FLAW DETECTION IN CONCRETE
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PRELIMINARY RESEARCH

BACKGROUND

A common fault in concrete structures is delamination. When reinforcement materials in the concrete corrode, their volume increases. This results in a stress on the concrete that eventually exceeds the tensile stress of the concrete causing separation of the concrete above and below the reinforcement bars. These faults can cause various types of problems, such as potholes in bridges.

Through the years, common techniques for locating delamination in concrete surfaces have been either knocking the concrete lightly with a hammer or rattling a chain on the surface and listen for a hollow sound. These methods have proved effective but when dealing with larger areas it goes without saying that they might not be the most time effective. To increase efficiency in locating faults like delamination in large concrete surfaces, there have been developed several methods, such as using ultrasound, infrared light or radar signals to detect faults. These techniques are referred to as non-destructive evaluation techniques (NDE) and have proved effective in this field. Using ultrasound, the echo can be used to locate faults, and the same method can be used with radar signals. By heating and cooling the surface infrared, cameras can be used to find faults since delaminated areas heat and cool at different rates than non-faulty areas.

The main focus of this project is to design a mechanism that is able to scan the concrete surfaces of tunnels used for cooling in nuclear power plants. These tunnels are normally taken out of operation for a certain period each year to clean the surfaces. This period could then be used to carry out these measurements. The measurements can be done either while the tunnels are empty or while they are filled with water. Depending on which measurement approach will be taken, appropriate measurement techniques will be researched, evaluated and the most suitable one chosen.

REQUIREMENTS AND LIMITATIONS

This product is needed to ensure the structural integrity of concrete in tunnels. It could also prove useful in many other scenarios, such as examining asphalt for faults. The following lists known limitations and requirements for the project.

- To get the most correct reading the sensor must be in a 90 degree angle to the surface.
- We got two different sensors, one that needs to be in contact with the surface and one that doesn’t need to be in contact to do the reading. If we choose the sensor that doesn’t need contact then we must do the measurement in water. There are also a number of other sensors on the market which could be used.
- If the robot discovers a crack, we need to know where it is. Therefore it’s important to have a good positioning system.
- The robot must be able to store or transfer the data. The tunnels can be up to 200 meters long and it would be difficult to use a 200 meter cable.
- The equipment must be easy to use and require a minimum of manual work.
- The amount of time that the plant is out of operation is limited.
- No attempts will be made to develop new measurement instruments.
- Functionality will be prioritized over costs.

GOAL AND EXPECTED RESULT

The goal is to come up with interesting solutions and to choose and develop a concept that could work in reality. The expected result of the project is a theoretical report.
DISSEMINATION OF RESULTS
To present the result a written report has been made. There will also be an approximately 20 minute long oral presentation.

METHODOLOGY
Several different methods will be used to solve the problem, mainly literature studies and studies of already existing products but also interviews and some brainstorming at the early stage to come up with ideas.

PROJECT ORGANIZATION
The project is carried out with students from mechanical engineering and electrical engineering in collaboration with Technical Geology, as it is related to current research projects there, with supervision from Peter Ulriksen. The students from mechanical engineering are Tove Mattsson, Michael Lennartsson, and Sofie Lang and from electrical engineering is Hjalti Kristinsson.

PROJECT SCHEDULING
Milestones
- Deadline for report 1, 2 March (week 7, sp 1)
- Deadline for full report, 1 May (week 4, sp 2)
- Deadline for full corrected report, 11 May (week 6, sp 2)
- Oral presentation, 11-13 May (week 6, sp 2)

Gates
- Brainstorming, week 1, sp 2
- Evaluation and choosing concept, week 2, sp 2
- Concept Development, week 4, sp 2

<table>
<thead>
<tr>
<th>Project plan</th>
<th>Sp 1</th>
<th>Sp 2</th>
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<tbody>
<tr>
<td>Deadline</td>
<td>w 6 w 7</td>
<td>w 1 w 2 w 3 w 4 w 5 w 6</td>
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<td>Report 1</td>
<td>2 March</td>
<td></td>
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<tr>
<td>Brainstorming</td>
<td></td>
<td></td>
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<tr>
<td>Evaluation</td>
<td></td>
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<tr>
<td>Choosing Concept</td>
<td></td>
<td></td>
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<tr>
<td>Concept Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing Report 2</td>
<td>1 May</td>
<td></td>
</tr>
<tr>
<td>Correcting Report 2</td>
<td>11 May</td>
<td></td>
</tr>
<tr>
<td>Oral Presentation</td>
<td>11-13 May</td>
<td></td>
</tr>
</tbody>
</table>
PRODUCT DEVELOPMENT

GATHERING OF INFORMATION

Information regarding what types of sensors are applicable for detecting flaws, such as cracks or delamination, in the concrete was gathered both on the internet as well and our meetings with Peter Ulriksen. After searching the internet for information relevant to the product it is evident that flaw detection in concrete and asphalt is an active research area. The working principles of sensors most suitable for this product are described in short in the following sections.

ULTRASONIC SENSORS

Ultrasonic sensors can be used in a wide variety of applications, including common applications such as proximity sensing and object detection. The working principle of these sensors is that an ultrasonic sound signal is emitted and then the time until an echo is received is measured. These sensors can be used to analyze concrete areas by altering the working principle slightly. Instead of emitting a signal of constant frequency it sweeps a certain frequency range, for example 5 kHz to 5 MHz By applying FFT (Fast Fourier Transform) on the echo any discontinuities indicate an interface such as concrete-to-air or concrete-to-sub-grade.

To be able to apply this method to detect flaws such as delamination in the concrete the sensor either must be in direct contact with the surface of the concrete or be submerged in water. For the product in question it is easiest to use the excellent conductivity of water rather than establishing direct contact. An alternative to submerging the entire product in water is to use a beam of water to transfer the acoustic signal. This can be done by creating a laminar water beam and emit the signals into this beam.

RADAR SENSORS

With the help of a GPR transducer (ground penetrating radar), electromagnetic waves are used to image the structure of concrete. Typically frequencies ranging from a couple of hundred MHz to several GHz are used. By measuring the time it takes for the signal to travel from the emitter and “echo” back to the receiver changes in the structure can be detected. Corroded rebar and delamination will be detected as areas of low propagation velocity. This is mainly due to the higher dielectric properties from infiltrated water and chlorides. A lot of different companies have information on this kind of technique and claim that void and variations in the concrete matrix can be easily detected. Some recommend using an array of closely spaced antennas to gather data from a larger area in one pass. Most research and projects that have been carried out on concrete testing with GPR concern bridges, highways and pavements in concrete. The ones so far found states that using GPR is quicker and gives more detailed data than most traditional methods e.g. checking the sound by rattling a chain on the surface of the structure. The main drawback as compared to the use of mechanical waves is that GPR gives less detailed data. If multiple sensors are to be used simultaneously some sort of imaging algorithm must be used to account for the differences between individual sensors even if careful calibration is done. The radar emitters and receivers don’t necessarily have to be in contact with the surface.

1 (Malå Geoscience)
2 (Digital Concrete Imaging)
3 (3d-Radar AS)
4 (Geophysical Survey Systems Inc)
5 (Penetradar Corporation)
6 (US Department of Transportation, Highway Administration)
7 (Transportation Research Board)
MECHANICAL SENSORS

A unit that sends out ultrasonic pulses through an array of transducers can be used to detect delamination in concrete. By analyzing the echo, 2D or 3D images will be presented, reflecting the internal properties of the concrete. Each contact point is spring-loaded which allows measurements on uneven surfaces. There is no need for any preparation of the surface or need to use contact liquids to establish a good contact with the surface. The sensors can’t be dragged between the different measurement points but must be lifted when positioning since the mechanical waves are transversal, parallel to the surface. The device is polarized which means that measurements are required in two directions. 

BRAINSTORMING

The group met on two occasions to brainstorm for all possible and impossible ways to solve the task. The results from these sessions are the concepts described in the following sections.

EXPANSION RIG

This implementation is based on the method of mounting an acoustic flaw detector on a conveyor belt. To be able to use this mechanism on areas of variable widths, these conveyor belts will be expandable. The rig consists of four of these conveyor belts mounted in a rectangle that can then adapt to the dimensions of the tunnel to be inspected. The conveyor structure will be mounted on a platform with motor driven wheels, as well as controllable suspension in order to move the bottom conveyor from the ground when not measuring. Since the conveyors are expandable a proximity sensor will indicate when the acoustic sensor has reached either end. The motor controllers for the conveyors will give the position of the device on the conveyor and the controllers for the driving motors will give position along the tunnel. Together these two will give a very good positioning and the collected data could be used to construct a 3-D view of the tunnel.

MULTIPLE SENSORS

Four bars will be attached to a vehicle, two vertical and two horizontal. The two horizontal bars will cover the roof and the floor while the vertical will cover the walls. The side bars should be approximately 3 meters long so that they cover the whole wall on the lowest place. Then the side sensors will cover the lower parts of the wall when driving in one direction. By raising the bars to follow the structure of the roof the upper parts will be covered while driving back. The horizontal bar should be 2 meters. Sensors will be placed with a distance of 0.5 meters. That will require 7 sensors each on the vertical bars and 5 sensors each on the horizontal bars, a total of 24 sensors.

To reduce the number of sensors, one of the horizontal bars could be removed. Instead, the floor could be scanned in one direction and the bars moves to scan the roof in the other. Sensors would in this way be reduced to a number of 19.

The number of sensors could be reduced even more by removing one of the side bars too. Then the vehicle would have to drive four turns in the tunnel. This results in 12 sensors.

---

(Betontest)
Bars should easily be attached to and removed from a vehicle. All measurements will be done when the tunnel is empty of water. The model contains a great number of sensors but the problem of moving the sensors is solved.

**THE TILTING MODEL**

The tilting model is based on the same idea as the expansion rig but without the problem of having to expand the sides. The difference in dimension will be considered by tilting the rig.

![Figure 2: Tilting model](image)

**FLEXIBLE ROBOT**

One solution could be a vehicle with one or several arms which can put a sensor in the right places. This idea would result in a mechanism with a control program similar to that of an industrial robot but looking more like a cherry picker. With the help of either force feedback or the use of vacuum creating pumps, mechanical sensors could be applied on the walls with the right amount of pressure. To use mechanical waves that give very detailed data would thus be possible. The robot would also be comparatively small when it is not in use since it could “fold” itself together as no huge frame is required. This structure is highly flexible but the demand for programming and computing power will be huge. It will also be comparatively slow.

**RAILS IN CORNERS**

Robust construction with two arms in a 90 degree angle is put on rails placed in the corners. Moveable detectors slide back and forth on the arms as the equipment moves along the tunnel. The equipment would be manually moved from one set of rails to another. This construction could be used with any kind of sensor depending on how quickly the measurements must be made. It will be very easy to measure the position of the equipment as it is on rails. The distance to the wall is constant which makes placement of the detectors considerably easier. Obviously there are many other solutions with rails that could be used. The described equipment is but one to exemplify one of our options. The biggest drawback of this method is that it requires permanent alteration of the tunnel wall.

![Figure 3: Rails in corners](image)
**Submarine**

One of the greatest advantages to use a submarine to position the sensor is that the sensor doesn’t need to be in contact with the walls of the tunnel. The submarine is supposed to travel in the tunnels in circles and scan the walls at a certain height. When the submarine has finished one lap it will adjust the height and continue around the tunnel. The same principal is used on the ceiling and the floor. Since the sensor is able to do the measurements up to a meter from the wall there is an opportunity to do two measurements the same lap and then move the submarine out from the wall and the floor at the same time in a 45 degree angle.

One big problem is that it’s difficult to know the position of the submarine in the tunnel. If the sensors discover a crack in the concrete and it’s impossible to locate it then it’s useless. To solve this problem, supersonic sound sensors will be placed in the tunnel to triangulate the position of the submarine. To determine the distance to the walls the submarine will use laser.

**Climbing robot**

There are a few different alternatives that could be suitable for making a climbing robot. The ideas here could also be used to adhere a sensor to a surface if one wants to use mechanical waves. To use electrostatic forces to make a robot able to climb is not new, it has been done and that robot was able to carry over 30 kg. It might also be possible to scale this up. That is at least a possible option. Climbing robots using microscopic fibres like geckos have also been developed. These robots are however sensitive to dust and moisture. It might also be possible to somehow use vacuum creating pumps to maintain a robot on the wall. This however seems more complicated and might be better suited for getting the right pressure against the wall once the sensor is in place.³

**The ideal sensor**

It is apparent that the choice of device to move the sensor is highly interconnected with the choice of sensor. The simplest possible construction would be obtained by the use of a direction and distance independent sensor. A small cart with a motor and a detector sticking out behind it that can be rotated to measure up, down and to the sides could be used. Or something similar to the submarine with the control in vertical direction being greatly simplified as it could stay on a constant depth. However a detector which can be placed at any distance from the wall and is not dependent on a 90 degree angle is hard to find. At least we have not succeeded this far.

³ (Graham-Rowe, 2008)
Criteria for evaluation of concepts

Various factors have to be taken into consideration when choosing an idea. The following table describes the various aspects that are used to evaluate the ideas. All aspects will be graded on a scale of 1 to 5 and then multiplied by the weighing factor specified in the following table.

<table>
<thead>
<tr>
<th>Aspect ID</th>
<th>Aspect Name</th>
<th>Details</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Positioning</td>
<td>How good is the positioning system of the concept? Higher grade indicates more accurate positioning.</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>Data collection</td>
<td>How is data collection, storage and analysis handled in the concept? This refers to how many measurements are made, i.e. distance between measurements. Higher grade indicates more measurement points.</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>Data processing</td>
<td>How is measurement data stored and whether the analysis is done in real-time or after the entire sweep has been performed? A higher grade indicates more real-time handling</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>Transportability</td>
<td>How easy is the transportation of the concept device? Refers to both size and weight. A higher grade indicates that a concept is easy to transport.</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>Probable sweep time</td>
<td>How fast can the concept operate? A higher grade indicates a faster sweep.</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>Degree of complexity</td>
<td>How complex is the concept? Does it require a specialist on location? A higher grade indicates a simpler concept.</td>
<td>2</td>
</tr>
<tr>
<td>G</td>
<td>Price</td>
<td>Is the material for the concept device expensive? A higher grade indicates a lower price</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>Automation</td>
<td>How much manual work is needed to perform a sweep with the concept? A higher grade indicates less manual work.</td>
<td>2</td>
</tr>
<tr>
<td>I</td>
<td>Alteration to tunnel</td>
<td>Does the concept require any permanent alteration to the tunnel to operate? A higher grade indicates no or small changes.</td>
<td>3</td>
</tr>
<tr>
<td>J</td>
<td>Setup time</td>
<td>How much time does it take to set up the equipment before a sweep can be performed? A higher grade indicates less time needed.</td>
<td>2</td>
</tr>
<tr>
<td>K</td>
<td>Flexibility</td>
<td>How sensitive is the concept device to tunnels of various height and widths? A higher grade indicates less sensitivity</td>
<td>2</td>
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</table>

Table 1: Aspects used to evaluate ideas
# Evaluation of Concepts

<table>
<thead>
<tr>
<th>Concept</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>Total</th>
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<td>Expansion rig</td>
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<td>12</td>
<td>12</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>15</td>
<td>8</td>
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<td>8</td>
<td>90</td>
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<tr>
<td>Multiple sensors</td>
<td>12</td>
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<td>12</td>
<td>4</td>
<td>10</td>
<td>6</td>
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<td>8</td>
<td>15</td>
<td>8</td>
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<td>Tilting model</td>
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<td>8</td>
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<td>8</td>
<td>15</td>
<td>8</td>
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<td>90</td>
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<tr>
<td>Flexible robot</td>
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<td>12</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>8</td>
<td>15</td>
<td>8</td>
<td>8</td>
<td>86</td>
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<tr>
<td>Rails in corners</td>
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<td>15</td>
<td>9</td>
<td>6</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>6</td>
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<td>Submarine</td>
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<td>10</td>
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<td>2</td>
<td>8</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td></td>
<td>98</td>
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</table>

*Table 2: Evaluation of Concepts*
Further Development
Out of the 6 concepts described in the brainstorming chapter, there were two concepts very close to being tied for points. These two concepts will therefore both be developed in more detail and then submitted to a secondary evaluation to choose the final concept.

Submarine
A great deal of research has been done in the field of small unmanned submarines in the last decades. This type of submarines is usually called *Autonomous Underwater Vehicle* or AUV for short. The first step in the further development of this concept is therefore to investigate the most common commercially available AUV’s to see if they can be extended to perform the actions required to solve the task of detecting delamination in concrete tunnels.

Available models
There are mainly two types of commercially available AUV’s that will be considered as possible bases for this concept, REMUS in USA and GAVIA in Iceland.

REMUS is a light-weight, low-cost AUV produced by Hydroid, LLC. The smallest model is designed for operation in shallow water and is only 1.6 meters in length and has a torpedo shape with a diameter of 0.19 meters. It can be fitted with a very wide variety of sensors and might therefore be suitable for inspecting tunnels. A downside of this model is the fact that even if it is only 1.6 meters in length it is highly unlikely that it will be capable of turning around a tunnel that is around 3 meters in width. For this reason it cannot be used for operation in tunnels of this scale.10

![Figure 1: The REMUS 100 AUV](image)

GAVIA is a small, fully modular AUV design created by Hafmynd Ltd. The modularity of the design has many benefits, such as high portability, rapid change of batteries and the ability to customize the configuration. The Base unit torpedo shaped like the REMUS and is 1.7 meters in length and 0.2 meters in diameter. The specifications for the GAVIA state that it has a turning radius of less than 3 meters, but that still is not enough to be able to turn around in the tunnel. Therefore the GAVIA AUV, just like the REMUS, cannot be used to inspect the tunnels.11

10 (Hydroid)
11 (Gavia)
Since neither of the AUV’s investigated can be used for the purpose of inspecting concrete flaws in tunnels, an AUV must be created from scratch. The following sections describe various part of the design.

**Sensors**

To be able to detect flaws such as delamination in the concrete, ultrasonic sensors are most suitable. These sensors will have to be able to penetrate at least 50 cm into the concrete in order to get a good measurement of the cement integrity. After researching available sensor modules, two viable modules were found. These modules are sub-bottom profilers, either from Tritech or EdgeTech. Both of these modules are designed for AUV use so they are compact and energy efficient. These modules are however only capable of inspecting a narrow section at a time. This means that if the concrete should be inspected with a short distance between measurements the AUV will have to circle the tunnel more often. Another option would be to mount several sensor modules in an array to measure a larger area at a time. This would of course result in higher power consumption, increased weight and probably a large increase in price.

**Power supply**

The aim is to supply the AUV with power via rechargeable batteries. Therefore all design will aim to minimize weight and power consumption. In order to minimize delays in complete sweeping of tunnels, the AUV will have and easily exchangeable battery module like in the GAVIA. That would mean that instead of having to stop the sweep while charging, the module can be exchanged and the sweep resumed. The size of this module will be dependent on the power consumption of the final design.

**Propulsion**

The AUV will be propelled with two DC motors to increase maneuverability. This will enable the AUV to make turns almost on the spot which is very beneficial in this application.

**Positioning**

There are two methods that are suitable for positioning of the AUV. One method is to deploy two or more acoustic transponder buoys that the AUV can use to position itself with. The other method is somewhat more complex and is the way that the GAVIA AUV can be equipped with. The method is to use high precision Inertia Measurement Unit, a Doppler Velocity Log and then applying Kalman filtering to provide optimal position estimation.
**DESIGN**

Since the smallest AUVs available on the market have a turning radius of 3 meters they won't be able to turn around in the tunnels. Therefore we have come up with a new design with two motors instead. When the AUV needs to turn around it will reverse one of the engines and the AUV will spin around on the spot. The AUV is equipped with eight sensors placed in pairs. The sensors are about 20 centimeters in diameter and this will make the AUV about 50 centimeters wide and 70 centimeters high. The AUV will be about 70 centimeters long.

![AUV Model](image)

**FIGURE 6: AUV MODEL**

**MULTIPLE SENSORS**

The second option with high points was a device with multiple sensors. It has certainly not got as high points as the submarine but the possibility to make a combination with other concepts still makes it interesting. Developing this concept will include finding what type of vehicle is suitable, what sensors to use and how to move the sensors to the measurement points. There are various options based on sensors attached to some kind of vehicle. The model has, compared to the other similar models, the expansion rig and tilting model, certain advantages. It is smaller and easier to transport which yields a better result in the category transportability (D). The shorter probable sweep time (E) is due mainly to large number of sensors which is compensated for by the price (G), the need for calibration or complexity (F) and the inability to vary the exactness of the measurements (B). Since the main drawback of this model is that it requires multiple sensors and calibration of them, one option could be to use a sliding sensor as in the tilting model. This would significantly increase the sweep time, which was actually the main strength of this model, but also yield the possibility to vary the distance between the measurement points, thus making it possible to vary the number of measurements per unit area. To make the equipment more widely usable it is desirable to be able to change the distance between the measurement points. Then the question must be if time really is a factor. The reactor will be closed for at least a couple of weeks for maintenance so in this particular case perhaps the speed that can be obtained with a sliding sensor could be enough.

The section area will be scanned, as shown in the figure below, by passing through the tunnel four times. When scanning the higher sections at the ends of the tunnel, more passes will have to be performed.
To see if the idea with the moving sensor is possible, the required speed for the sensor is calculated. The lengths of the four tunnels are 85 meters and 55 meters. Scanning of the longer tunnel is assumed to be performed during one day, 8 hours. By also assuming constant speed so that the resulting movement is triangular the problem can be simplified. More time is required to scan the higher passages.

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<th>Length of tunnel (m) (85*4)</th>
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<tbody>
<tr>
<td>Measuring time (h)</td>
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<tr>
<td>Speed of vehicle (m/s)</td>
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</table>

<table>
<thead>
<tr>
<th>Distance between measurements (m)</th>
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<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
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<tbody>
<tr>
<td>Distance for sensor to cover (m)</td>
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<td>3.007</td>
<td>3.015</td>
<td>3.027</td>
<td>3.041</td>
</tr>
<tr>
<td>Time for sensor to cover distance (s)</td>
<td>8.47</td>
<td>16.94</td>
<td>25.41</td>
<td>33.88</td>
<td>42.35</td>
</tr>
<tr>
<td>Speed of sensor (m/s)</td>
<td>0.354</td>
<td>0.177</td>
<td>0.119</td>
<td>0.089</td>
<td>0.072</td>
</tr>
</tbody>
</table>

The calculations indicate that using one moving sensor is reasonable. Using one sensor will also decrease the problem with signaling treatment to compensate for varying calibration of the sensors which otherwise could cause a striped picture. Problems with sensors affecting each other could also be overlooked.

**Available Vehicles**

There are many types of commercial lifts that can be used for this application. It’s of importance to keep the construction small to be able to get through narrow passages if needed and to make it easy to transport. With a small construction the weight will also be reduced. To rotate in a small area there are solutions with tilted tires. For picture see appendix B.

2630ES, scissor lift produced by JLG, has a highest-platform-height of 7.7 meters. The machine dimensions are 0.76x2.30 meters which makes the model suitable for this tunnel. Its maximum lifting capacity is 230 kg. The vehicle is electrically driven and the lift is driven with hydraulics. The weight of the machine is 2200 kg but can vary based on options.
The sensors used in this construction are the ones referred to in the section “radar sensors” above. There are various companies that sell these sensors, which give many possible options. Radar sensors specifically fit for concrete are for example the GPR antennas from GSSI, which have frequencies ranging from 900 to 2600 MHz. A higher frequency offers a more detailed picture but shallower penetration. The depths range from 0.4 to 1 m. These antennas should be placed as close to the surface as possible to optimise data quality. However, the very existence of road scans that use this technique makes it feasible that a sensor that provides good enough pictures even at a certain distance from the wall can be found. The smallest sensor out of the ones found here weighs approximately 0.5 kg and measures less than 11x10x16 cm.

**Positioning**

The positioning of the equipment will require some sensors. Some kind of emitters must be placed in the tunnel that can be detected by the vehicle so it knows where in the tunnel it is. With the help of a couple of e.g. acoustic transmitters, the vehicle will be able to triangulate its position. One way is to preprogram a route in the tunnel based on the tunnel drawings and use it twice or if necessary more times until points on all heights have been scanned. This requires a very exact model of the tunnel. Another way is to mark the end and starting points with some kind of transmitters and program the vehicle to follow the wall until it reaches the one at the other end and then reverse back measuring other parts of the tunnel. Extra transmitters can be added where the tunnel height changes and extra measurements will be needed. Sensors at the end of the side bar will detect the distance to the wall and can be used in the control of the vehicle movement. Sensors on both bars can be used to detect the distance to the ground and the ceiling to control the movement of the lift. A system to triangulate the position of the vehicle must still be used to recreate the tunnel so that the measurements can be placed. Otherwise extremely detailed information from the motors must be saved to try to recreate the way the vehicle has driven. This will be difficult and probably inexact.

14 (Malå Geoscience)
15 (Digital Concrete Imaging)
16 (3d-Radar AS)
17 (Geophysical Survey Systems Inc)
18 (Penetrader Corporation)
19 (Geophysical Survey Systems Inc)
**Motors**
As the positioning of the sensors is very important, servomotors would be a good option. They are fairly easy to control and can be set very accurately. They do also provide force when they are not working but static in a certain position. The power will be taken from the truck battery.

**Design**
Our design is based on the scissor lift JLG 2630ES. The basket on top of the platform will be removed. Since this application only needs a lifting capacity of approximately 100 kg, the bars can be dimensioned differently, thereby weight and battery needs can probably also be reduced. One should remember that the stability of the scissor is extremely important, even though it is the goal to keep a constant speed, uneven floor surface etc can cause unwanted acceleration. With a robust structure, oscillations at the top where the bars are fastened can hopefully be minimized. To make the design as compact as possible it is advisable that the bars with sensors and servo motors can be detached.

![Figure 9: Design for vehicle with sensors](image-url)
CONCLUSION

COMPARISON

To choose which concept will be developed further, the various aspects of the two concepts will be compared. Each concept has its strengths and weaknesses, so comparing the two should give a rather good idea of which is better.

The positioning of measurements is considered quite critical so that will be compared first. Positioning of the AUV can be somewhat more difficult than for the multiple sensors model. This is due to the fact that when submerged in water we have no absolutely fixed reference point. Positioning for the AUV is likely to include very complex control algorithms and position correction may take considerable time to achieve.

Another problem with the AUV is that if something were to go wrong, like the failure of some sensors or motors, it requires that there is a diving specialist on site to retrieve the AUV. In comparison if something were to break down on the multiple sensors model, repairs could possibly be done on location with less work effort.

It was stated in the requirements that price would not be considered a great factor. However if the development cost of these two concepts are estimated it seems rather obvious that since we cannot use an existing AUV to extend, but need to design and build one from scratch, the development cost will most likely be very high. For the multiple sensors model we can however use an existing platform to build from which is likely to reduce the development cost.

Even if one of the AUVs could be used it would be bigger and more difficult to handle than the option with the scissor lift.

It appears that the multiple sensors model is more suitable for the purpose of inspecting concrete tunnels for flaw than the AUV. The final choice of concept is therefore the multiple sensors model.

FURTHER DEVELOPMENT

Now that a viable concept has been chosen some of the next development issues can be stated. These issues will however not be addressed in this report since they are beyond the scope of this project.

One of the most significant development issues is the signal handling. Because the concept uses multiple sensors the control algorithm will have to consider various issues to eliminate possible interference between them. The algorithm will also filter out all refracted signals, which can be a difficult task since the tunnel will possibly cause extremely high volumes of echo.

Another issue is that there may be irregularities in the tunnels. Irregularities include for example anodes in the floor as well as so called stone-traps that serve the purpose of catching stones that happens to enter the tunnel. These irregularities are not necessarily present in all tunnels and most definitely not always in the same positions.
BIBLIOGRAPHY


APPENDIX A, SKETCH OF TUNNELS
APPENDIX B, LIFT

Figure 4: Tilted tires