, the anti-phase signal, and which electrode is the measurement electrode. Using table 5.8 it is possible to find out which electrodes correspond to which measurement number.

The simulation is carried out for different mesh sizes. These different mesh sizes gave considerably different results. The measured voltages for the finest mesh are shown in figure 5.30. In this figure it can be seen that there are small differences between the fish position. But for larger mesh sizes, the results seem to be different, as can be seen in figure 5.31. Even the sign of the difference between the $+45°$ and the $-45°$ pose changes when the mesh size is changed. This means that with 4 plates the simulation can give no clear view of the fish pose, so probably in the real measurements the correct fish pose can not be reconstructed with only four plates. Therefore based on the simulations the experimental values can not be examined in very high detail. It was not possible to use a smaller mesh size, because for mesh sizes smaller than 0.0008, the finite elements program *femm* reported errors.

Comparison experiment vs simulation

When comparing results from the simulation with the measurements from the real setup, the values are relatively comparable. However, at first sight the situation without fish also looks almost the same. This is because in some measurements water has a larger influence than the fish. The effect of the fish can be seen most clearly in the dif-

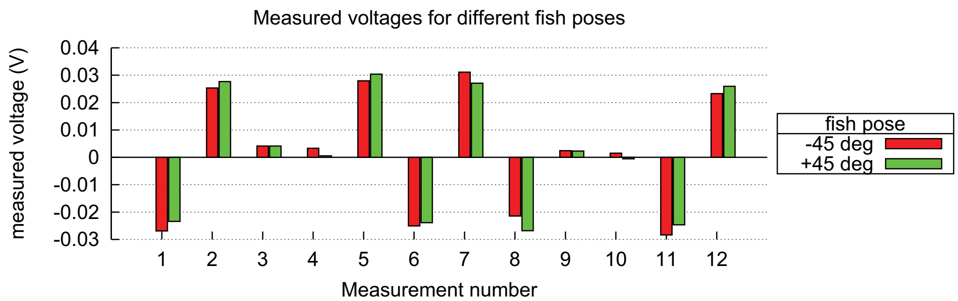


Figure 5.30: The measured voltages for a tomography simulation measurement for two different fish poses

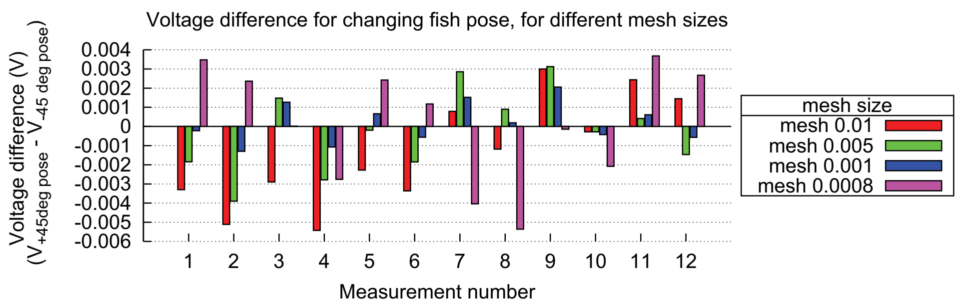


Figure 5.31: The differences between the fish poses -45 end +45 degree. It can be seen that the sign of the differences is not always the same.

ferential measurements (3, 4, 9, 10), where the situation without fish gives a value of 0 volt. For all plate combinations, there are small differences between the simulation and measurement. This is probably because the location and size of the fish in the simulation is not exactly the same as in the real situation. This is partly caused by the fact that in the simulation the fish is modelled as an oval shape with the same diameter from top to bottom, while in reality the fish is not exactly oval and has not the same diameter from the top to the bottom. Another problem is that the fish used in this experiment has a little curving, which could not be simulated because the simulation program was 2D.

That a fish is present can be seen most clearly from the differential measurements. This is done by activating two outer electrodes, and measuring an electrode in between (measurement 3, 4, 9, and 10). In these measurements a voltage is read, which indicates that there should be an object with a conductivity differing from the water.

Conclusions about the experiments

The experiments have shown that it is possible to detect a fish using three electrodes in a tube. The experiments have also shown that when using four electrodes, and the fish

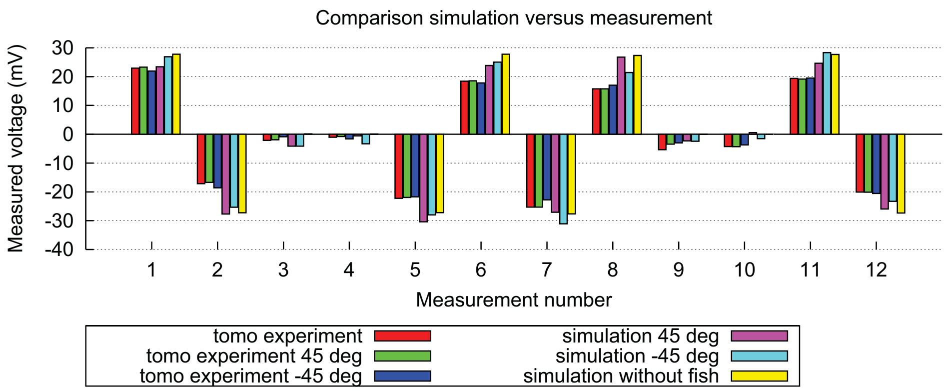


Figure 5.32: The voltages for the different plates in simulation and real measurements

is not in the centre of the tube, it is possible to detect in which quadrant of the tube the fish is.
The signals from the differential measurements give the most information about the fish location, however the signals are relatively small. Therefore an accurate measurement method which is insensitive to noise, such as an lock-in amplifier is recommended.
The different measurements for the different poses of the fish are very small, therefore it is unlikely that even smaller details than the fish pose (such as fins or stickles) can be detected properly. Therefore fish species recognition using electrical resistive tomography is unlikely to give reliable results.
When comparing the results from the simulation with the experimental data, it was found difficult to get the exact same data. This is because *femm* is a program that uses a 2D world, while in the real situation the world is three-dimensional. Because the fish is represented by an elliptic cylinder, and not the exact shape of the fish, which diameter changes from top to bottom, the results are not exactly equal.

5.4.6 Conclusions for tomography

Tomography can be used to get information about the shape of a fish, however the measurements needs to be very accurate, and signals are small, the signal to noise ration needs to be high. Tomography is functional in laboratory and medical setups, but for a fish counter some more pollution can be expected which makes the measurements less accurate. Therefore tomography is probably not accurate enough for species recognition.
For tomography there are a lot of different reconstruction algorithms. Because tomography seems to be not a good manner for recognising fish species, the reconstruction algorithms are not investigated extensively. If tomography is going to be used for fish detection, it is advised to use a reconstruction algorithm that does not take much processing power.

5.5 Conclusions about electrical measurements

Based on the simulations and experiments that are carried out, and described in this chapter, the next conclusions can be drawn.
The water has both a permittivity, and a conductivity. Because the conductivity is not a constant, but changes, it is very difficult to measure the permittivity accurately. Therefore capacitive measurements for detecting fish, or fish species are not recommended.
When the current is measured, a fish passing a sensor gives only a very small difference in measured current. Since there will also be some noise caused by changing water conductivity, and other noise sources present, it is almost impossible to detect fish using non-differential current measurements. Measurement using an differential setup are less influenced by noise caused by changing water conductivities. Therefore for fish detection a differential measurement setup is recommended. However, for fish species recognition a highly detailed image of the fish is necessary. The simulations and experiments have shown that it is difficult to get measurements that are accurate enough to precisely detect the fish pose. When it is already difficult to detect the fish pose, it is almost impossible to detect the exact shape of a fish, making it possible to detect for example stickles. Therefore it is not recommended to use tomographic measurements for recognising fish species.

6 Conclusions and recommendations

6.1 Conclusions

The comparison of different methods has shown that electrical and optical measurements have the best prospectives to detect and recognise fish species underwater. These methods have been further investigated.

The experiments and simulations that were carried out in order to detect fish by capacitance indicate that it is not feasible to measure the capacitance accurately without influence of the resistivity at 'lower frequencies' ($<$ 100 MHz). Therefore it is difficult and unpractical to detect fish by using capacitive measurements.
Experiments using resistive measurements, have indicated that it is difficult to detect fish using non differential methods. Using a differential measurement, it becomes possible to clearly detect fish.
Because species recognition needs more information about the fish than can be captured by one differential measurement, tomography was tested. The measurements have indicated that very precise, and high resolution measurements are necessary to get enough information to recognise fish species.

Optical fish species recognition is also difficult because the water is turbid. To get the best quality of images, which is necessary for fish species recognition, it is important to get a nicely illuminated area. Experiments in a real fish passage have shown that when a light source is placed close to a camera, the image can get overexposed by reflections from particles that are close to the camera. When the water is very turbid, it is advised to keep the path of the light through the water as short as possible, by placing a light source in front of the camera. This has as advantage that the contrast between a fish and no fish is relatively high, because a fish blocks almost all light, while water blocks less of the light.
Laboratory experiments have shown that it is possible to get an image with enough detail for detecting single prickles when looking through a layer of almost 40 centimetre water.

6.2 Recommendations

Optical

Further investigation in the placement of a light source for camera measurements is recommended. It was already shown that a light source close to the camera gives an overexposed image, while a light source opposite to the camera should make it possible to detect the silhouette of a fish. It is recommended to investigate the effects of a light source at the side of the camera, but with some distance from the camera (e.g. above or below the camera). This can be done by placing an object under 30-50 centimetre of water, and check the sharpness of the edges for different positions of the light sources. It is also advised to use different sources of water, to deal with different turbidities.
When a camera setup is built with proper illumination, it is advised to confirm that this setup works for different water turbidities. In this report, the measurements are only carried out with water taken from a pond near the Hogenkamp building of the University of Twente, it is advised to also test if the images are of enough quality when water from another source, for example some rivers is used.
Another important step to creating a fish recognition is experimenting in the actual fish recognition. Several algorithms are available. It is recommended to test some of these algorithms with images from a fish in turbid water.

Electrical

It is also recommended to further investigate the possibilities of fish species recognition by using tomographic measurements. It is unlikely that the specific fish species can be determined, because detecting small details like prickles will be almost impossible. However some basic fish species classification can be done based on the size and and thickness of the fish.
It is recommended to further investigate tomographic methods with a higher resolution by using more electrodes. An experiment with multiple electrodes is actually planned to do as a summer project for Witteveen+Bos by Mark Wijtvliet. Also other ideas of Mark Wijtvliet for fish detection will be investigated.
Another aspect that needs to be reckoned with is the fact that some sludge can stay on the electrodes. In the setup in Roermond the electrical measurements gave little result caused by sludge that stayed on the electrodes, diminishing the contact between the electrode and the water. It is advised to find ways to prevent the sludge to stay on the electrodes, for example by a smooth surface with fast streaming water, where the water rinses the electrodes continuously.

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