2013 - 2014

PROJECT REPORT

SIRIUS – Creative Product Development

Development of a solution for automatic detection of clearcut obstacles

SLU & Skogforsk

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Abstract

To promote growth and survival of forest regeneration, scarification prior to operational tree planting is required. However, due to obstacles such as rocks and stumps present on clearcuts after final harvesting, scarification often fails to produce suitable microsites for the tree plants to grow in. This report presents a complete product development process with the purpose of finding a solution for obstacle detection on clearcuts. A solution that efficiently identifies obstacles would greatly improve the performance of the scarifier by giving it a possibility to actively avoid obstacles and thus making better mounds. After extensive Needfinding and benchmarking of related technologies, a Time-of-Flight (ToF) camera was chosen as the most appropriate technology for obstacle detection. The camera illuminates the scene and measures light reflection time, establishing a 3D point cloud in which shapes could be found. Protruding objects such as rocks and stumps produce certain shapes distinguishable from the data utilized through algorithms design for obstacle detection. A possible complement to the ToF camera is an IR-thermography camera measuring surface temperature. The temperature measures can then be used to derive moist grounds and accumulation of water in the terrain. Both the ToF camera and the IR-thermography were tested in the field to evaluate performance. The ToF camera, using the obstacle detection algorithm, detected 94 % of obstacles above ground and the IR-thermography showed clear deviations in temperature. These tests indicate that a large proportion of obstacles in the terrain can potentially be identified using selected technology.

Acknowledgements

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- Håkan Lideskog project coach at LTU. Håkan has helped us with much knowledge and study material on forest regeneration as well as practical help with running the project.
- Emil Hällstig, research engineer at Optronic. Emil has helped us with issues regarding the camera equipment that was bought for the project.

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1. Introduction

This report covers the work from a product development project regarding obstacle identification to allow for efficient forestry machines. The work was done within the frames of the SIRIUS course held at Luleå University of technology in 2013. The SIRIUS course is held for senior year students in mechanical engineering and aim to teach students about all the aspects of a real product development project. The project sponsors were SLU - The Swedish University of Agricultural Sciences, and Skogforsk - The Forestry Research Institute of Sweden.

1.1. Background

The purpose of site preparation preceding reforestation is to create a proper environment for the seedlings when being planted that satisfy their biological needs. Each year, between 350 and 400 million seedlings are planted in Sweden [1]. When performing site preparation the humus layer of the soil is removed and the mineral soil is exposed. This benefits the root growth of the seedling since the mineral soil is loosened. Loosening of the soil is also beneficial for planting in moist soils as it improves the ratio between air and water in the soil. However, the seedlings may dry out if site preparation is performed on dry soils. By increasing the amount of oxygen in the soil the decay process for the humus layer is accelerated, which releases nutrients for the seedling [2]. Figure 1 shows a seedling planted where site preparation has been performed.

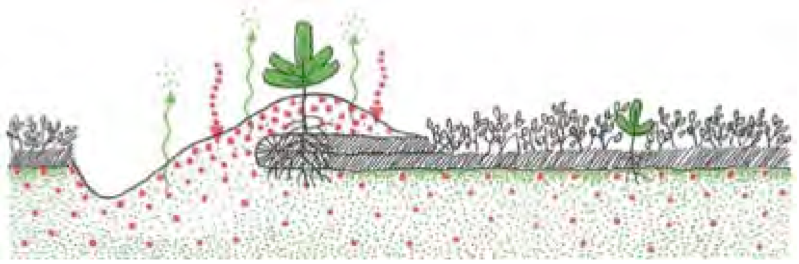


Figure 1. Seedling planted on prepared soil [2]

By removing slash and humus the temperature at the surface increases due to better absorption of sunlight. This is also beneficial for the seedlings since it improves root growth and the ability to absorb nutrients and water. When air temperatures drop at night, the temperature near the seedling is slightly higher due to radiation from the surrounding ground, since the humus layer and slash has been removed and the mineral soil is exposed.

The exposed mineral soil also protects against pine weevil predation that is harmful for conifer seedlings. The seedling should be surrounded by at least 20 cm of mineral soil in order to be protected against pine weevil. Another benefit of exposing the mineral soil is that the influence of competing vegetation is decreased [2].

Scarification can be performed either by disc trenching or mounding. Both techniques have in common that they create mounds, which means that the soil is inverted with the mineral soil lying on top of the humus layer. Trenching is a continuous method for scarification that creates a ridge along its path. The trenches are made by rotating discs mounted on a forwarder or an agricultural tractor. The ground impact caused by this scarification method is significantly higher than the impact caused by mounding [3]. Figure 2 shows scarification being performed by a disc trencher. Here, the large ground impact also can be seen.

Figure 2. Disc trencher [4]

Mounding is another scarification method frequently used in Sweden. This is performed intermittently creating mounds in the direction of travel. These are made by digging wheels mounted on the forwarder that are hydraulically operated with a rotation speed adapted to the vehicle's speed. Due to the intermittent operation, the ground impact is lower compared to trenching [3]. Mounding as it is most commonly performed today is shown in Figure 3.

Figure 3. Mounding [4]

If a scarified microsite does not fulfil the requirements for a good seedling environment, the seedling stands a smaller chance of survival. If too few seedlings survive, the landowner must either redo the scarification and planting process, or expect a lower yield on his forest. In a study from 2011 by Larsson [3], as much as 43% of all sites created by mounding were not approved due to inferior quality. In 80% of these cases, the presence of a physical obstacle such as a rock or stump was the reason for the failure. Other 20 % was due to slash or misshaped mound.

Hence, by detecting obstacles such as rocks and stumps and avoid hitting them with the scarifier, scarification would be enhanced. This need was identified by SLU and Skogforsk and is the main reason to why this project was initiated.

1.2. Purpose

The purpose of this project is to develop a product that can identify physical properties of the terrain in a way that will enhance the quality of the scarification process. The information can be used to decide whether an area is a suitable scarification site or if there are physical obstacles such as rocks, stumps or slash that is obstructing the microsite. Whatever technology is chosen for the application, it must be able to work with the machinery that is used today. The detection (the information retrieval of any kind) shall be able to communicate with the scarification machinery to automatically guide its positioning and speed, thus increasing the proportion of approved sites without any additional effort from the driver. In a future extension, obstacle detection is a necessary function for autonomous vehicles as it could be used not only for guiding scarification but to guide the forwarder itself.

1.3. Goal and Deliverables

In the initial project description, the stated goal was “a solution for automatic detection of clearcut obstacles shall be developed, manufactured and tested to such extent that it can be used for validation activities”. The project group has interpreted this task in order to set up quantified goals that can be measured and verified by the testing of the prototype. The goals set up by the project group are to:

- Increase the efficiency of scarification and planting by improved identification of relevant ground properties.

- Increase ratio of successful scarification sites by 20% in relation to today’s solutions while maintaining the required number of microsites/ha.

The deliverable of the project is thus a prototype that can detect relevant ground properties well enough to fulfil the goals set up. The performance of the product is to be verified by making tests in actual driving conditions.

1.4. Scope

The scope of the project covers the mechanism of the information retrieval itself and the production of an output signal with information of the terrain properties. The group is to choose an appropriate way to emit or create a signal and a way to capture and interpret the signal. However, once the signal is interpreted it will not be adjusted to suit any particular control system. It will be an open source system that any company in the Swedish forestry industry shall be able to use.

Furthermore, the measures taken to avoid an obstacle based on the output signal is not within the scope, even though appropriate measures will be recommended. A rough estimate on possible product cost based on potential profit will also be made. The project will however not include considerations for production cost of the product once it is ready to be commercialized.

2. The product development process

By using a predefined product development process, you get a reference frame that all necessary steps are covered in order to generate a product that end up fulfilling the needs and expectations of the sponsor. In order to create a successful product you must account for all possible aspects from identifying the right needs, to design and test the product and eventually implement the manufacturing within the existing constraints of the company.

Ulrich and Eppinger [5] describe a product development process as the sequence of steps or activities that are used to formulate, design, and commercialize a product. In order to clarify the product development process they have defined a number of steps, shown in Figure 4. The method is a well-established and proven general model for technical product development.

Figure 4. Product development process based on Ulrich and Eppinger [5].

Planning: Starts with an opportunity to satisfy one or many needs on the market, often guided by corporate strategy, assessment of technology and market objectives. The result of this phase is the projects “mission statement”, which specifies the target market, business goals, key assumptions, and constrains.

Concept Development: During this phase the needs of the intended target market are identified. After which different product concepts are generated and evaluated to meet these identified needs, usually accompanied by a set of specifications, an analysis of competitive products, and an economic justification of the project. The result of this phase should be one or more concepts selected for further development and testing.

System-Level Design: Comprises the definition of the product architecture, decomposition of the product into subsystems and components, and preliminary design of key components. The result of this phase usually includes a geometric layout of the product, a functional specification of each of the product’s subsystems, and a preliminary process flow diagram for the final assembly process.

Detail design: Includes the final specifications of the product, in form of geometry, materials, tolerances, manufacturing method for the product’s components, and which standard components to be purchased from suppliers. This forms the so-called “control documentation” for the product, which is the output of this phase. Other issue’s that is also addressed is the production cost and robust performance of the product.

Testing and Refinement: Several preproduction versions are manufactured and evaluated to determine whether they work as designed and meet the requirements. The output of this phase should be a verification of the products reliability and performance.

Production Ramp-up: Here the product is manufactured using the intended production system, partly to train the staff but also to work out any remaining problem. It is also during the end of this phase the product is launched to the market.

Since this method is a general model for technical product development some modifications have been done to suit the project, as shown in Figure 5. Seeing that similar products do not exist on the market, Needfinding and research of related technology is considered to be of such importance that they have been added as a unique phase. The system-level and detail design phases are less comprehensive in this project and have thus been combined into a single design phase. The last phase in the Ulrich and Eppinger - method is cancelled since it aims to launch a physical product, which is not included in this project.

Figure 5. The product development process used in the project

3. Project planning

A group of five students have been working with the project for approximately 20 hours per week from early April to mid-January, with breaks during the summer and winter holidays. For a project of this magnitude to run smooth and efficient, a thorough planning is essential. The first assignment of the project was for all the team members to create an individual plan where they stated personal expectations, goals and interests. Based on the individual plans, a group plan was made where the team goals were stated and responsibilities were assigned to different team members. A time plan was also made where deadlines were set for the different stages of the product development process, see Appendix A.

4. Identifying Customer Needs

The purpose of the Needfinding is to give the designers a tool to identify the needs, not the solution to a problem. In that way the designers will be more open minded to the problem and that will in return generate more creative solutions [6]. A Needfinding process can be divided into a four- stage process for studying people [6]:

Frame and prepare: In this stage all the preparation takes place. The goals for the project are defined so it is clear what the research should focus on. The customer groups related to the project are identified, in order to retrieve relevant information for the project. Before the customer interviews, questions are prepared in relation to what the research aims to investigates.

Watch and record: This stage is about observing the research area. By observations it is possible to see the situation from an outside perspective, a situation that might be oblivious for someone who experiences it often, making it hard for them to see that there is a problem at all. Through this, it is possible to detect the needs and problems in the research area.

Ask and record: Interviews with customer groups are a useful tool to gather information and needs. It is important that the questions are open- ended so the person will have a chance to describe situations in their own words. Another good thing is to record the interviews so you really get the person's answers and not a rewritten statement, because that will increase the risk of missing the essence.

Interpret and reframe: This stage of the Needfinding process is about analysing the result from the above stages. The result that is shown from this process should be evaluated and show the needs that must be solved. The needs should be prioritized on importance level and later be quantified and put in the specification of requirements.

4.1. Frame and prepare

Since the project mainly is focused on scarification, the people of interest for interviews should be involved in the forest industry and somehow coupled to the scarification process. It is important to have a wide range of objects to interview in order to identify the needs related to scarification. The Needfinding is divided into five main groups according to Figure 6.

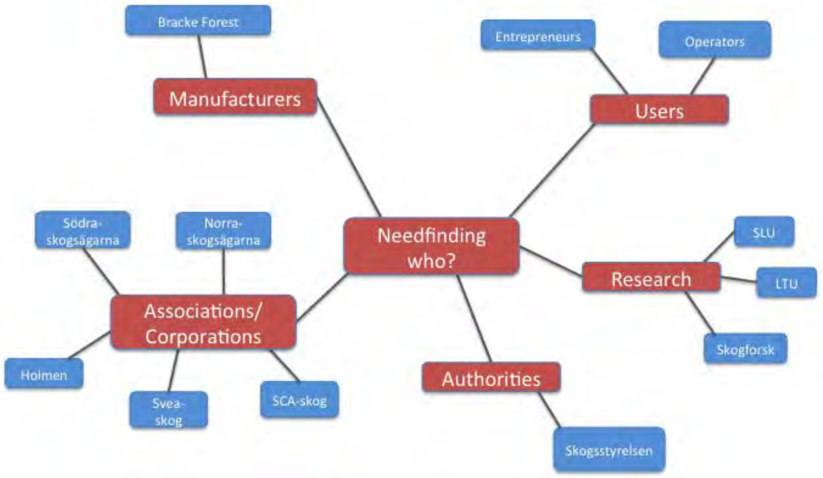


Figure 6. Interest groups

User: This group contains the end users, the ones who operate the scarifier. This group has a lot of experience operating the machine and good knowledge about which flaws the machinery has.

Research: This group consists of various universities/ research centres, where the need for this research project emerged, and can thereby be a useful reference about how the need of improvement for scarification was found.

Associations/Corporations: Associations and corporations have a close relation with landowners and good knowledge of which needs landowners express. They also help landowners to make forest plans and perform inspection on harvesting and scarification sites, which means that they can provide good information of flaws in today's scarification.

Manufacturers: The manufacturer of scarifiers can provide good information about the market needs and current problems. They also have a good understanding in how the scarifiers work and what improvements are feasible.

Authorities: The agency for issues related to forestry can provide insight on the legal aspects and constrains of the scarification process.

When the five main interest groups were identified, specific questionnaires with questions tailored for each specific group was created, see Appendix B.

4.2. Ask and record

The interviews with the subjects for the Needfinding were mainly done by phone for the reason that it would be ineffective and time consuming to visit every subject at each site. The questions for the interviews were made in an open- ended way to encourage a meaningful answer from the subject without leading them to an answer [7]. The questions were also constructed so that they would suit the subjects' different areas of expertise, e.g. entrepreneurs and manufacturers got different questions.

Beside the phone interviews, two interviews for the Needfinding were conducted in the customer's environment, one at Bracke Forest and the other at Skogsforsk. Bracke Forest is a world leading developer and manufacturer of equipment for forest regeneration. They have first-hand experience of how the scarifiers work, which problems that may occur over time and market trends. Therefore, interviews were conducted with a designer at Bracke Forest to gather information about how scarifiers work, today's problem areas, and their thoughts about our project. The agenda was set before the meeting so they would have a chance to prepare and in that way the interview became more of an open dialog with good exchange of information and well thought answers. Skogforsk is the central research body for the Swedish forestry sector and is financed by the government and other stakeholders as well as by funding agencies and commissions. They also act as sponsors for the project described in this report. At Skogsforsk the interview was held as a dialog about our project and scarification in general. The results of the interviews can be seen in Appendix C.

4.3. Interpret and reframe

Needs were formed by the answers from the different interest groups, see Table 1. Then, corresponding metrics were established in order to give measurable targets, see Table 2. The needs and metrics were thereafter ranked by relative importance based on the interviews as well as input from SLU & Skogforsk and Bracke Forest.

Table 1. The needs that must be satisfied by an obstacle-detecting product

No.	Need	Relative Importance
1	Avoidance of obstacle	5
2	Productivity increases enough to justify investment in the product	5
3	Must be functional at all operational conditions	5
4	Improved quality of plantation sites	5
5	Decrease the ground disturbance	4
6	Decrease dependence on driver's skills	4
7	Decrease wear on the scarifier	3
8	Decrease the need of complementary scarification	3
9	Avoidance of lichen, small trees and ancient remains	2
10	Avoidance of wet ground	3

Table 2. The metrics that must be satisfied by an obstacle-detecting product

Need No.	Metric	Imp.	Unit	Marginal Value	Ideal Value
1,4,5,6,7, 9	Ability to distinguish between obstacles and suitable scarification point	5	binary	yes	yes
1, 4, 10	Depth for detection of ground properties	3	cm	20	>20
1,4	Prescanning distance	4	cm	500	500<x<1000
1, 8, 2, 5, 4	(Increase) Proportion of approved scarification sites	5	%	20	>20
2, 8	Unit production cost	4	€	<40 000	<30 000
3	Temperature range	5	°C	-5<°C<60	-5<°C<70
3	Operational in Nordic weather conditions	5	Binary	yes	yes
3	Operating speed of machine	4	km/h	0<km/h<3	0<km/h<6
3	Shock resistant	2	m/s^2		
1	Volume of rocks to be avoided	4	dm^3	6	<6
1,4	Diameter of stumps and roots to be avoided	4	cm	10	7
1,4	Thickness of slash-layer to be detected (slash of >2cm diameter)	3	cm	10	5
1, 4	Sideway scanning distance	3	cm	3400	4200
10	Ability to determine water content in ground	3	binary	yes	yes

5. Benchmarking of Related Technologies

In this section, technologies that might be used as a solution or sub-solution for the final concept are presented. This is done to give insight of what already exists on the market today and is of great importance for subsequent concept generation. Each of the identified technologies is presented with a short summary below.

5.1. Time-of-Flight Cameras

Time-of-Flight (ToF) cameras provide a depth image [8] of the scene in front of the camera. This is obtained by measuring the time it takes for a light pulse to travel from an illumination source to an object in front of the camera and back to the sensing device [9]. The light source emits modulated infrared (IR) light [8] and the phase difference between the emitted and received signal is used for calculating the distance for each pixel in the sensor [8], [9]. This is illustrated in Figure 7 where the red wave denotes emitted light and the blue represents received light.

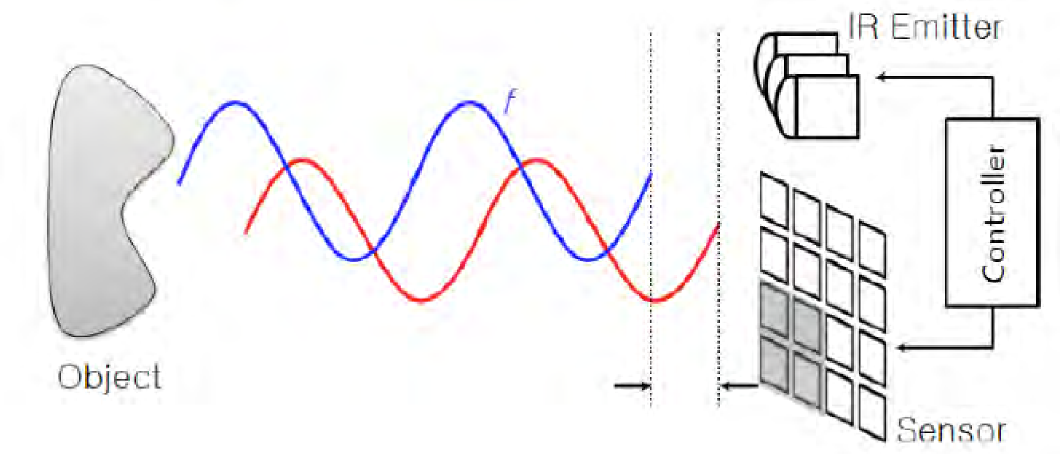


Figure 7. ToF measuring technique **[8]**

ToF cameras can be used for obtaining a complete 3-dimensional (3-D) mapping of the scene in front of the camera without the use of traditional computer-vision algorithms [8].

5.2. Stereo Vision

By comparing two pictures of the same object, taken with a slight sideway offset, it is possible to make a 3-D mapping of the scene using computer algorithms. The computer algorithm identifies points along edges of objects in each picture, since the pictures are taken with an offset the points will have a 1-D offset from one picture to the other, by comparing these offsets the algorithm can calculate depth of the object. Information from all points is then combined to create a 3-D mapping [10].

The technique is commonly referred to as Stereo Vision and can be applied to for instance robot navigation, 3-D movie recording and object tracking [10]. A thesis work was recently made at Aalto University of technology in Helsinki where Stereo Vision was successfully used to identify planting points within created microsites on clearcuts [11].

5.3. Laser

1-D Laser uses electromagnetic radiation to measure the distance between the sensor and objects in front of it, i.e. the sensor measures only the distance to one point. In order to scan an area, many sensors are needed or the sensor will need to be moved in order to span an area to measure [12].

Laser scanner uses the same technology of electromagnetic radiation as 1-D laser to measure distance. There are two principles of laser scanners, either the sensor is moved in one direction; where a line is measured with one sensor, or the sensor is moved in two directions simultaneously; to scan an area instead of just a line [12].

5.4. GPR

Ground Penetrating Radar (GPR) uses electromagnetic radiation to scan for objects underground. Depending on what power and wavelength that is used, varying depth of measurement and varying sizes of detectable objects is achieved. It is possible to scan from a few centimeters down to several kilometers. An important parameter is how wide the receiving angle is, since this determines how large the scanned area under the GPR will be. There are both handheld versions and versions that are made to be positioned just a few centimeters above ground [13]. During the work with related technologies two local companies that produce GPR-systems was found; Geoscanners in Boden and Malå Geoscience in Malå.

The process of analyzing output data from a GPR is made manually and at this time there are only some basics scripts made for detection of symmetrical patterns, such as rebar in concrete [13].

5.5. Ultrasonic Sensors

Ultrasonic sensors emit ultrasound, sound that is generated above the human hearing range. Ultrasound has a short wavelength and can reflect off very small surfaces, which makes the technique useful for nondestructive testing [14]. Ultrasound is reflected at the boundary between differing media [15] and the ultrasonic sensors measure the time of flight between the transmitter and receiver to calculate the distance to an appearing obstacle.

5.6. GNSS

GNSS is short for Global Navigation Satellite System, often mistakenly referred to as GPS. The system consists of satellites, ground control stations, and GNSS receivers. To determine its position, the GNSS receiver calculates the distance of the received signals, emitted from the satellites. The accuracy of the positioning and the time to establish a position depends on how many satellites are within range of the receiver. There are today two globally operational GNSS's, the American NAVSTAR GPS, and the Russian GLONASS [16].

By complementing the GNSS receiver with RTK reference stations, it is possible to reach an accuracy of +/- 2.5 cm. However, this depends on the quality of satellite and 3G Internet receptions [17].

5.7. Mechanical Positioning Sensors

Capacitive sensors are analogue sensors that measure the change in capacitance between the sensor and the surrounding. This provides a resistance towards e.g. a metal or liquid. If an object reaches the proximity of an electrical field, the capacitance grows, and the sensor provides a signal. The sensor can also detect a change in the dielectric constant, e.g. water on the other side of a glass slide [18].

Inductive sensors produce a high-frequency magnetic field at the active sensor surface. As soon as an electrically conductive object approaches this surface, a part of the electromagnetic energy is absorbed. Thus, attenuation occurs and the amplitude of the oscillator decreases. As there is a direct relationship between amplitude and the distance of the conductive object, a signal is released as soon as the object has achieved a defined operating distance [19].

5.8. Positioning of Excavator Bucket

With GNSS receivers, high-speed computers and rapid response tilt sensors it is possible to determine the position of the bucket teeth of an excavator within a few centimetres. In order to determine the position of the bucket teeth, it is crucial to know the movement of the ropes or beams connecting the bucket to the machine house. By using tilt sensors, rotation encoder on rope drum, wire reel sensors on hydraulic cylinders and measurement of fluid flow through hydraulic cylinders it is possible to determine the bucket position relative the housing [20].

5.9. Vibrating Probe

Surfaces with different hardness will give different reaction forces when subjected to mechanical force from a rigid body. A softer surface will absorb the mechanical energy by deforming, while a harder surface will not deform but rather exert a reaction force on the rigid body [21].

This principle is the basic idea behind the vibrating probe technology tested in 1983 by Lammasniemi [21]. The probe itself is dragged along the surface of the terrain that is being measured. In the probe there is a rotating imbalance causing the probe to vibrate. There is also an accelerometer that measure the reaction force from the surface on which the probe is resting. Different types of reaction force characteristics can be related to different types of objects such as rocks, stumps, or soft moss [21].

5.10. Soil Moisture Measurements

A neutron probe uses radioactive material to measure soil water content. An access tube is inserted in the ground and the source tube installed at the desired depth. Lowering the source tube causes collisions between high-speed neutrons and hydrogen atoms in the soil. Due to loss of energy, low-speed neutrons are created. Some of the slow speed neutrons are reflected back to the source tube and counted by the neutron detector. With the right calibration equation it is possible to read the volumetric soil moisture content [22].

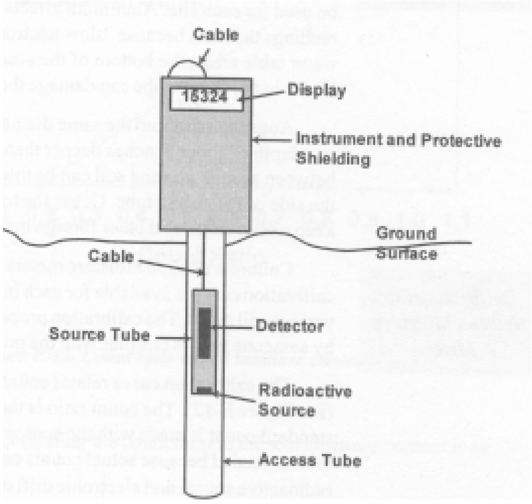


Figure 8. Neutron probe [22]

Electrical resistance blocks use gypsum blocks to measure the soil moisture content. The electrical resistance block consists of two electrodes enclosed in the porous material. The changes in soil moisture content will cause a change of the water content of the porous block. Increased moisture content equals decreases resistance [23].

5.11. IR-Thermography

Infrared thermography is a method of collecting the temperature profile of a scanned area. All objects above absolute zero emit heat, i.e. infrared radiation, and the intensity of the infrared radiation is a function of the temperature [24]. The warmer an object is, the more infrared radiation is emitted. In thermal imaging, the camera not only captures the heat emission from the object, but also captures reflected heat from the surroundings, and in some cases, the transmitted heat from underlying objects [25].

6. Concept Development

The aim during this phase was to develop concepts that met the needs formed during the Needfinding process, shown in section 3.3. Initially, all the investigated possible technologies were listed in a Brainstorming session and then compared to a list of metrics, illustrated in Table 2, in order to select a concept for further development and evaluation. The process of generating and selecting concepts is described closer in this section.

6.1. Concept Generation

To facilitate the concept generation, the main problem was divided into sub-problems in order to allow independent solutions for each sub-problem, giving more room for creativity. This provides a better overview where many sub-solutions can be combined to a total solution.

To work out solutions to the sub-problems, a Brainstorming session [5] with the whole group was held, of which the results can be seen in Table 3.

Table 3. Results from Brainstorming session using Ulrich and Eppinger method [5]

Transmit signal	Type of sensor/detection of signal	Placement	Data handling	Action to be taken
GPR	GPR	In front of machine	1-D-line	Move mounder sideways
US	US	Behind machine	2-D-surface	Stop program
ToF	ToF	On top of machine	3-D-volume	Change ground pressure
Laser	Laser	Between tandem-axles	Many 1-D-line -> 2-D-surface	Change speed of rotation
Pin-jointed-arm with broach	Resistive-sensors	On dozer blade	Many 2-D-surface-> 3-D-volume	
Wheel with rotating disk	Inductive sensors	On mounder	Log terrain data	
			Detect obstacles	
			Detect suitable planting site	

6.1.1. Extending the concepts through consultations and further investigations

The different solutions from the Brainstorming were combined and visualized into different concepts presented in Appendix D. From the benchmarking of related technologies, section 5, a number of technologies were identified as suitable to solve the problem and was investigated further. These technologies were; ToF camera, Stereo Vision, Ultrasonic sensor, 1-D Laser, Laser scanner, GPR and GNSS. The group also generated three mechanical concepts; a ground penetrating disc, a ground-penetrating blade, and a vibrating sled. IR-Thermography is a technique that is investigated apart from the other concepts. It will not alone fulfil the goal, but can be seen as a supplement to the other concepts, due to its potential ability to detect soil moisture and thereby enable e.g. obstacle detection or autonomous navigation for forestry machines.

Most of the research was conducted by searching the Internet and thereafter establish contact with manufacturers and experts. The group arranged a field trip to Geoscanners in Boden to retrieve more information regarding the technology of GPR and to discuss the possibility of using it in this application.

Contact was also established with a PhD in active physics, Emil Hällstig, who is a guest researcher at LTU, and a senior consultant/research co-ordinator at Optronic in Skellefteå. A meeting was held at LTU where the group had a chance to discuss ToF Cameras and Stereo Vision in general and related subjects such as signal processing and ToF applications.

To retrieve more information about ultrasonic sensors, contact was established with Professor Johan Carlson at the department of computer science, electric and space engineering at LTU.

All the information that the group accumulated on the different techniques was compiled in a spreadsheet including a short description, technical metrics and 'pros and cons' for using the technology to address the project goals, see Appendix E**.**

The technical metrics from each concept, see Appendix F, was compared against the list of metrics established during the Needfinding phase, section 4. The method that was used for data collection is described in Figure 9.

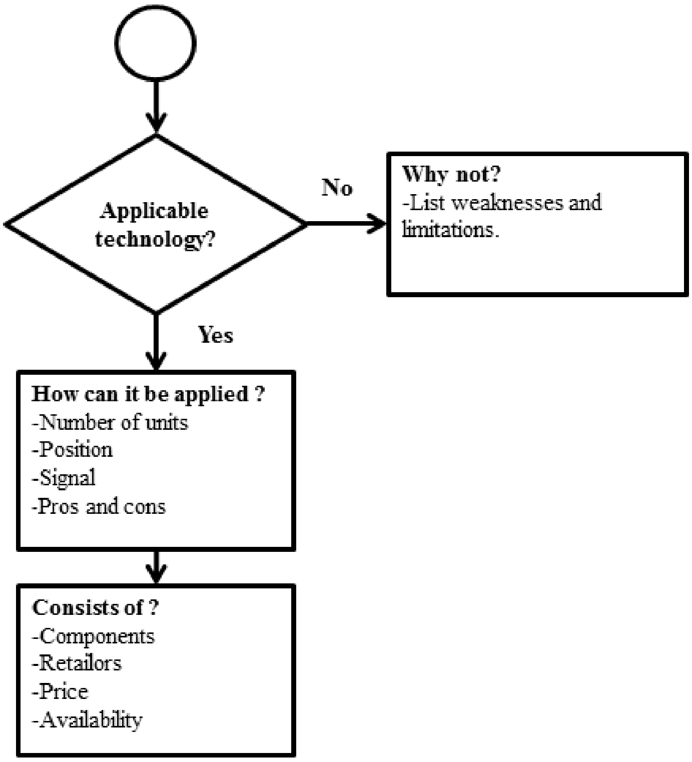


Figure 9. Method for data collection

This information was presented to the project sponsors at SLU & Skogforsk along with reflections on the task and suggestions on what techniques to use as a final concept. A discussion was held after the presentation where Urban Bergsten, Professor in Forest Regeneration and Silvicultural Technology, and Back Tomas Ersson, Forester/MSc in Forest Management, both from SLU, provided feedback on the feasibility of the different concepts from their respective area of expertise. This feedback and collected data were the foundation for the concept selection. On the meeting it was suggested that the focus now should lie on detection above ground and the possibility of determining soil moisture by IR-thermography. Limiting the problem to detection above ground, the project still had the prerequisites to reach the goal.

6.2. Concept Selection

To determine which concepts to move forward with, they were compared against each other using metrics. Evaluating how they performed in comparison with a reference ranked the concepts. Despite the feedback from SLU & Skogforsk the group chose to compare all the concepts, this to ensure the reliability of the result. GPR was set as a reference due to a good overall performance. The concepts were then expressed with either positive, negative, or equal (0) performance compared to the reference in Table 4. Performance data can be viewed in Appendix F. This technique is called concept screening and is a method that aims at determining which concepts to move forward with [5].

Table 4. Concept screening matrix

	GPR	ToF	Stereo Vision	1-D Laser	Laser scanner	US	Sword	Disc	Vibrating probe
Accuracy	0	+	-	+	+	0	-	-	-
Field of view	0	+	+	0	+	0	-	-	0
Compactness	0	+	+	+	+	+	-	-	-
Data processing	0	+	-	+	+	+	+	+	+
Price	0	+	+	+	+	+	+	+	+
Performance	0	0	-	0	0	-	0	0	-
Durability	0	0	-	0	0	+	-	-	-
Sum	0	5	-1	4	5	3	-2	-2	-2
Rank		1	4	2	1	3	5	5	5

The output of the concept-screening matrix indicated that ToF, 1-D Laser and Laser scanner were concepts to move forward with.

In order to distinguish between these technologies a concept-scoring matrix [5] was made. Each of the performance metrics was given a weight to validate the importance of the result. The weights were chosen as objectively as possible with basis from knowledge acquired during the project from the needs and metrics, which in turn, were acquired from interviews described in section 3. The concepts were then ranked from 1 to 5, depending on how they performed, and then multiplied with the weight. The sum of each concept gave a rank of which concept to move forward with. The result of this can be seen in Table 5.

Table 5. Concept scoring matrix

	Weight	ToF	Laser scanner	1-D Laser
Accuracy	20	3	3	4
Field of view	15	3	4	1
Compactness	5	3	3	2
Data processing	15	4	3	2
Price	10	3	3	5
Performance	20	4	3	2
Durability	15	3	3	3
Sum	100	3.4	3.15	2.7
Rank		1	2	3

The result of the concept-scoring matrix indicated that ToF was the concept to move forward with, and was therefore chosen, partly because it got the highest score, but also because of good availability of support from the manufacturer and local expertise.

6.3. Final Concept

When it came to the decision of selecting a camera to purchase for further evaluation, Emil Hällstig informed the group about a prototype camera E70/RGBZ, called C-series, which had not yet reached the market. The advantage with this camera, compared to the one already investigated, is that an instant RGB picture accompanies the data. The camera can be seen in Figure 10 and a data sheet can be found in Appendix

Figure 10. ToF camera, Fotonic C-series [26]

For evaluating the possibility of detecting soil moisture by IR-thermography, a camera was borrowed from LTU. The camera can be seen in Figure 11, and a data sheet in Appendix H.

Figure 11. IR-Camera, ThermalCAM E45

Combined, these technologies have the potential to theoretically reach the project goals. To evaluate the technologies further, tests needs to be carried out and analysed under real operating conditions.

In Appendix I a rough estimation of potential profit from an obstacle detection solution is made. The estimation is based on the assumptions that obstacle detection can increase the value of the scarification or decrease operator time. The potential profit gives a possible price range for an obstacle detection product investment. The excel spread sheet can be found in the supplied DVD for the reader to test different values of price and interest.

7. Detail Design

Ulrich and Eppinger [5] describe the output of this phase as the control documentation for the product. This includes drawings or computer files describing the geometry, specifications of parts to be purchased, and the process plan for fabrication and assembly of the product, etc.

7.1. Camera Position

The position of the ToF camera on the forwarder affects the field of view. The distance from the camera to the measured ground surface must be within the camera's range. However, if the distance is too short, the field of view becomes too narrow and it will not be possible to scan the areas where the mounding units situated at the back of the machine will pass through.

Three different camera positions were evaluated: roof mounted facing downward, roof mounted facing forward and bonnet mounted. If the camera is mounted on the roof of the forwarder with an inclination angle of approximately 38°, see Table 6, the field of view lies within the range of 10 m. The width of the field of view is sufficient for the width of the mounders. The major disadvantage using this position is that the hood and front wheels become inside the field of view. It is possible to remove these measurement points, but that will leave fewer measurement points to analyse. The green lines in Figure 12 indicate the field of view if the camera is mounted at this position. Figure 12 also shows camera position and position of the mounding units.

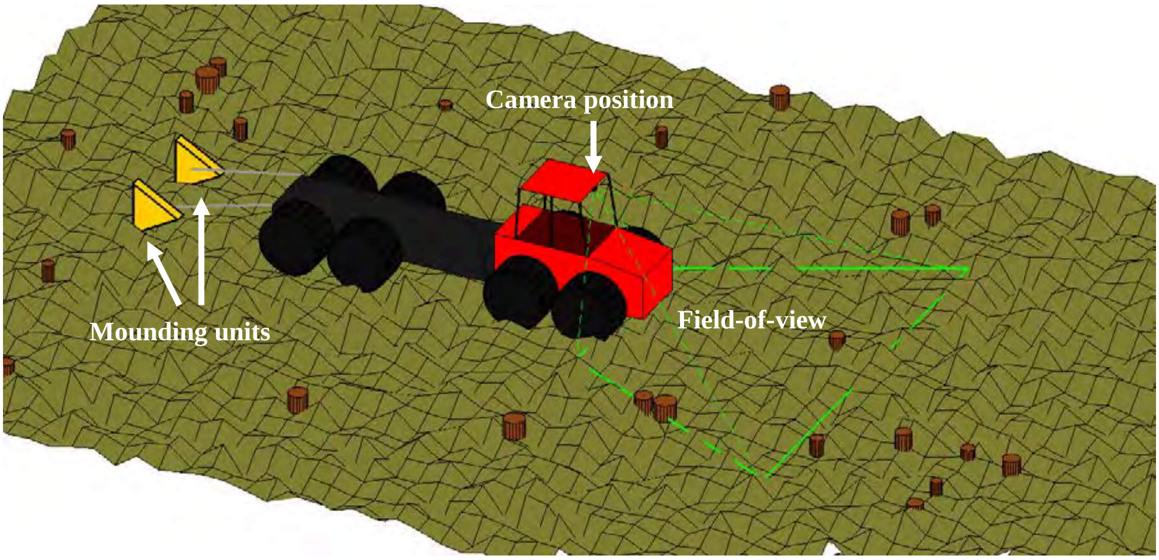


Figure 12. Roof mounted camera facing downwards

If the inclination angle is changed so that the hood falls outside the field of view, most of the scanned area will be at a larger distance from the camera than 10 m. At this measurement distance there will be a significant amount of noise, and thus, aliasing is likely to occur. The field of view for this setup is shown in Figure 13.

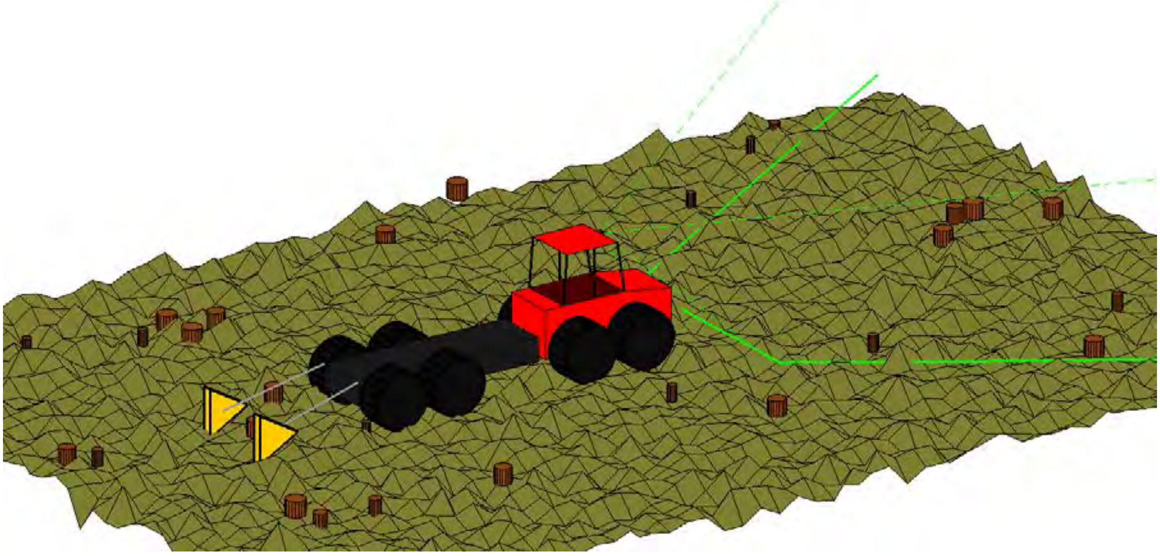


Figure 13. Roof mounted camera facing forwards

If the camera is mounted on the bonnet at the front of the forwarder there is nothing that will obstruct the camera, illustrated in Figure 14. Since the measurement distance is rather short, the resolution will be good with a pixel density of maximum 4.1 cm in width for the suggested height and inclination angle. The field of view will be too narrow close to the forwarder, but is sufficient further out from the forwarder, enabling the mounding units to pass within the field of view.

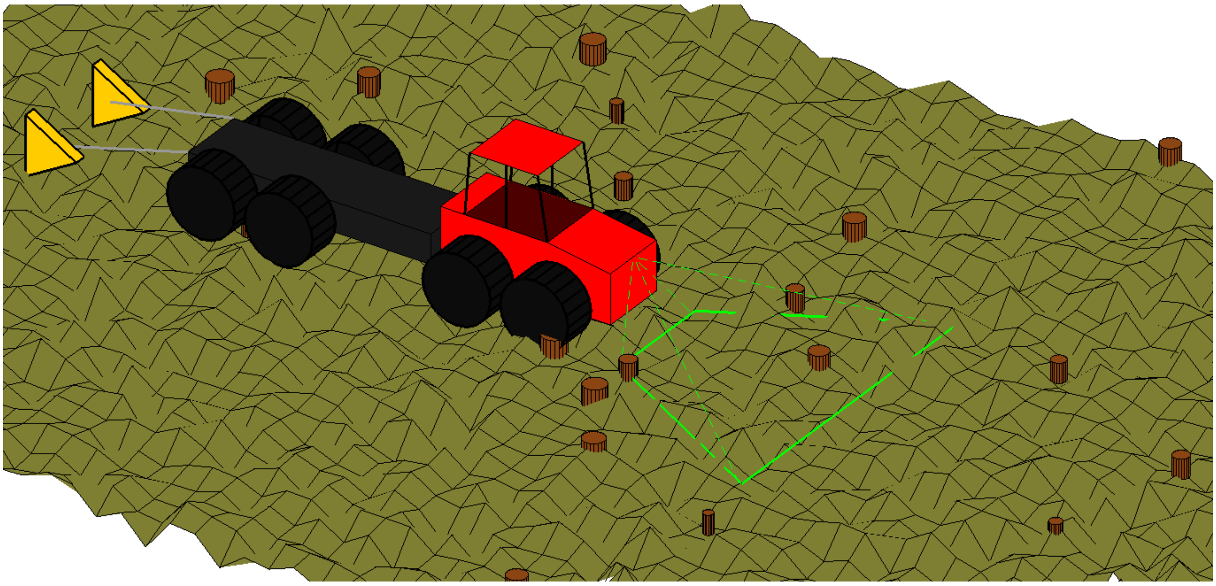


Figure 14. Bonnet mounted camera

The three different positions are summarized in Table 6, along with height and inclination angles used. After evaluating these options a decision was made that the camera should be mounted on the bonnet.

Table 6. Summary of camera positions

	Roof, facing downwards	**Roof, facing forwards**	**Bonnet**
Camera height, h	3 m	3 m	1,9 m
Inclination angle	38,4°	71,5°	45,0°
Smallest measurement distance	3,07 m	4,24 m	2,00 m
Largest measurement distance	7,06 m	Inf.	5,99 m
Smallest distance in front of forwarder	0,63 m	1,5 m	0,64 m
Largest distance in front of forwarder	6,39 m	Inf.	5,68 m
Smallest width	4,29 m	5,94 m	2,51 m
Largest width	9,88 m	Inf.	7,50 m
Resolution	1 pixel = 6,18 cm	1 pixel = Inf.	1 pixel = cm
Comments	The bonnet and front wheels obstruct the view.	Avoids bonnet, but is directed into the sky. Poor resolution and most of the view is outside the range of the camera.	Good field of view and resolution. Not enough width in the region close to the forwarder.

When mounting the camera the inclination angle should be adapted to the height of the camera. A side view of the camera and its field-of-view is shown in Figure 15. The camera is positioned at a height h above the ground surface with an inclination angle θ. The vertical field-of-view for the camera is limited by an angle of 53°, see Appendix G.

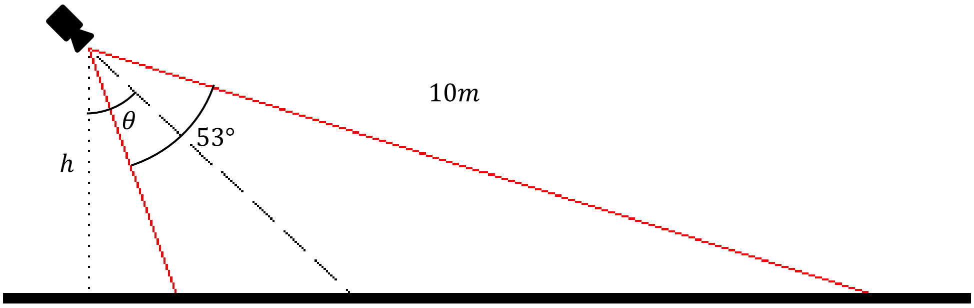


Figure 15. Side view of camera position

From the figure the inclination angle for this specific ToF camera mounted at height h can be derived as

$$\theta = \arccos\left(\frac{h}{10}\right) - \frac{53^\circ}{2}. \tag{1}$$

This will keep the field-of-view within the 10 m range of the camera.

7.2. Camera Support Structure Design

As the camera was going to be tested on a forwarder, a support needed to be designed and built to perform the tests. The main purpose was to attach the camera to the forwarder, and also to have good adjustability. Two important parameters when analyzing the data from the preparatory tests were the angle of the camera compared to the ground, and also the height above the ground, see Equation (1). In order to be able to adjust the camera height, the support was designed to be mounted on the dozer blade on a forwarder. Thus, when raising and lowering the blade the camera height can be changed. In order to easily adjust the angle of the camera, the support was designed so that the camera had a predetermined angle, described in section 6.1, when the top part of the support, the outer casing, was horizontal. Also, two long slits were machined in the casing, in case the angle needed to be adjusted, see Figure 16.

Since the camera was expensive and a rare prototype, it was important that it would not break during tests. Thus, the support was created with robustness and simplicity in mind. In order to keep branches and other debris from hitting and possibly scratching the camera, the support was designed to protect the camera. Other risk possibilities were rain, snow or wind that could damage the electronics of the camera, whereupon a sleeve was manufactured to cover a part of the back. A 3-D model of the support, green in the picture, is shown in Figure 16.

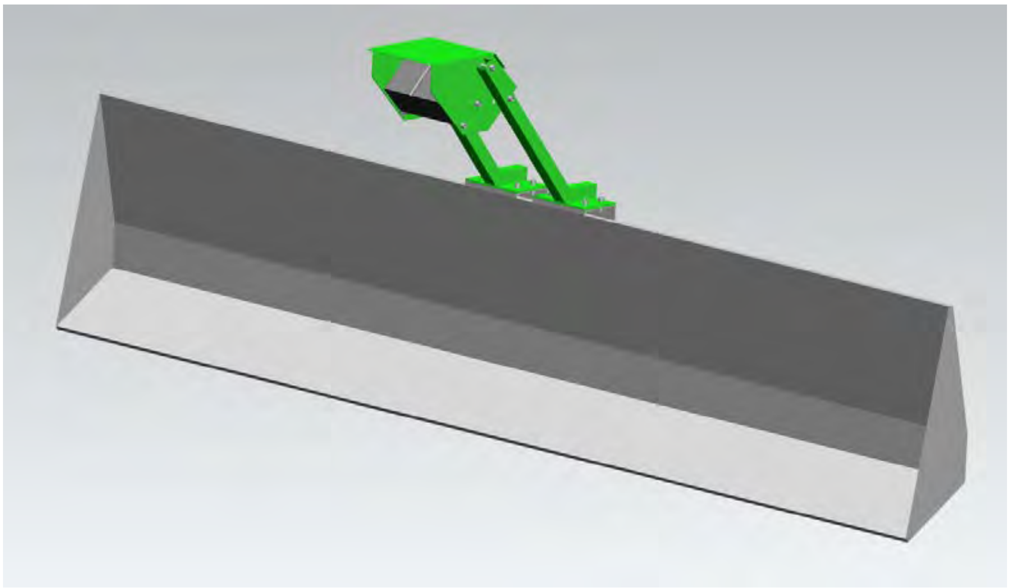


Figure 16. Support of ToF camera mounted on a forwarder dozer blade.

There were two main concepts for a solution with the camera mounted on the machine. One concept is to integrate the camera in the front of the machine as a permanent solution. Another solution is to bolt the camera support onto the machine when needed, as described above in this section.

If the ToF-camera gains other functions than detecting obstacles, such as part of a solution to navigate the mounder, an integrated concept is to be sought for whilst if the camera is not used for more operations a hang-on solution will be more likely to be adopted. As mentioned earlier, the camera is not to be subjected to severe hits by e.g. branches or bushes since they either could directly break the camera or scratch the lenses, thus it needs to be positioned in such a way that these contacts are prevented. By assumption, the manufacturers of mounders have experience in how equipment can be mounted in front of the machine so it will not break. Thus, they will also be able to find a position where the camera is protected. If a hang-on solution is to be designed, this solution will not follow the contours of the mounder and therefore most likely will be subjected to a greater risk of branches breaking the camera.

Assuming that the camera will be used for more than obstacle detection and that there is interest from the manufacturers of mounders in adopting this solution, a concept with the camera integrated in the front of the mounder was designed. As this was a very early concept, more of an idea, not much consideration has been taken in how user-friendly this solution will be. Another problem that could arise is that the front must be rigid enough not to cause severe vibrations, which could distort the picture. However, even if the current mounders are not rigid enough they do not have a cut-out for the camera, why a redesign is necessary anyway. A 3-D model, that also holds space for an IR-camera, can be seen in Figure 17.

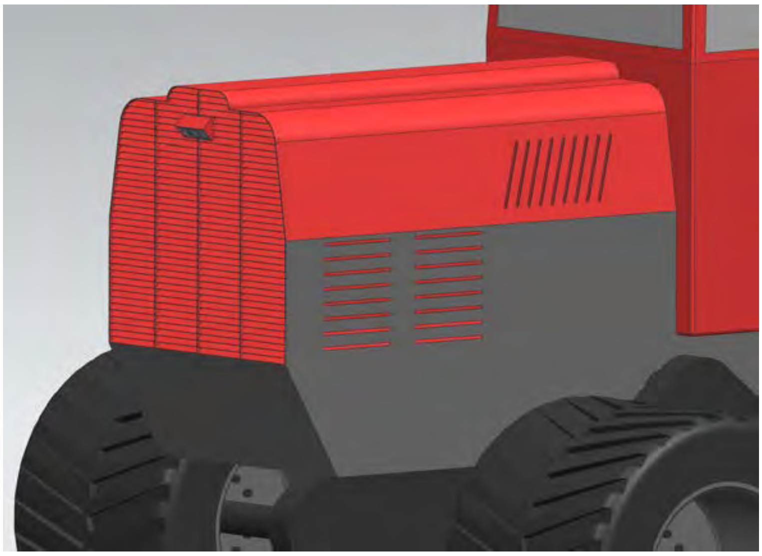


Figure 17. Camera integrated with the base machine

Figure 18 show the fabricated support mounted on a forwarder.

Figure 18. ToF camera mounted on forwarder

7.3. Design of Experiments

To verify that the camera works as intended, tests were planned to be executed under conditions similar to the actual conditions of the application. Ulrich and Eppinger [5] define a robust product as one that performs as intended even under non-ideal conditions and should be robust to noise factors. The approach to robust design is based on a method called Design of Experiments (DOE) in a seven-step process suggested by Ulrich and Eppinger [5]. Since the camera is an already existing product, the steps of the DOE have been narrowed down to a four step process adapted to investigate if the camera will work as intended in its operating environment:

I. **Identification of control factors, noise factors and performance metrics:**

- **Control factors:** These factors are known, such as the camera height from ground surface, operation speed of machine and pre-scanning distance of the camera. The height of the camera and the pre-scanning distance is based on calculations where an optimized height and inclination angle were determined for the best field of view and picture resolution.

- **Noise factors:** Variables that cannot be explicitly controlled during the manufacturing and operation of the product. This may include different terrain types, weather conditions, and other things that can affect the camera.

- **Performance metrics**: This point should be used to see how well the product fulfills the requirements for the project. The data from the experiment will be post-processed.

II. **Developing the experimental plan:** This step consists of all the preparations needed to conduct the experiment with the ToF camera. To be able to test the noise factors influence on the camera it is important that the execution of the test is as realistic as possible. This requires a clearcut area, a forwarder to mount the camera on, and research of what equipment that is needed to use the camera and analyze the data with.

III. **Run the experiment**

IV. **Conduct the analysis**

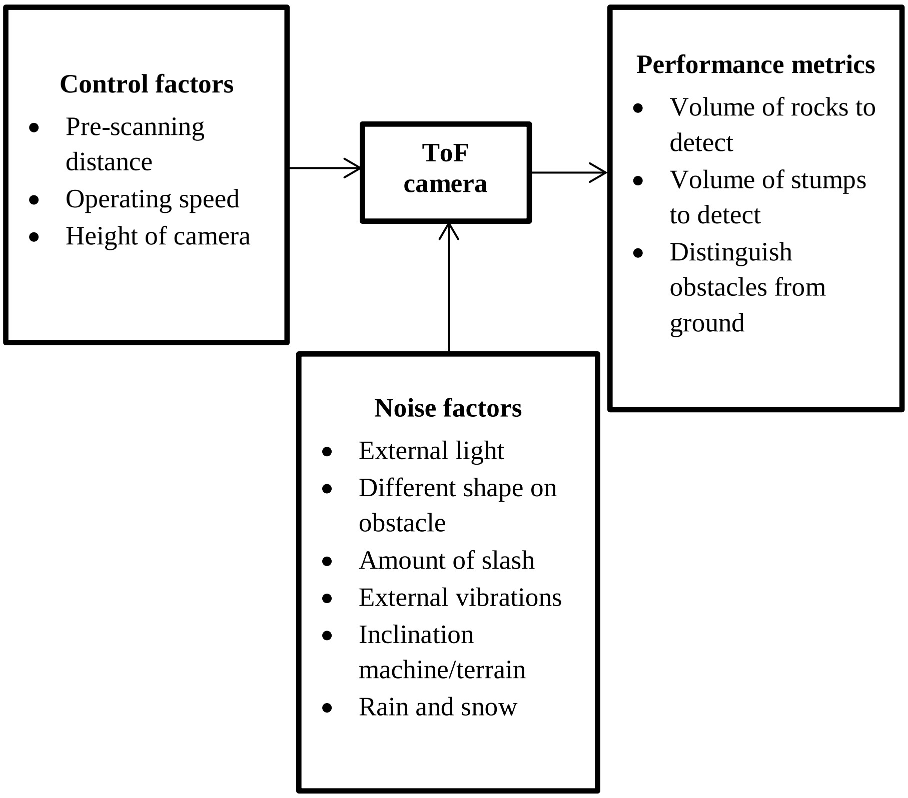


Figure 19. Parameter diagram for the ToF camera

7.3.1. Preparatory Test ToF Camera

The preparatory test will give an opportunity to learn how to handle the camera and the equipment that is needed to perform tests. It will also give an opportunity to test the software and analyse how the data can be used.

Purpose: Gain knowledge of the camera, its software, and collect data for further development.

Location: The test was performed in an indoor environment at LTU and on a clearcut located in Porsön, nearby the campus.

Equipment needed to perform the test: ToF Camera**,** Battery, Converter, Cables, Net adapter, Computer to store data, Router, System camera, Spirit level, and a Ladder.

Goal: The goal with the preparatory test was to gain basic knowledge of how to use the camera, the associated software, and equipment needed to perform the tests. The goal was also to get data for post-processing and evaluation.

Test procedure: During the tests the camera was placed on a ladder and the height above ground measured. The bracket made for the camera gave the camera an inclination angle against the ground of approximately 45° and the bracket was kept in the right position by using a spirit level. During the indoor test, data and pictures of a bucket placed on a plane floor was retrieved. The outdoor tests were performed under conditions that represent the real operating conditions for the application. The documentation consists of photographs and data for post-processing. The experimental setup used during the tests is shown in Figure 20.

Figure 20. Experimental setup

7.3.2. Analysis of Indoor Tests

The point cloud generated from the TOF camera was transformed and rotated to a coordinate system against the ground surface as described in section 7.4.2. Figure 21 shows the point cloud transformed to the ground. The deviating pixels corresponds to the bucket that was placed 2 meters in front of the camera. Due to the inclined angel of the camera, shadows will appear behind the obstacles and data points will be located at the front of the bucket, which can be seen in Figure 21.

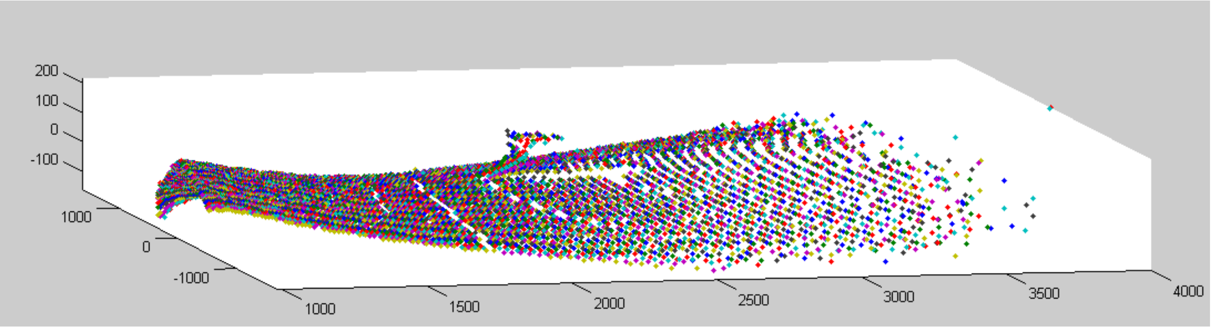


Figure 21. Point cloud from the TOF camera with a bucket placed 2 meters in front of the camera

In Figure 22 the bucket is placed 3 meters in front of the camera. The tightness of the pixels get less further away from the camera but it is still possible to recognize the deviating pixels that corresponds to the bucket.

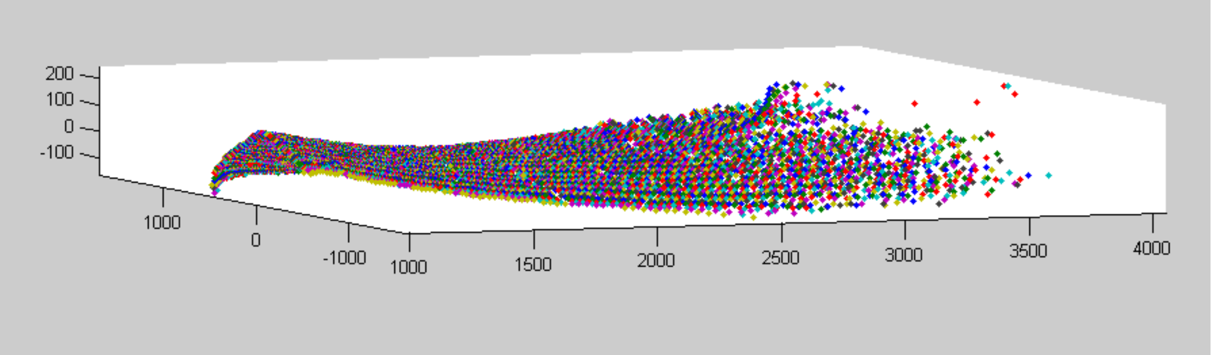


Figure 22. Point cloud from the TOF camera with a bucket placed 3 meters in front of the camera

7.3.3. Analysis of Outdoor Tests

Figure 23 shows one of the scenes that were measured during the outdoor preparatory tests. The image shows two large stumps in the foreground that are distinguished from the rest of the terrain.

Figure 23. Camera view during outdoor testing

The same view as a point cloud is shown in Figure 24. This image is hard to interpret with the naked eye. However the two stumps can be identified. The figure also reveals the shadows that occur behind the obstacles. These appears as the white areas within the point cloud.

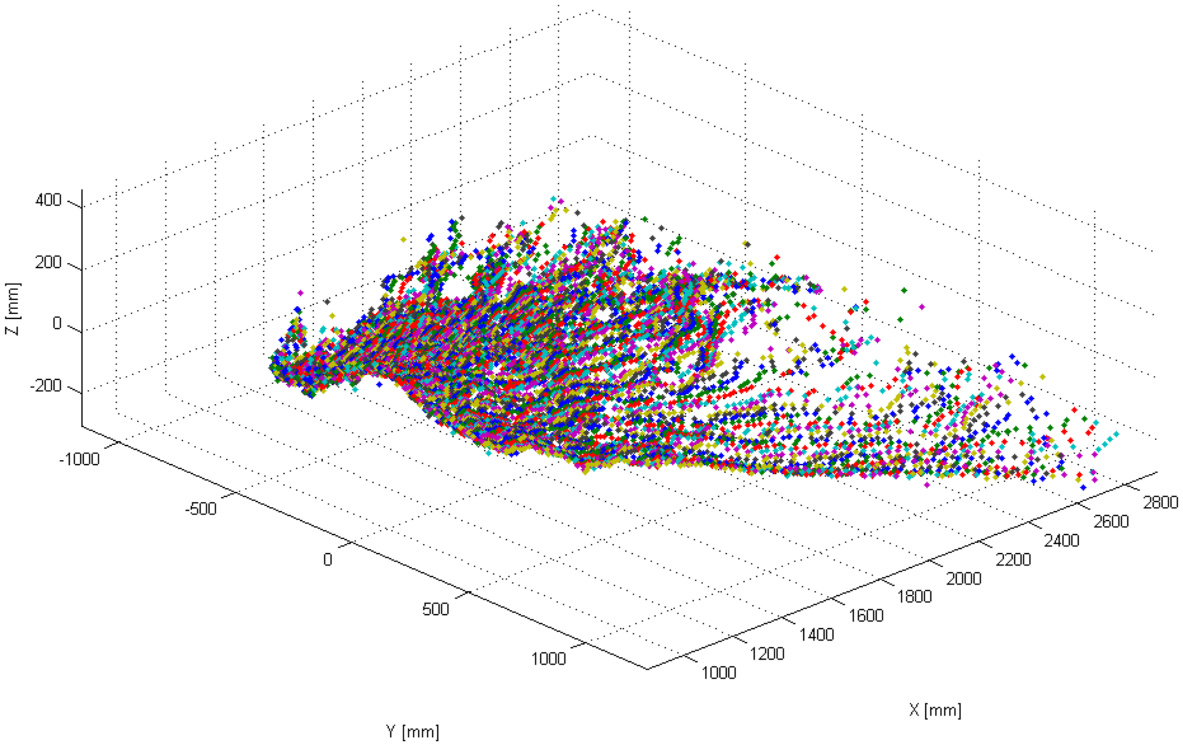


Figure 24. Point cloud over clearcut terrain

From the preparatory test, it can be seen that an algorithm for obstacle detection needs to be developed that can detect the deviating point cluster and register them as obstacles.

7.4. Data Processing

Data processing is needed for interpreting the output from the ToF camera in order to determine whether obstacles will interfere with the mounding procedure.

7.4.1. Graphical User Interface

The main application for the obstacle detection system is required to process data from the ToF camera in real time and position the detected obstacles relative to the position of the mounding units. While the program runs, it will continuously do the following:

- Get the latest frame from the ToF camera
- Determine the forwarder’s motion since last captured frame and adjust the coordinates for previously detected obstacles
- Identify any new obstacles and position them relative to the forwarder
- Determine whether an obstacle will interfere with the mounding operation

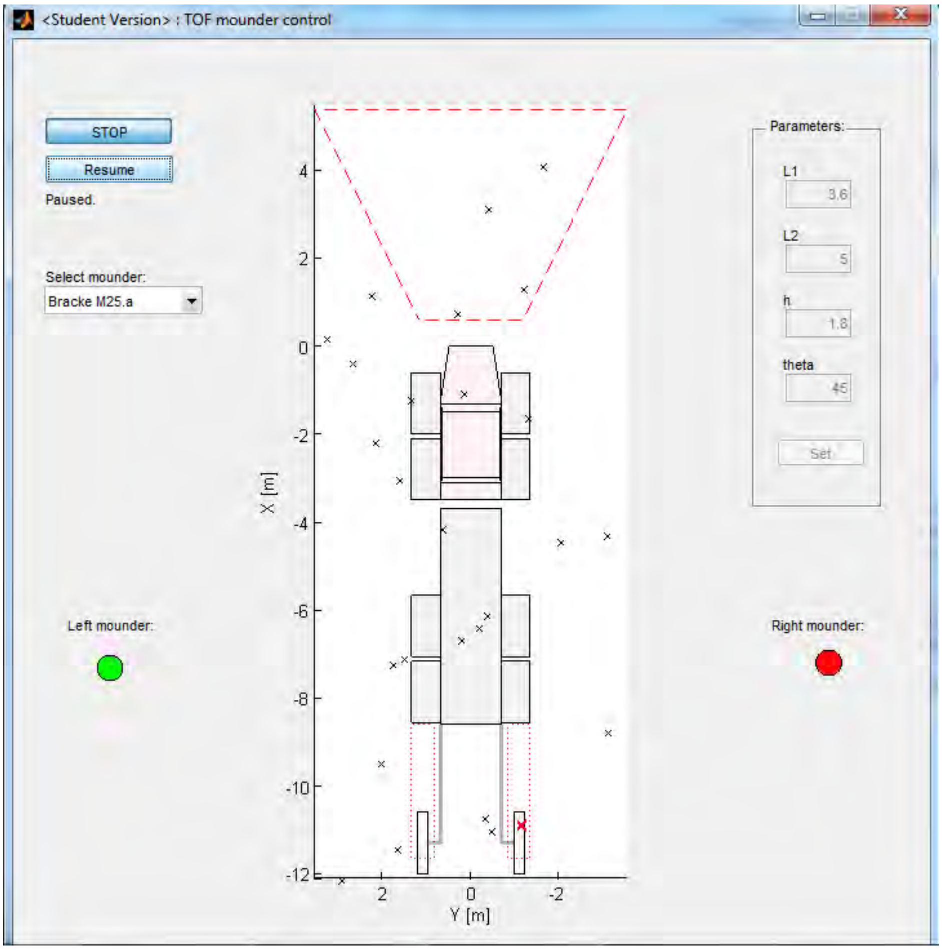
The program and its graphical user interface (GUI) were created in MATLAB and the intention is to implement the techniques described in the following sections on the final product. The idea is that the final version of the GUI will allow the driver/operator to:

- Control and monitor the obstacle detection process

- Specify camera position and important forwarder dimensions
- Choose which mounding unit to interact with the obstacle detection system

Since the obstacle detection and operation of the mounders will be fully automated, none input is required from the driver during operation. This enables the driver to focus on other tasks such as driving the forwarder and navigating through the terrain. If necessary, the obstacle detection process can however be monitored.

The program described here, however, simulates the process with the obstacles being randomly positioned with a uniform distribution. The purpose of making this simulated program is to determine what features should be added to the user interface and how it should work. A screenshot of the GUI is shown in Figure 25.


<Student Version> : TOF mounder control

Paused.

Select mounder: Bracke M25.a

Parameters:

L1 3.6

L2 5

h 1.8

theta 45

Figure 25. Graphical user interface

In the upper right corner of the GUI a set of parameters are listed. These describe the dimensions of the forwarder together with the height and inclination angle for the camera. These parameters are set for each forwarder that will be used or if the camera position is changed. A pop-up menu allows the operator to choose from a set of predefined mounding units. This selection influences the position of the mattock wheels and thus the region where any obstacles will interfere with the mounding operation.

Table 7. Parameters for the forwarder and camera

Parameter name	Unit	Description
L1	[m]	Distance – camera position to forwarder waist
L2	[m]	Distance – forwarder waist to rear end
h	[m]	Camera height
theta	[°]	Camera inclination angle

The main window shows a two-dimensional plot of the forwarder being shown from above. The dashed red lines denote the camera's field-of-view and detected obstacles are marked with crosses. As the forwarder drives through the terrain the marked obstacles in the plot will appear to move relative to the forwarder since the origin of the coordinate system in the XY-plane is defined as the position of the camera. The coordinates for obstacles that are driven past will be deleted to prevent memory overflow.

The user controls the process by two toggle buttons. The upper button starts and stops the measurements. As the process is stopped the coordinates for detected obstacles will be erased since it is not certain that the forwarder will be at the same location when the measurements will resume. There is also a pause button, which stores the current coordinates and allows the driver to resume the process.

When a detected obstacle comes within a critical area near the mounding units the corresponding indicator in the GUI changes colour from green to red and the subjected obstacle is highlighted in the plot. When this happens the final program is supposed to communicate with the mounding unit so that necessary precautions can be taken to avoid the obstacle. The critical areas around the mounding units are denoted with dotted red lines in the plot.

7.4.2. Transformation into Vehicle Coordinates

The coordinates obtained from the ToF camera are based on a coordinate system with its origin at the camera position and the z-axis pointing in the camera's direction [27]. In order to relate the measured terrain to the position of the forwarder these coordinates must be transformed into the vehicle's coordinate system, which has its origin at the front of the forwarder on the ground surface. Here, the x-axis is pointing in the forwarder's direction and the z-axis is directed upwards. The two different coordinate systems are displayed in Figure 26.

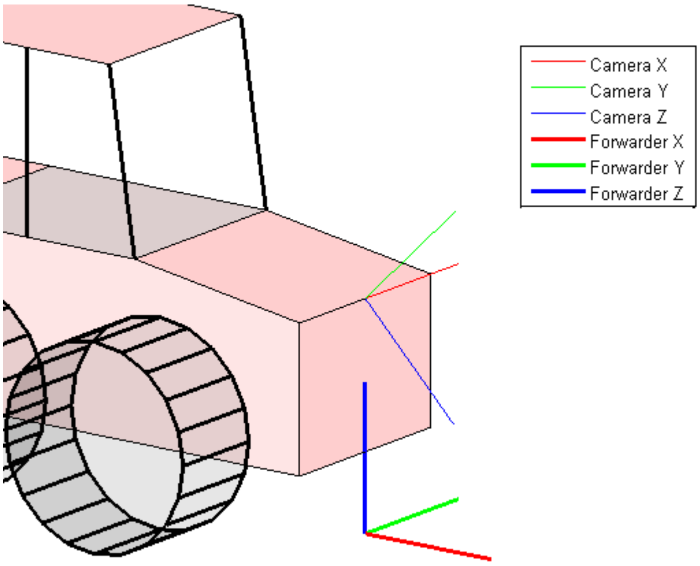


Figure 26. Definition of coordinate systems

The position of the camera is defined by its height h above ground surface and the angle θ between the camera's direction and a vertical line.

After the data has been acquired from the camera it is transformed by rotating it by θ around the camera x-axis, 180° around the y-axis and 90° around the z-axis. This is performed by using the rotation matrices [27] in equation (2), (3) and (4).

$$\boldsymbol{R_x} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}, \tag{2}$$

$$\boldsymbol{R_y} = \begin{bmatrix} \cos 180° & 0 & \sin 180° \\ 0 & 1 & 0 \\ -\sin 180° & 0 & \cos 180° \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \tag{3}$$

and

$$\boldsymbol{R_z} = \begin{bmatrix} \cos 90° & -\sin 90° & 0 \\ \sin 90° & \cos 90° & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{4}$$

If the coordinates to all measured points are gathered in a 3-by-n matrix $\boldsymbol{M}$ where every column is a column vector representing a data point [27], then $\boldsymbol{M}$ is described as Equation (5)

$$\boldsymbol{M} = \begin{bmatrix} x_1 & x_2 & \dots & x_n \\ y_1 & y_2 & \dots & y_n \\ z_1 & z_2 & \dots & z_n \end{bmatrix}, \tag{5}$$

where the transformed coordinates are obtained from (6)

$$\boldsymbol{M}_{tr} = \boldsymbol{RM}, \tag{6}$$

where $\boldsymbol{R}$ is defined as (7) [27]

$$\boldsymbol{R} = \boldsymbol{R_z R_y R_x}. \tag{7}$$

Finally, the z-coordinates are added with h so that the origin becomes at ground level. Figure 27 shows the coordinates for a completely flat ground surface using both the camera coordinate system and the vehicle coordinate system.

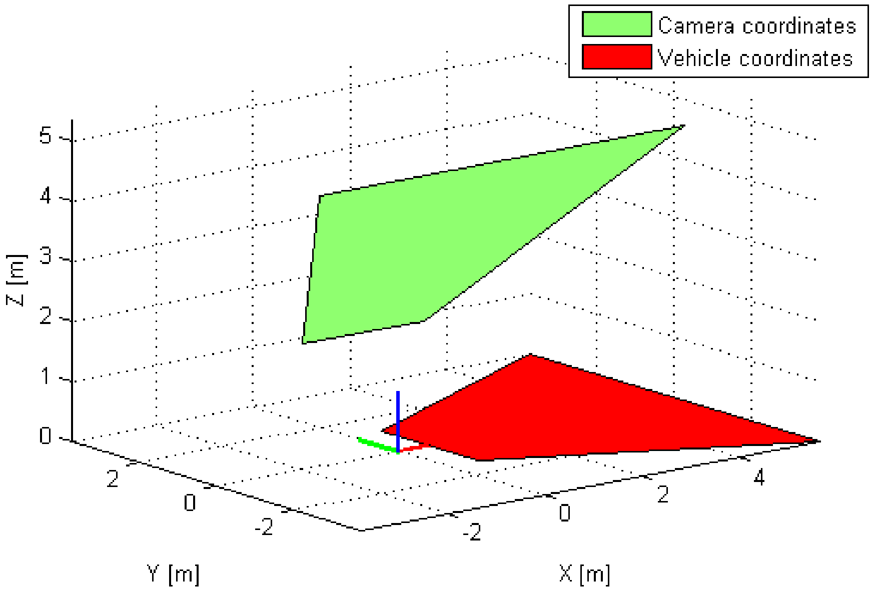


Figure 27. Field-of-view in camera coordinates and vehicle coordinates

7.4.3. Algorithm for Identifying Obstacles

For each frame that the TOF camera captures it is necessary to interpret the 3-D image in order to identify and position any obstacles in the frame. This requires data processing in order to obtain functional obstacle detection. For this purpose, a simple algorithm was developed and implemented in MATLAB. For each frame the algorithm will perform the following:

- Divide the terrain within the camera field-of-view into a number of segments
- Perform a plane fitting on the data points within each segment
- Repeat the two previous steps for a set of overlapping segments
- Identify pixels with significant positive deviation in the z-direction from both fitted planes
- Group these pixels into a set of coherent obstacles and determine their position
- Sort out small obstacles

The segmentation is performed by applying a square grid onto the data points received from the camera after the transformation has been done. The number of segments, and thus the size of each segment, determines the size of the obstacles to be detected. All data points within each segment are formatted as three column vectors $\bar{\boldsymbol{x}}$, $\bar{\boldsymbol{y}}$, and $\bar{\boldsymbol{z}}$ containing the x-, y- and z-coordinates for each point.

The plane fitting is performed by using multilinear regression [28] using the equation

$$\bar{\boldsymbol{a}} = (\boldsymbol{X}^T\boldsymbol{X})^{-1}\boldsymbol{X}^T\bar{\boldsymbol{z}}, \tag{8}$$

where the matrix $\boldsymbol{X}$ is defined as

$$\boldsymbol{X} = [1 \quad \bar{\boldsymbol{x}} \quad \bar{\boldsymbol{y}}] = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ \vdots & \vdots & \vdots \end{bmatrix}. \tag{9}$$

This is done in order to obtain the plane coefficients for the segment in a column vector as

$$\bar{\boldsymbol{a}} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}. \tag{10}$$

The fitted plane can now be described by the equation

$$z = a_1 + a_2 x + a_3 y. \tag{11}$$

Figure 28 shows the result from the plane fitting over all segments in the point cloud data obtained from the camera.. The fitted planes are shown as the grey transparent planes in the plot. Those data points whose residuals in z-direction exceed a certain value are shown as red dots in the plot. Other data points are represented by blue dots.

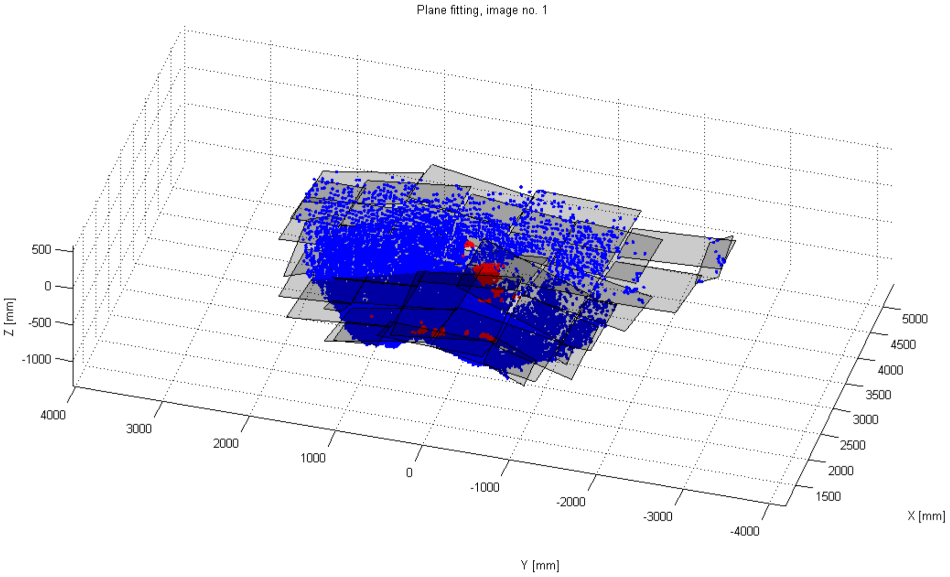


Figure 28. Plane fitting over point cloud data

The minimum value for the residuals for potential obstacles influences the result of the obstacle detection. Choosing a small value will increase the certainty of all obstacles being detected, but will however result in a large amount of false detections where there are no actual obstacles in the terrain. In this example the minimum residual value is set to 100 mm. Figure 29 shows the protruding pixels plotted in the XY-plane.

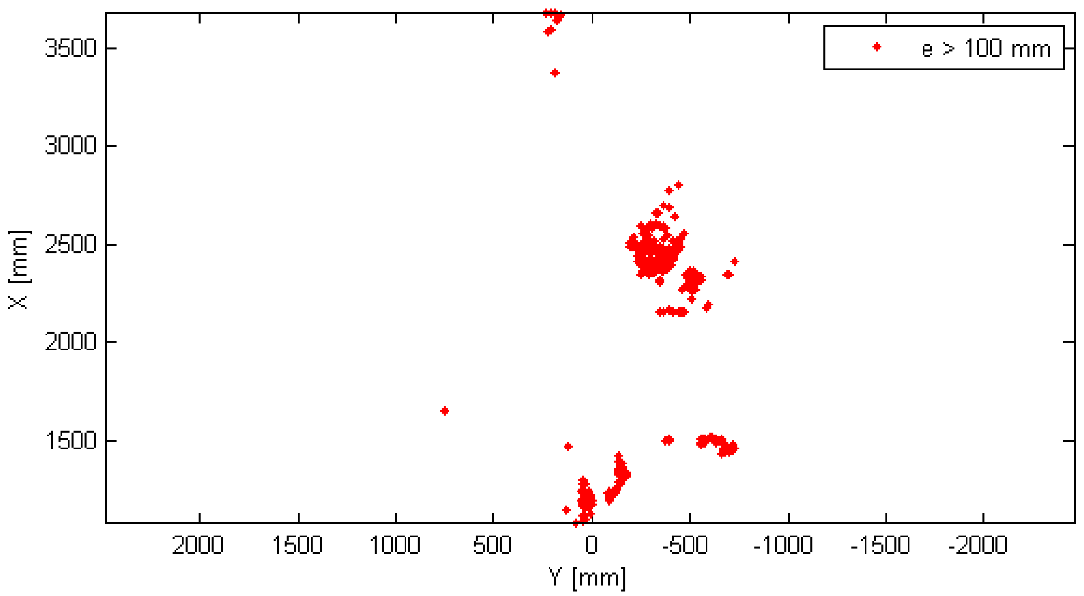


Figure 29. Two-dimensional plot over protruding pixels

In order to determine the size and position of the obstacles the protruding pixels are grouped into a set of contiguous formations. These formations represent possible obstacles in the terrain in front of the vehicle. The grouping is done by merging all pixels that are adjacent in the data matrices obtained from the camera into a group. This is implemented in MATLAB as a data structure where each element is a row vector containing the indices of all pixels in the group. Figure 30 illustrates the pixels in a data matrix where the protruding pixels in Figure 29 are assigned the value 1. If two or more of these pixels are adjacent they will belong to the same group. Isolated pixels will be ignored.

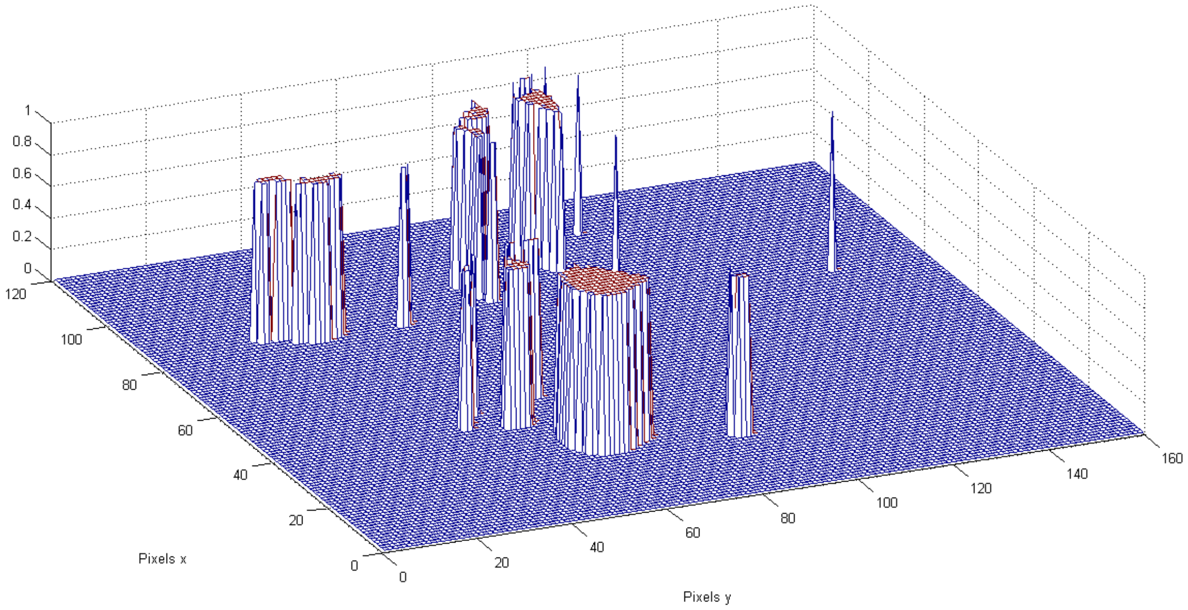


Figure 30. Adjacent pixels in data matrices

Each group of pixels are assigned an x- and y-coordinate by calculating the mean value of the coordinates for the associated pixels. An approximate area is calculated for each obstacle based on the mean x-value and camera position. Finally, all detected obstacles with too few pixels or too small area are deleted from the data structure. The input parameters for the algorithm used in this example are summarized in Table 8.

Table 8. Parameters used for the algorithm

Parameter	Unit	Value
Number of segments	[-]	16
Minimum residual value	[mm]	100
Minimum number of pixels	[-]	5
Minimum cross-section area	[mm^2]	5000

The remaining groups of pixels form the result of the obstacle detection algorithm. This is shown in Figure 31 where the detected obstacles are shown as the coloured formations in the plot. The assigned coordinates are shown as black crosses.

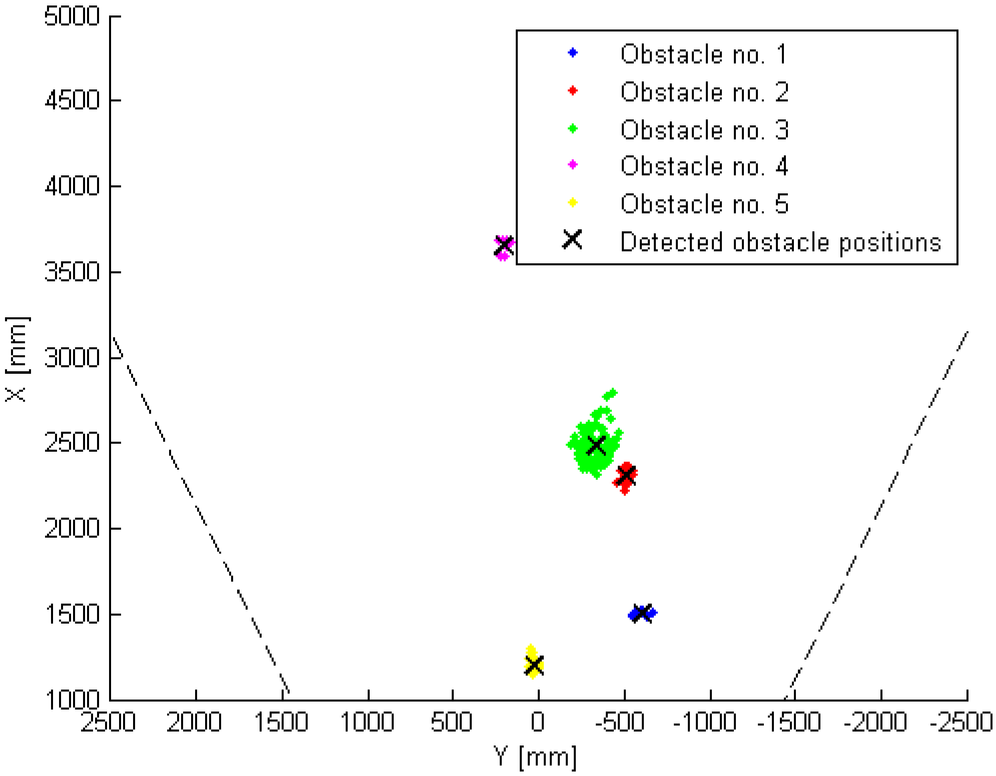


Figure 31. Plot over detected obstacles

As a comparison Figure 32 shows a picture of the actual terrain with each obstacle highlighted in the corresponding colour to the detected obstacles in Figure 31.

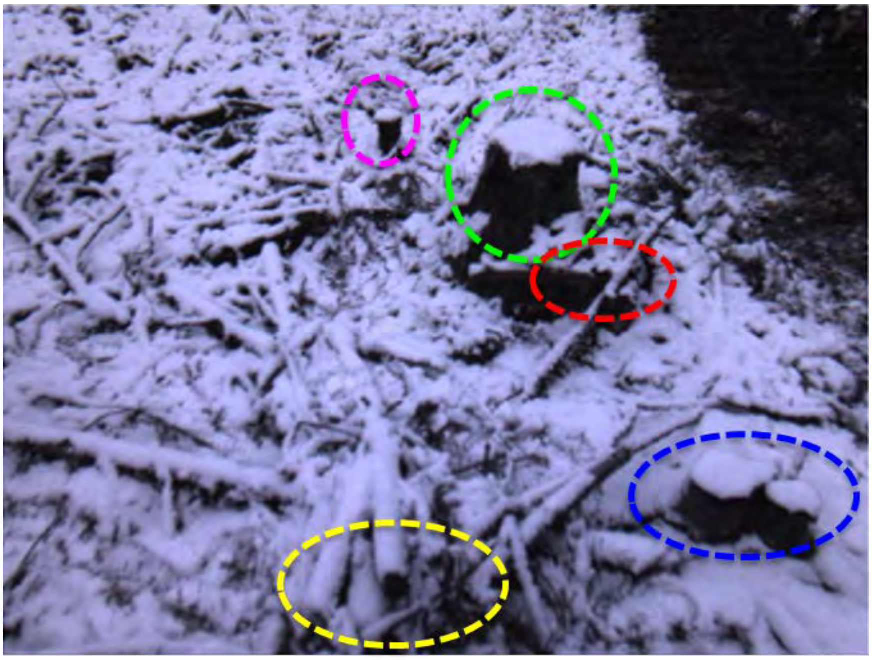


Figure 32. Actual obstacles

8. Final Concept - Testing and Evaluation

A number of tests were performed in order to determine whether the final concept satisfies the project goals. This was also an opportunity to measure and validate its performance in the product's real operating environment.

8.1. Main Test ToF Camera

The ToF camera is going to be tested in its real operating environment mounted at the front of a forwarder. This test will give information about how well the camera performs under the influence of noise factors, and how well it will satisfy the metrics formed during the Needfinding phase, see Table 2.

Purpose: To test the performance of the camera in its real operating environment.

Location: The test was conducted mid-day early November in northern Sweden, nearby Skogforsk, Sävar. At the time the weather was cloudy with a snow cover of around 1 centimeter. The temperature was around 0 degrees Celsius during the whole test.

Equipment needed to perform the test: ToF Camera**,** Battery**,** Converter**,** Cables**,** Net adapter**,** Computer to store data**,** Router**,** System camera**,** Ladder, and a Spirit level

Test procedure: The camera was mounted on the forwarder's dozer blade, see Figure 33, which enabled the height to be adjusted to desired value. The inclination angle was adjusted to the optimal angle calculated as aforementioned in Section 6.1. When driving the forwarder, the aim was to keep a straight course and constant speed to facilitate the data post processing.

Figure 33. Experimental setup

Different tests were executed to investigate the following metrics separately:

Speed: The forwarder was driven a given distance, of approximately 25 and 50 meters, with an average speed of 1.5km/h and 3 km/h. From this test, it will be possible to evaluate the speeds impact on the collected data.

Vibrations: Data was collected and a picture taken when the forwarder was standing still, with the engine running. For comparison the same procedure was executed, but with the engine off. Through comparison of the data, this will give an estimation of the effects of engine vibrations.

Obstacle size and position: With the forwarder standing still, data was collected, and the geometry from the camera to different obstacles in the field of view is measured, together with obstacle size. The size and position that can be derived from the resulting data is then compared to the measurements. This was done in order to evaluate the accuracy of the camera.

8.2. Analysis of Main Test ToF Camera

Figure 34 shows the resiudals plotted in a diagram where the X-axis represent the distance to the obstacle along the ground surface, and the Y-axis represent the sideway distance from the center of the camera to the obstacle. The resiudals in the plotted diagram are pixels that deviates with a specific value, see Table 8, after the plane fitting. In Figure 34, the potiential obstacles are color coded and the dashed circels marks the manually measured distance to corresponding obstacle.

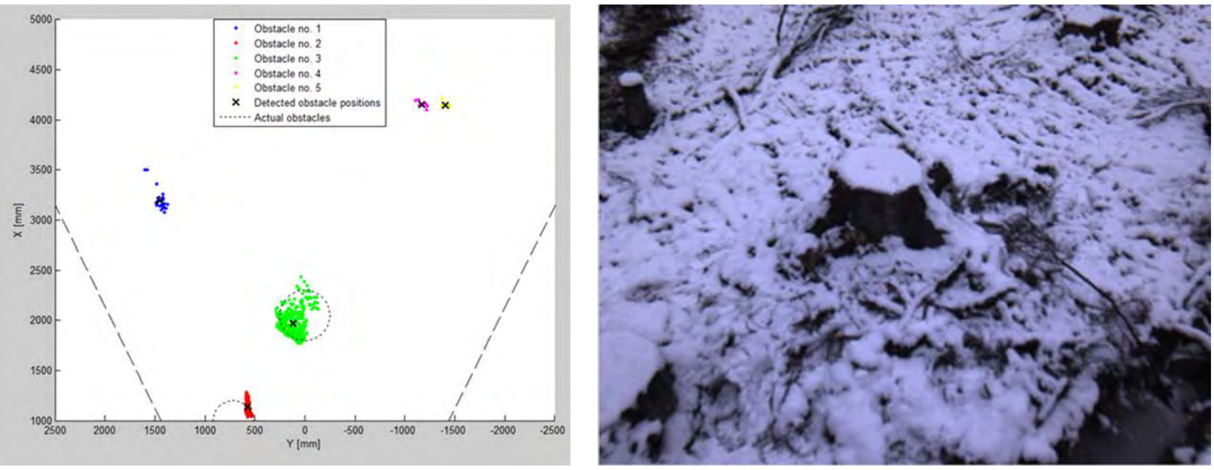


Figure 34. The left plot illustrates the residuals over the scanned area, and the right picture represents the scanned area

In Figure 35 there are 4 color-coded obstacles. The dashed circle corresponds to the manually measured distance to the stump coded with blue color. The green and the purple obstacle are stumps that can be seen in the picture of the scanned area. The red obstacle is slash in front of the picture. The slash in front of the picture will probably not be an obstacle during scarification, but it has deviating residuals that are captured by the program, which register the slash as a potential obstacle.

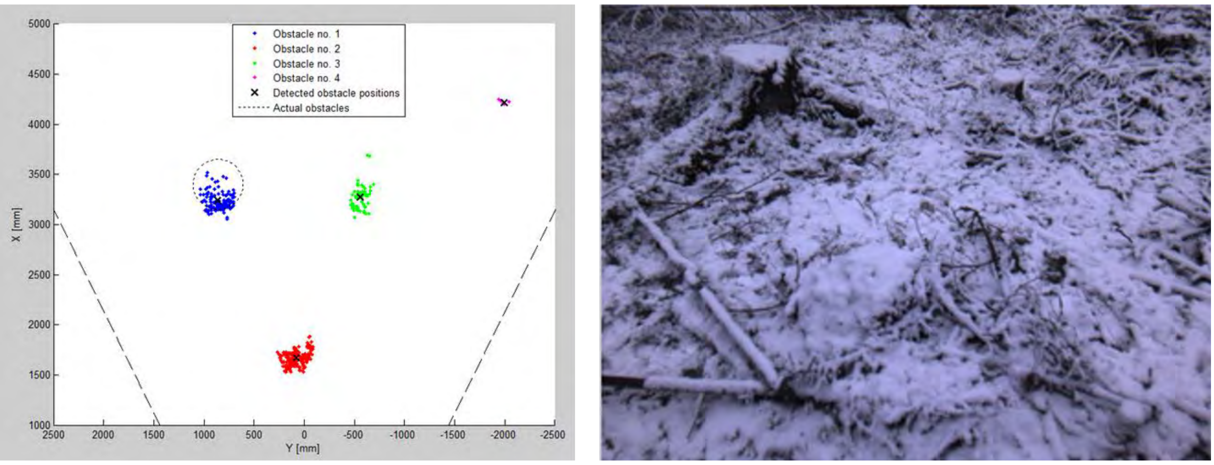


Figure 35. The left plot illustrates the residuals over the scanned area, and the right picture represents the scanned area

In Figure 36, the right picture, there are 3 stumps. The dashed circles correspond to the manually measured distance to the corresponding obstacle. The dashed circles are behind the cross mark which could be a result of flaunting manually measurements.

However, due to that the camera has an inclined angle, shadows will appear behind the obstacles and data points will be located at the front of the obstacle. In turn, this leads to that the center of the point cloud, representing the obstacle, will be in front of the actual obstacle.

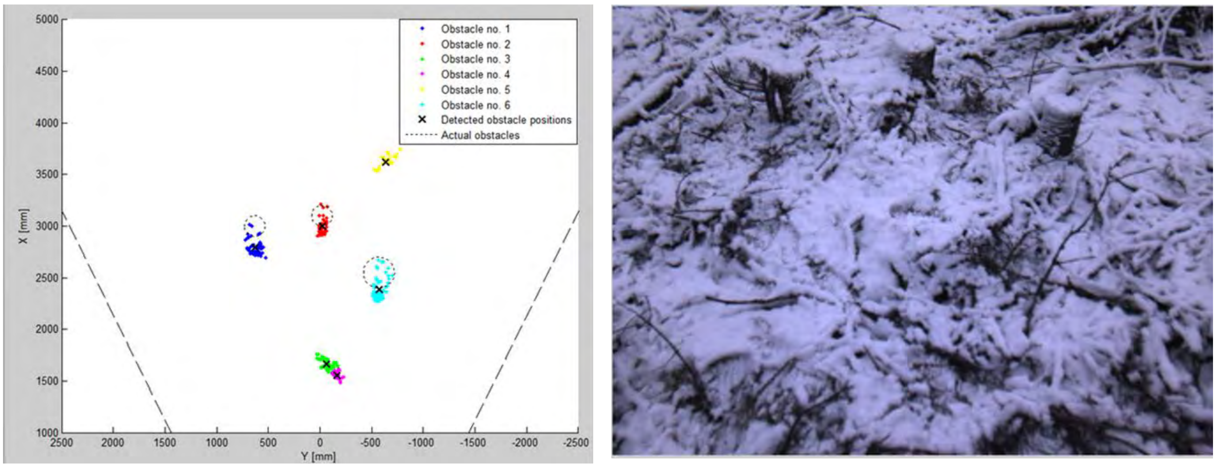


Figure 36. The left plot illustrates the residuals over the scanned area, and the right picture represents the scanned area

A mean value of the accuracy for all pictures was then calculated to validate the efficiency of the detection algorithm, which can be seen in Figure 37. The accuracy was determined by dividing the number of correct detected obstacles by the number of actual obstacles in the image. The results from the tests showed an accuracy of approximately 94 %.

In some cases the detection algorithm detected more obstacles than there actually were in the picture. This was caused due to slash on the ground that had data points above ground surface, which was register as obstacles. What this means is that the detection algorithm for the camera sees more obstacles than there really is.

	Number of obstacles in the picture	Number of detected obstacles	Number of missed obstacles	Number of wrongly detected obstacles	Number of correct detected obstacles	Accuracy
Picture 1	5	5	0	0	5	1
Picture 2	3	7	1	5	2	0,666666667
Picture 3	4	5	0	1	4	1
Picture 4	2	5	0	3	2	1
Picture 5	4	6	0	2	4	1
Picture 6	3	4	0	1	3	1
						0,944444444

Figure 37. Accuracy of detection algorithm

8.3. Infrared and Soil Moisture Test

The execution of the test will be to use a soil moisture meter to measure the moisture content in the soil and compare it to the picture from the IR-camera. This is done to see if it is possible to recognize different soil moisture with the IR-camera.

Purpose: Test if it is possible to detect different soil moisture on a cutting area using an IR camera.

Location: The test was conducted mid-day in the end of October in northern Sweden, Luleå. At the time the weather was clear, with a temperature of 6 degrees Celsius.

Equipment needed to perform test: Infrared camera, system camera, and a soil moisture meter.

Goal: To be able to conclude if an IR camera is a promising tool to use to detect soil moisture with on a cutting area.

Test procedure: Temperature profile and RGB images was captured over areas with different soil moisture content, distinguished by eye. A soil moisture meter was then used to measure the soil moisture content in various places over the captured area.

8.4. Analysis of Infrared and Soil Moisture Test

Figure 38 illustrates areas with very distinguished ground properties where the humidity in the soil can more or less be recognized by the eye as water puddles. The hypothesis is that it is possible to relate the temperature to different soil moisture. In the areas where the water content is high there should be a lower heat radiation i.e. a lower temperature.

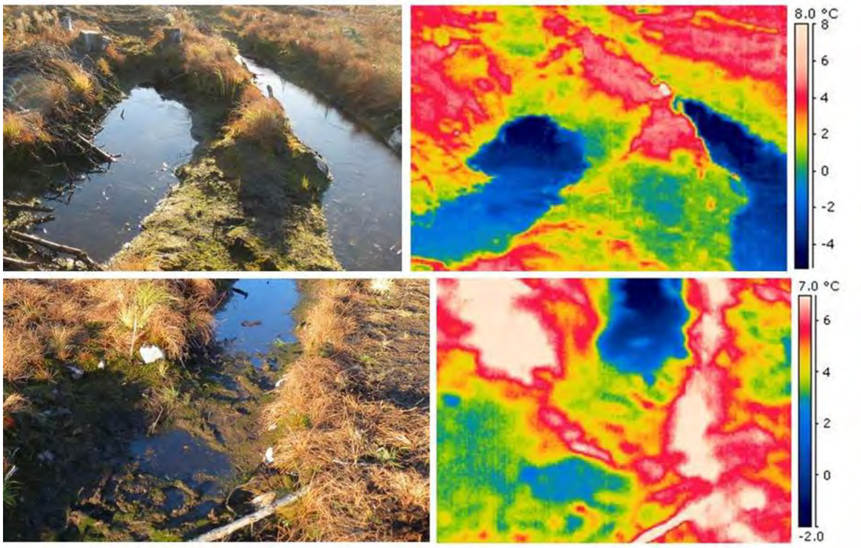


Figure 38. Infrared pictures on the ground with easily distinguishable ground properties

Figure 39 illustrates areas with ground properties that cannot be recognized by the eye. Even with the help of an infrared camera it is hard to tell if the temperature difference is caused by soil humidity, or if it is caused by shadows from nearby objects that have prevented the ground from heating up. However, it can be seen in the lower picture in Figure 39 that the side of the stump that has been illuminated by the sun is clearly visible in the IR-image.

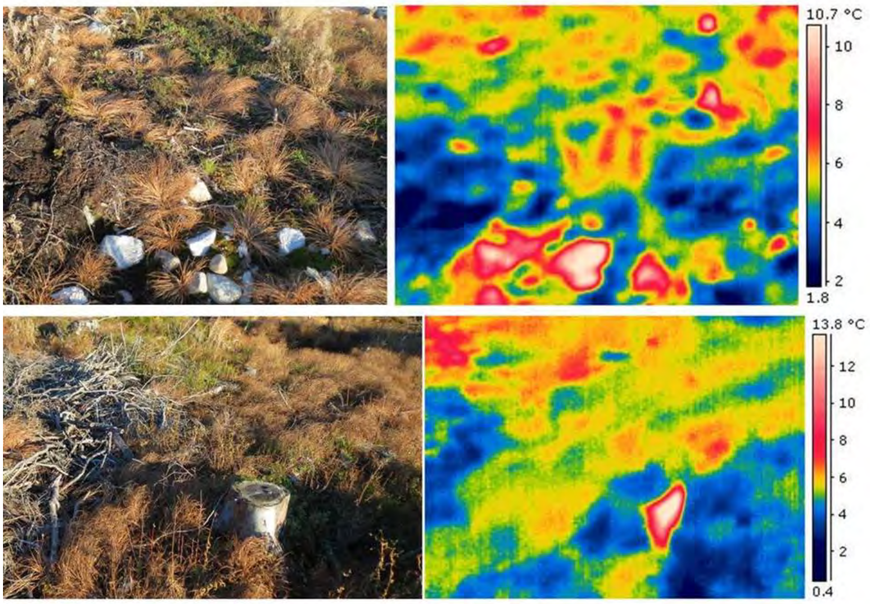


Figure 39. Infrared pictures on the ground with unclear properties

9. Discussions/Conclusions

The concept generation and selection have resulted in a solution for obstacle detection where a TOF-camera is used to map the terrain in 3-D and identify obstacles. The obstacles are found using an obstacle detection algorithm and are then given coordinates relative to the cameras position, which is described in section 6.4. IR-thermography is used as a supplement to the TOF-camera for identifying collected water in the terrain since this is also obstacles that should be avoided when scarifying. The TOF-camera supplemented with IR-thermography was selected since it was the concept that best fulfilled the list of metrics established during the Needfinding phase. In this concept, both TOF-camera and IR-thermography shall be placed at the front of the forwarder, since it was found in section 6.1 that this placement will give the best possible field of view. The suggested placement is illustrated in Figure 40 below. Since both ToF-camera and IR-thermography have been tested and evaluated, the project group have fulfilled the goal stated in the initial project description: "a solution for automatic detection of clearcut obstacles shall be developed, manufactured and tested to such extent that it can be used for validation activities".

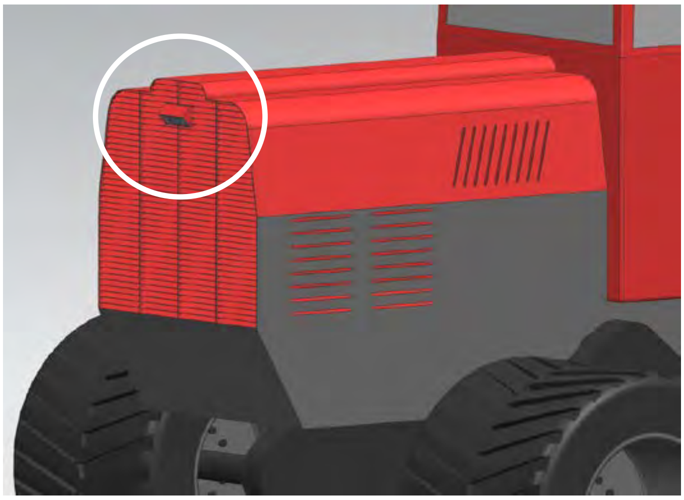


Figure 40. Hood mounted camera for obstacle detection

The field test of the TOF-camera indicated that this technique would work for an obstacle detection application for scarification operations. The field test performed in Sävar had a reliability of 94 % obstacle detection; this number however does not include stones that are in level with, or below ground level. It is unknown how many of all the obstacles that are made up of these 'shallow' stones. If the obstacle detection catches all the stumps and stones that rise above ground level, then it will likely add up to >50 % of all the obstacles [3]. The product will thus fulfill the goal set up of increasing the amount of approved scarification sites with 20% in relation to total number of sites. That is provided that the scarifier will be able to avoid the obstacles once their position is known.

The initial tests performed in Luleå had a reliability of merely 42 %, with many false detections. These tests were conducted with poor knowledge on how to handle the camera and adjust the shutter time, which resulted in very few reliable pixels in the images. The results were therefore not accredited with as much importance as the field tests. The results do however show example of difficulties that can arise during different operating conditions. There was bright sunlight at the time that caused more noise in the images; the terrain itself also had higher field vegetation, which cover the lower obstacles and can also cause false detections.

The transformation of coordinates which is performed on the camera output is based on the assumption that the camera height and inclination angle is held constant as the forwarder drives through the terrain. In fact the roughness of the terrain will cause the vehicle to pitch and roll, which will affect the camera position relative to the ground and thus result in errors regarding the measured distances. These errors are considered to be small, as long as the pitch and roll angels are small.

A prerequisite for a successful avoidance of the detected obstacles is that the response time for moving the mounding unit is kept at a minimum. This is necessary if the driver suddenly steers clear of an obstacle or makes any unforeseen manoeuvres.

The infrared camera only gives temperature values on a scanned area and provides no information about the moisture content in the soil. This can make it confusing when looking at the temperature scale. An interpreter can falsely assume that a blue mark, which means lower temperature, automatically means high ground water content.

The images from the IR-thermography camera indicated that the water puddles and the soil around them were colder than the surrounding terrain; see Figure 38, section 7.3.2. There was however temperature differences in other places around the terrain as well, which can be seen in Figure 39, section 7.3.2. Stumps and rocks seem for instance to be warmer than the surroundings and some patches of soil, without the presence of water, seem to be colder than the surroundings. In order to make a thorough analysis, the ambition was first to compare values of soil moisture and temperature for many points across the terrain. The soil moisture measurements however, failed to deliver reliable values. Due to the arrival of subzero temperatures and snow in November, there were no more chances for further tests. Since only one test was performed, there is no data on how the result would look like during the rest of the year, which means that there is insufficient data of the climate impact on the camera performance and resulting images.

To be able to conclude if an infrared camera can be used to detect different soil moisture on a clearcut, more tests are needed. The tests should also be conducted over a larger time scale to see the climate influence on the camera performance.

10. Future work

Before this solution for obstacle detection can become a functioning product, there are several aspects that require more work. The ToF-camera have been confirmed too work well for the application but it will take many more tests to be confident about the performance. The camera need to be tested with varying conditions such as: weather, brightness, vegetation and terrain topography.

The coordinates of the obstacles is given relative to the position of the camera but as the obstacles disappear from the cameras field of view, the position of the obstacle is no longer known. The obstacle detection software therefore need to keep track of the coordinates based on the speed and direction of the machine. That will allow the software to warn the scarifier as an obstacle approach in the machines current path, the scarifier can then move sideways or lift to avoid the obstacle. The software therefore needs access to the machines speed and direction.

In order to determine if IR-thermography is a possible supplement to the TOF-camera, it will require further tests with reliable readings on soil moisture. One should also study the temperature-soil moisture relation in different types of terrain, at different weather conditions and at different times of the day to ensure that IR-thermography can indeed be used as a mean for detecting water collections in the terrain. If a temperature-soil moisture correlation is established, temperature data from the IR-thermography camera need to be added to the terrain mapping from the ToF-camera in a way that gives the coordinates of any collected water together with the other obstacles.

Once the coordinates of all obstacles are identified and follows the movement of the machine, this information need to be communicated to the scarifier itself. The obstacle detection software can either be installed in the cameras own hardware or in an external computer unit inside the forwarder. The scarifier will need some kind of software to control steering based on obstacle position.

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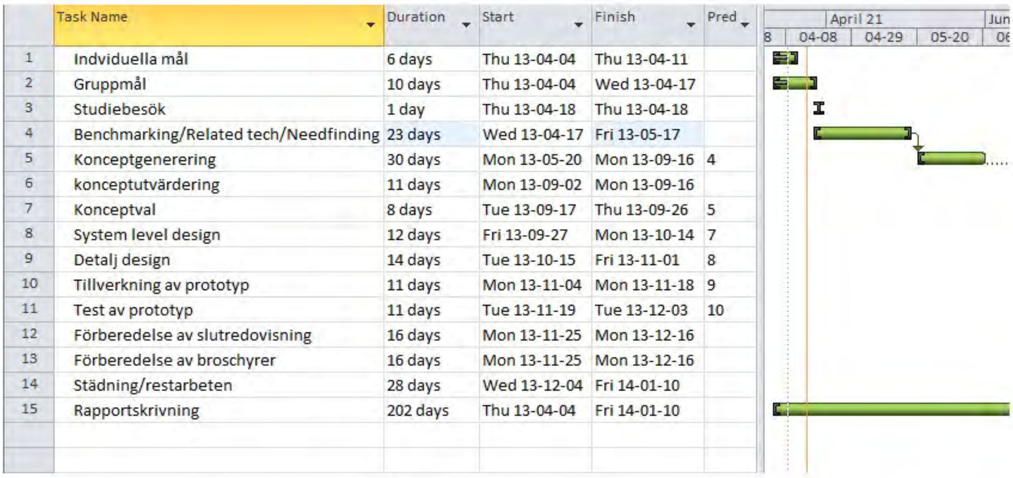
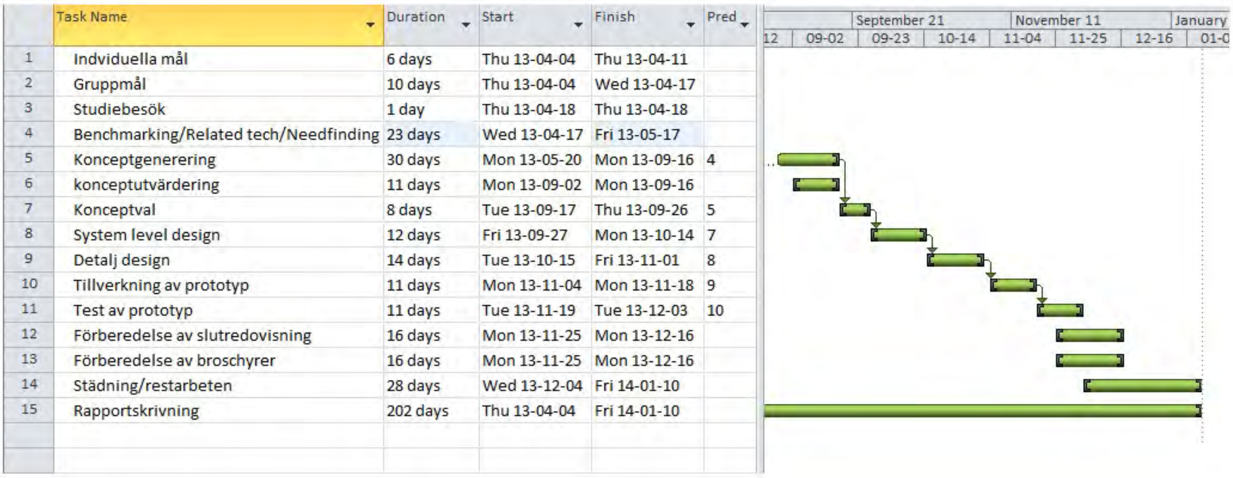
Appendix A

VT



	Task Name	Duration	Start	Finish	Pred
1	Indviduella mål	6 days	Thu 13-04-04	Thu 13-04-11	
2	Gruppmål	10 days	Thu 13-04-04	Wed 13-04-17	
3	Studiebesök	1 day	Thu 13-04-18	Thu 13-04-18	
4	Benchmarking/Related tech/Needfinding	23 days	Wed 13-04-17	Fri 13-05-17	
5	Konceptgenerering	30 days	Mon 13-05-20	Mon 13-09-16	4
6	konceptutvärdering	11 days	Mon 13-09-02	Mon 13-09-16	
7	Konceptval	8 days	Tue 13-09-17	Thu 13-09-26	5
8	System level design	12 days	Fri 13-09-27	Mon 13-10-14	7
9	Detalj design	14 days	Tue 13-10-15	Fri 13-11-01	8
10	Tillverkning av prototyp	11 days	Mon 13-11-04	Mon 13-11-18	9
11	Test av prototyp	11 days	Tue 13-11-19	Tue 13-12-03	10
12	Förberedelse av slutredovisning	16 days	Mon 13-11-25	Mon 13-12-16	
13	Förberedelse av broschyrer	16 days	Mon 13-11-25	Mon 13-12-16	
14	Städning/restarbeten	28 days	Wed 13-12-04	Fri 14-01-10	
15	Rapportskrivning	202 days	Thu 13-04-04	Fri 14-01-10	

HT



	Task Name	Duration	Start	Finish	Pred
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3	Studiebesök	1 day	Thu 13-04-18	Thu 13-04-18	
4	Benchmarking/Related tech/Needfinding	23 days	Wed 13-04-17	Fri 13-05-17	
5	Konceptgenerering	30 days	Mon 13-05-20	Mon 13-09-16	4
6	konceptutvärdering	11 days	Mon 13-09-02	Mon 13-09-16	
7	Konceptval	8 days	Tue 13-09-17	Thu 13-09-26	5
8	System level design	12 days	Fri 13-09-27	Mon 13-10-14	7
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11	Test av prototyp	11 days	Tue 13-11-19	Tue 13-12-03	10
12	Förberedelse av slutredovisning	16 days	Mon 13-11-25	Mon 13-12-16	
13	Förberedelse av broschyrer	16 days	Mon 13-11-25	Mon 13-12-16	
14	Städning/restarbeten	28 days	Wed 13-12-04	Fri 14-01-10	
15	Rapportskrivning	202 days	Thu 13-04-04	Fri 14-01-10	

Appendix B

Frågeformulär

(Entreprenörer)

Vad använder ni för beslutsunderlag vid val av markberedningsmetod?

Vilka markberedningsmetoder använder ni er av?

Vad fungerar bra respektive dåligt med er nuvarande markberedning?

Vad är de största utmaningarna vid markberedning (stubbar, stenar och grenar)?

Finns några förbättringar som ni skulle önska för att förbättra kvalitén på planteringspunkter? Vad finns för behov?

Är detektering av hinder något som skulle förbättra markberedning?

Frågeformulär

(Tillverkare)

Sveriges skogsmark består till 83 % av morän. I Moränmark finns stenar och block som utgör hinder vid maskinell plantering. Maskinell plantering av moränmark är därför ett komplicerat tekniskt problem, (Andersson et al, 1977).

Vad är de största tekniska utmaningarna vid markberedning i terräng med mycket hinder (stubbar, stenar och kvistar)?

Med avseende på tidigare fråga, vilka behov/funktioner efterfrågas från kunden?

Uppföljningsfråga, varför tror ni att det är just de behoven konsumenten efterfrågar?

Vad är den tekniska begränsningen för att kunna göra effektivare markberedare?

Ur ett biologiskt perspektiv vad är det som är mest önskvärt att förbättra inom markberedning?

Frågeformulär

(Forskning)

Gällande uppgiften vi fick tilldelat oss om hinderidentifiering, hur insåg ni att det fanns behov för en sådan lösning?

Ur ett biologiskt perspektiv vad är det som är mest önskvärt att förbättra inom markberedning?

Ser ni andra användningsområden för hinderidentifiering annat än vid markberedning/plantering?

Frågeformulär

(Skogsägarföreningar/Bolag)

Hur fungerar kommunikationen mellan er och markägare?

När och varför beställer ni markberedning?

Vad gällande markberedning brukar vara av störst intresse för markägarna?

Vad är det som fungerar bra/dåligt med markberedning?

Vilka förbättringar önskar ni till markberedningen?

Frågeformulär

(Skogsstyrelsen)

Vilka lagar och regleringar finns som är väsentliga för markberedning?

Vilka parametrar är det som styr val av markberedningsmetod?

Vad är bra med dagens markberedning?

Vad är dåligt med dagens markberedning?

Vad anser ni att det finns för behov gällande markberedning?

Appendix C

Intervju - Entreprenör

Vad använder ni för beslutsunderlag vid val av markberedningsmetod?

I grunden så är det markägaren som bestämmer, men företaget har viss påverkan av valet.

Hur går en marberedningsporcess till?

Markägaren ringer och beställer, sen väntar företaget på rätt tidpunkt (Rätt markförhållanden/ årstid)

Vid skapande av planteringspunkter, vad fungerar bra med er nuvarande markberedningsmaskin (högläggare/harv)?

Ger fler planteringspunkter (Företaget erbjuder bara harvning).

Vid skapandet av planteringspunkter, vad fungerar inte bra med er nuvarande markberedningsmaskin (högläggare/ harv)?

-

Vad är det största utmaningarna vid markberedning i terräng med mycket hinder (stubbar, stenar och grenar)?

I dagsläget är det marker med hög sten täthet som är det stora problemet. Åtgärder är att köra där det inte är sten och i sista hand bara dra därifrån.

Vilka förbättringar, för att underlätta vid skapandet av godkända planteringspunkter, skulle ni vilja tillföra er markberedningsmaskin (högläggare/ harv)?

GPS med realtid.

Intervju - Skogsägarföreningar/ Bolag

Hur fungerar kommunikationen mellan er och markägare?

Görs upp i samband med virkesköp.

När och varför beställer ni markberedning?

-

Vad gällande markberedning brukar vara av störst intresse för markägarna?

Ha bra förutsättningar för föryngring.

Vad är det som fungerar bra/dåligt med markberedning?

Att det ger en omvändtorva. Bolaget använder både högläggare och harv, något mer harv

Vilka förbättringar önskar ni till markberedningen?

Svårt att få upp mineraljord på vissa marker, vid svåra förhållanden används i dagsläget grävmaskin. Är för tillfället delaktiga i att ta fram en ny invers markberedare. (SLU)

Intervju - Skogsägarföreningar/ Bolag

Hur fungerar kommunikationen mellan er och markägare?

Rekommenderar, nästan i alla fall, markberedning till markägarna.

När och varför beställer ni markberedning?

-

Vad gällande markberedning brukar vara av störst intresse för markägarna?

Överlevnadsgraden hos plantorna.
Att det inte blir för fult, hur marken störs.

Vad är det som fungerar bra/dåligt med markberedning?

Fungerar dåligt på fuktiga marker, ger inga upphöjda planteringspunkter med mineraljord.

Friska marker där man resultatet blir sådant att plantorna kan sättas i harv spår där vatten ej kan stå.

Bolaget använder till 90 % harvning som marberedningsmetod. Det är tillgången som begränsar, men även logistik. I fall med högläggning behöver ofta markberedningen kompletteras med harvning på vissa ställen, vilket i praktiken innebär att två maskiner måste användas med höga kostnader

Vilka förbättringar önskar ni till markberedningen?

Svårt att få upp mineraljord på vissa marker, vid svåra förhållanden används i dagsläget grävmaskin. Är för tillfället delaktiga i att ta fram en ny invers markberedare. (SLU)

Intervju - Skogsägarföreningar/ Bolag

Hur fungerar kommunikationen mellan er och markägare?

Brukar mest sin egen skog.

När och varför beställer ni markberedning?

Har harv, högläggare och även grävmaskin (riktad markberedning). humumix (skonsam markberedning, används där det är mycket lav.) Samråd med samebyarna (SEC-certifierade). Använder till största delen högläggare

Vad gällande markberedning brukar vara av störst intresse för markägarna?

-

Vad är det som fungerar bra/dåligt med markberedning?

Generellt funkar markberedare idag ganska bra, ett problem är stenig mark. Resultatet är förarberoende, finns otroligt mycket inställningar.

Ibland är det så stenigt att det är svårt att ta sig fram med maskinen.

Har själva byggt en markberedare som kallas ”hackspetten” (tillverkad av Berggrens schakt i Arvidsjaur), används på extremt steniga marker.

Vilka förbättringar önskar ni till markberedningen?

Vill ha mindre påverkan på marken, skonsammare markberedning. ”Vill ha tillbaka högen i hålet”. Bra intermittent markberedning. Skyttmo invers markberedare (Bracke forest tillverkar, Skogforsk?).

Mindre markpåverkan utan att inverka på tillväxtpunkten.

Intervju - Entreprenör

Vad använder ni för beslutsunderlag vid val av markberedningsmetod?

Det bestämmer inte vi, kunden väljer själv.

Vilka markberedningsmetoder använder ni?

Harv och kontinuerlig högläggning

Vad är dem respektive metoderna bra till?

Harvning till steniga marker, Högläggning till fuktigare marker för att få upp högre planteringspunkt punkt.

Vad är dem respektive metoderna inte bra till? Vad stöter ni på för problem?

Det är terrängen som varierar, hyggesavfall osv. Högläggaren är känsligare för stubbar och stenar, harven klarar det bättre.

Vad är det som orsakar problem med svår terräng?

Planteringspunkterna blir för dåliga.

Finns det något ytterligare att önska? Finns det något behov som kan lösas bättre?

Vet ej, Det finns ju ”bracke planter” som monteras på grävskopa och det är väl en bra grej men om man ska mark bereda stora arealer så är konventionell högläggare och harv nog bäst.

Om man skulle kunna styra en markberedare med hjälp av hinder detektering, skulle det vara till någon hjälp?

Nej, det skulle inte spela någon roll.

Intervju - Myndighet

Vad finns det för lagar och regleringar gällande markberedning?

Man får inte skada kulturminnen och fornminnen. Man får inte laka ur marken (slammar igen vattendrag och frigör skadliga ämnen i marken). Vid renbetesmarker måste markpåverkan minimeras (skogsvårdslagen § 30-31)

Vilka parametrar styr val av markberedningsmetod?

Tillgänglighet av maskiner, Terrängtyp, harv bättre för steniga marker, högläggare bättre för normala marker eller fuktiga marker.

Vad fungerar bra respektive dåligt med dagens markberedning? Vilka är de största utmaningarna/problemen?

Stor variation mellan olika förare. Oerfarna/dåliga förare försämrar kvalitén på slutresultatet. Förarna kan vara till exempel: vara okunniga, vara trötta, inte bry sig om kvalité eller miljö.

Vilka behov finns? Vad kan förbättras?

Kvalitén på planteringspunkerna är avgörande, ett sätt att förbättra detta är inversmarkberedning så är på gång att utvecklas.

Sådd är något som har visat sig fungera väl på vissa marker i norra Sverige, möjligen kan detta koncept utvecklas för att utnyttjas på fler håll

Om man skulle kunna detektera hinder och sedan styra markberedningsredskap därefter, skulle det vara till någon nytta?

Det tror jag nog. Har faktiskt inte tänkt på den möjligheten! Borde vara positivt både för produktivitet och markpåverkan.

Intervju - Entreprenör

Vad använder ni för beslutsunderlag vid val av markberedningsmetod?

Kunden bestämmer metod.

Vilka markberedningsmetoder använder ni?

Harv och kontinuerlig markberedning, till sommaren även inversmarkberedning?

Vad fungerar bra respektive dåligt med nuvarande markberedning?

Resultatmässigt ligger vi bar till, det förekommer dock alltid ett visst slitage av maskiner och utrustning.

Vilka är de största utmaningarna vid markberedning i svår terräng?

Man tar sig inte fram, maskinen fastnar på höga stubbar så man måste backa och köra runt. Aggregatet kan fastna och dras sönder.

Finns något ytterligare behov? Kan något förbättras?

Vi jobbar med att skydda maskinerna bättre mot att köras sönder av svår terräng, förarens erfarenhet har stor påverkan på slitage av maskinen.

Om man skulle kunna detektera hinder och sedan styra markberedningsredskap därefter, skulle det vara till någon nytta?

Om man kan komma på en sådan lösning vore det ett bra hjälpmedel. Skulle kunna vara svårt att lösa eftersom terrängen man kör i är så pass olika. Om man lyckas skulle det minska bränsleförbrukning och slitage.

Intervju - Skogsägarföreningar/ Bolag

Hur fungerar kommunikationen mellan er och markägarna vid beställning av markberedning?

Sker i samråd mellan virkesköpare och markägare. Virkesköpare rådgivande och föreslår i regel MB metod

Vad gällande markberedning är viktigast för markägarna?

Tillräckligt med planteringspunkter, att MB sker i tid innan hygget växer igen, att mark/miljöpåverkan inte sker i onödig grad

Vilka markberedningsmetoder använder ni er av?

Högläggare, harv, grävmaskin, specialutrustad skördare med spade

Vilka är de största utmaningarna vid markberedning i svår terräng?

Gott resultat för kommande plantering (antal goda planteringspunkter), rimlig kostnad (man kommer alltid fram men med alternativa metoder som grävmaskin etc blir det dyrt, på stora objekt blir detta kännbart, men regel kan man stycka av objekt och använda flera metoder)

Vad fungerar bra respektive dåligt med er nuvarande markberedning?

Vi har funderingar kring täckningsgrad (att all markberedningsbar yta körs) samt jobbar med kvalitet (antal bra planteringspunkter) vi har gott underlag (planering) jobbar med moderna och bra systemstöd. Vi har också ett jobb att göra kring kostnadsbild och effektivitet i MB.

Om man skulle kunna detektera hinder och styra markberedningen därefter, skulle det vara till hjälp?

Menar ni under pågående körning eller analys innan? Jag tror att det mest praktiska är att använda sig av laserscaning och de terrängkartor som skapas från den för att förplaner körning. Sen kan det ju finnas viss nytta i att få feedback kring detta under pågående körning men jag tror att förarna i god tid hinner uppfatta och korrigera för de allra flesta hinder. Bäst är nog dock att prata med en förare. Hör av er så kan jag koppla ihop er med ngn/några.

Intervju - Tillverkare

Vilka är de största utmaningarna vid markberedning i terräng med mycket hinder?

Få till bra planteringspunkter! Då högläggar-hjulet kör in i ett hinder blir trycket i hydrauliken för högt och det roterar vidare till nästa punkt.

Vad utgör hinder? Vilken storlek på stenar etc.?

Det beror på marken, hur hårt de sitter fast. Stenar upp till ”fotbollsstorlek” är inga problem. Stubbar med diameter på 7-10 cm brukar gå att köra över.

Vilka lösningar finns i dagsläget för att undvika hinder?

Föraren får välja ett lämpligt körspår och kan välja mellan olika inställningsprogram för tryck, rotation, sidledsavstånd med mera.

Finns det något som ni skulle vilja tillföra de befintliga produkterna?

Just nu jobbar vi med att minska markpåverkan genom att vi utvecklar vår nya inversmarkberedare. Så småningom vill vi även kunna göra en kontinuerlig planteringsmaskin i stil med silva nova.

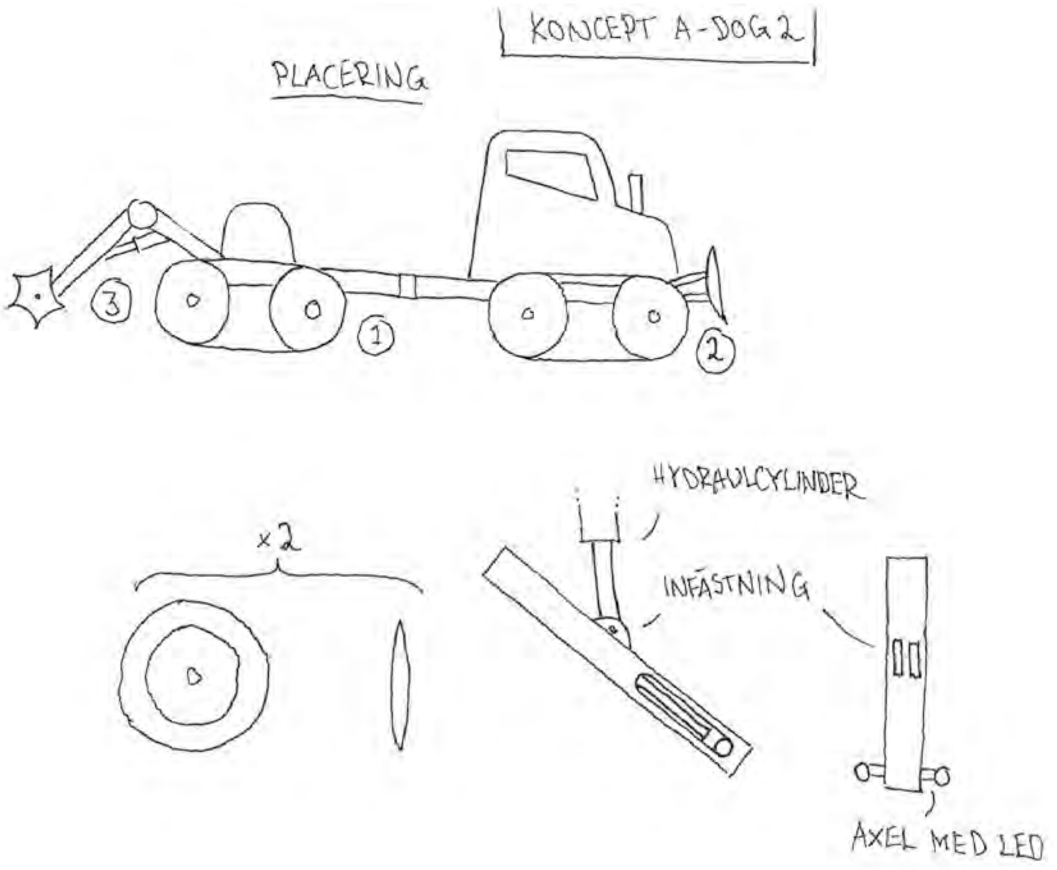
Vad är de tekniska begränsningarna för att göra markberedning mer effektivt?

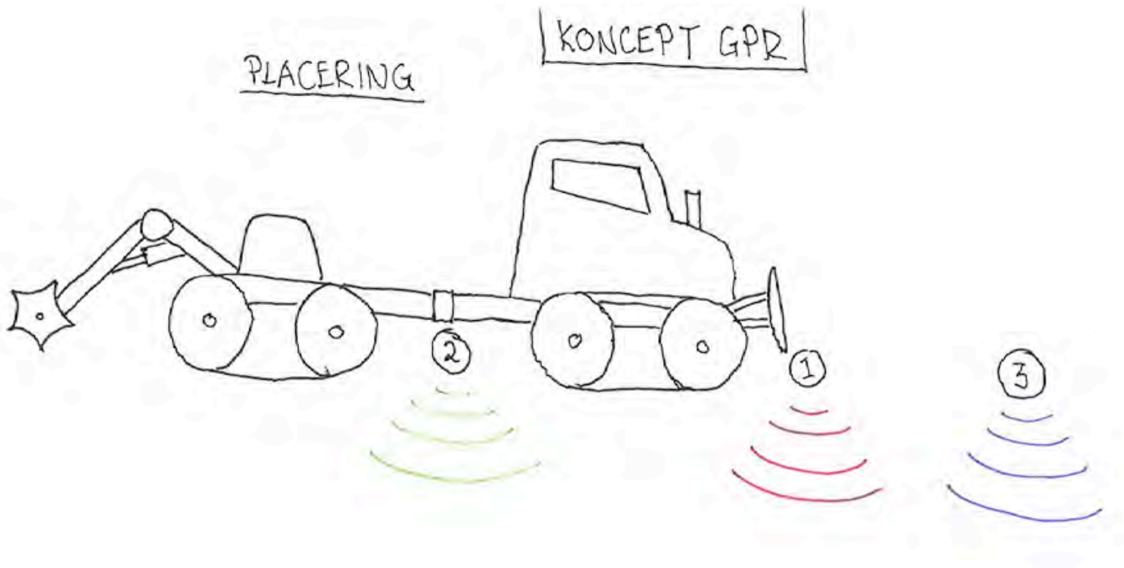
Att kunna detektera hinder ovan och under markytan och styra maskinerna därefter.

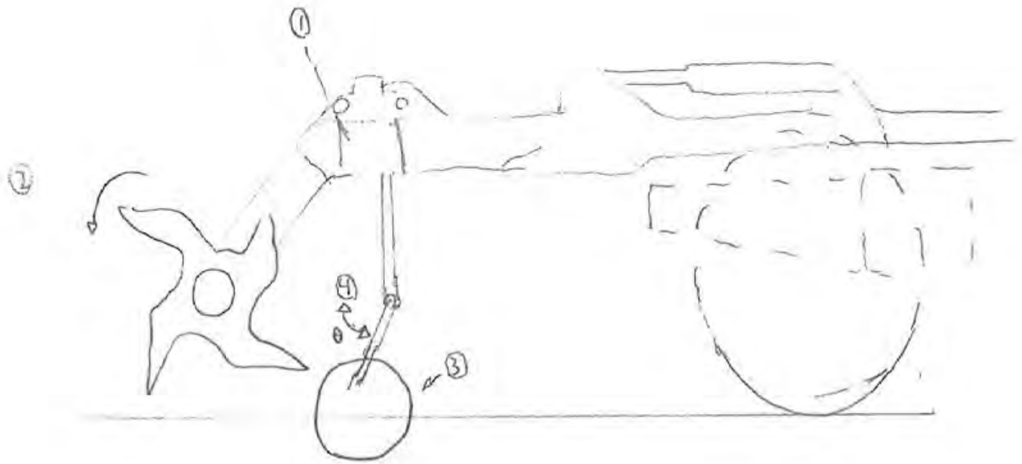
Vilka önskemål och behov har era kunder avseende markberedning?

Största behovet finns för högläggning i ”normalsvår” terräng. Generellt sett efterfrågar kunder markberedare som har liten markpåverkan

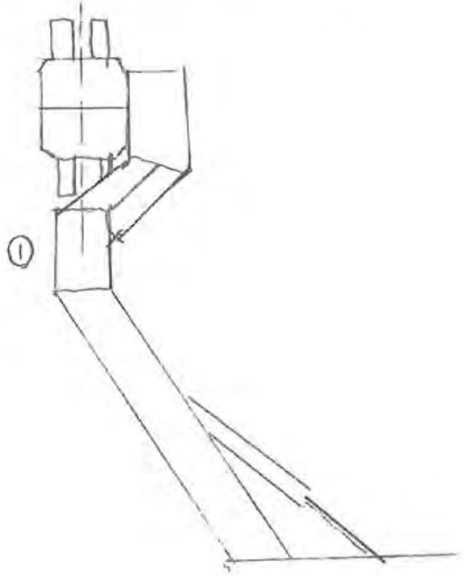
Appendix D


KONCEPT A-DOG 2
PLACERING
③
①
②
×2
HYDRAULCYLINDER
INFÄSTNING
AXEL MED LED


KONCEPT GPR
PLACERING
2
1
3



alltid Centrerad mot ①



① aggregat alltid i centrum mot denna del

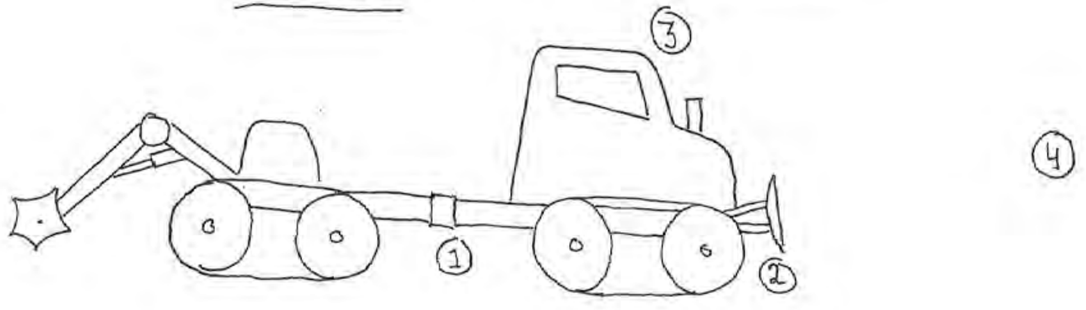
② aggregat roterar med intervall enligt programinställning

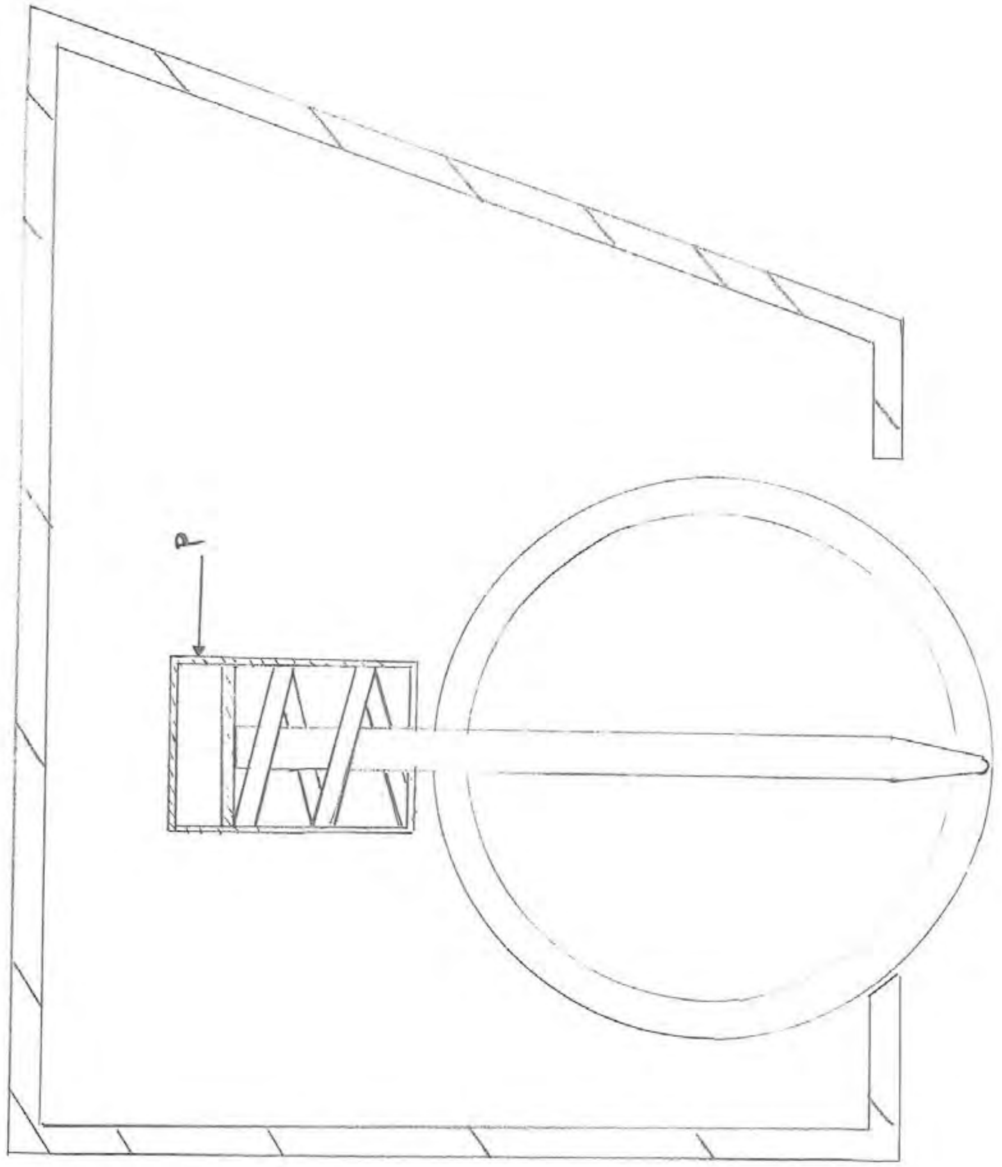
③ Ett smalt roterand hjul ansätts i marken till ett inställt djup

④ om hjulet träffar en sten under marken ändras vinkeln i led ⑪ och en brytare aktiveras vid en viss vinkel för att stoppa program och därmed förhindra att aggregatet går en hög.

KONCEPT - LASER, US

PLACERING

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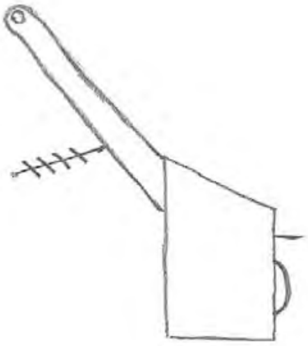
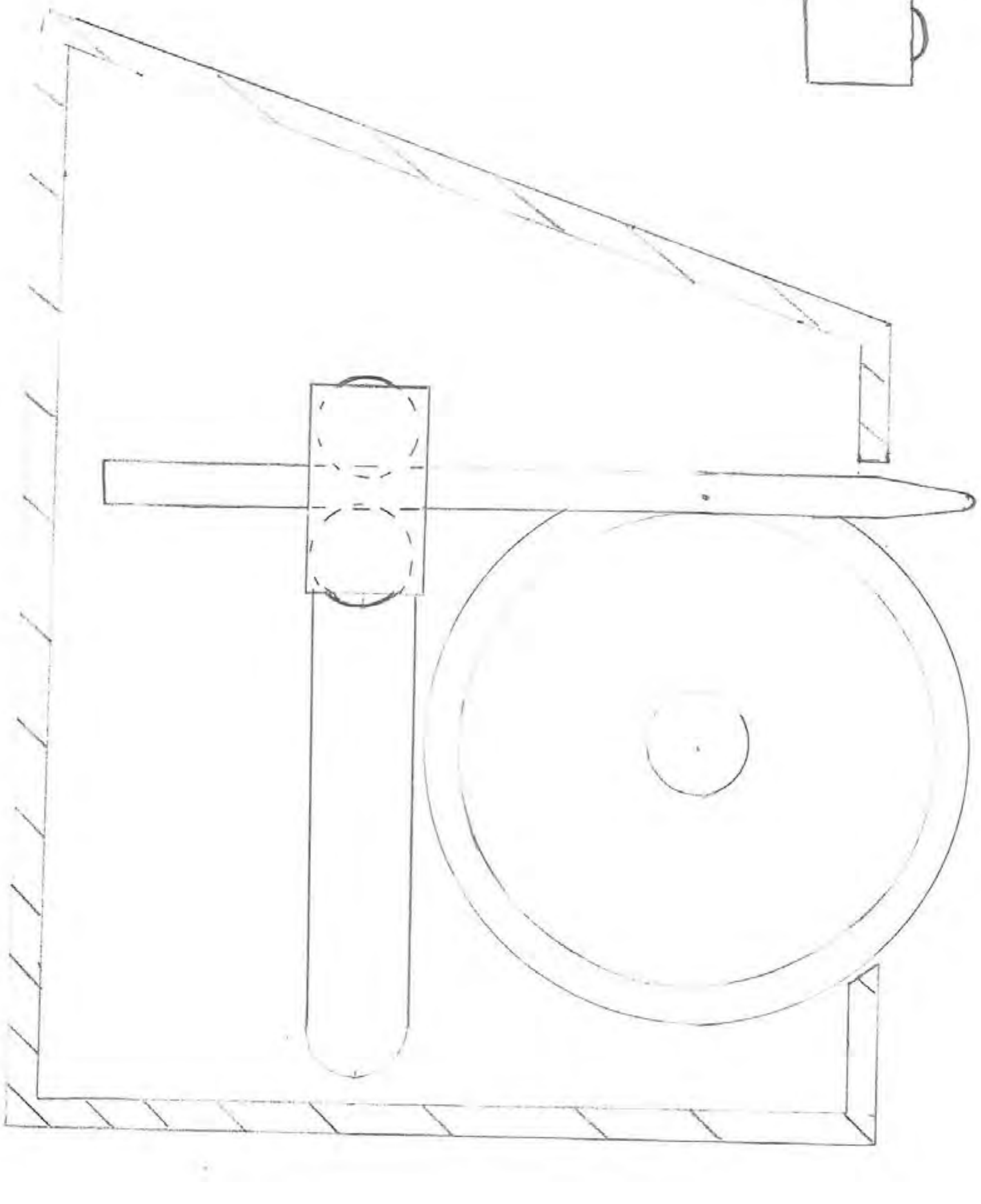
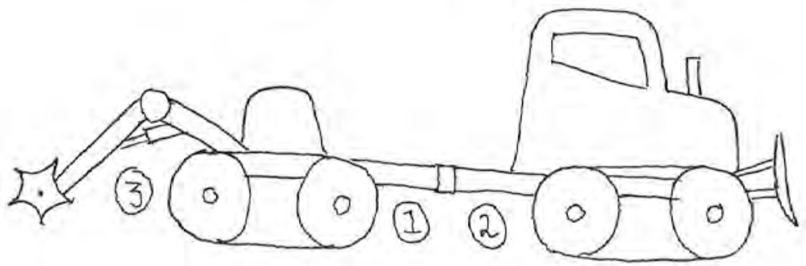
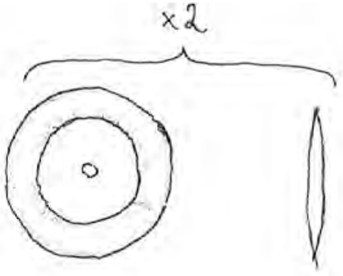


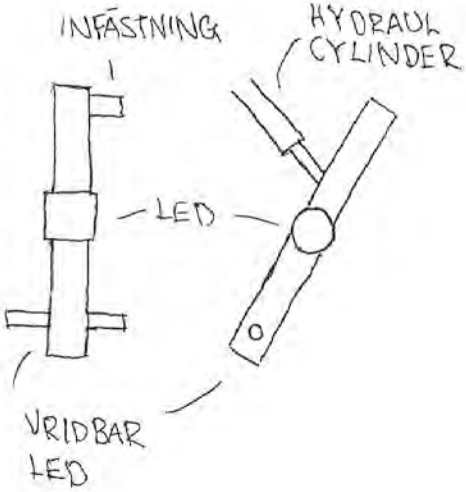


KONCEPT A-DOG

PLACERING



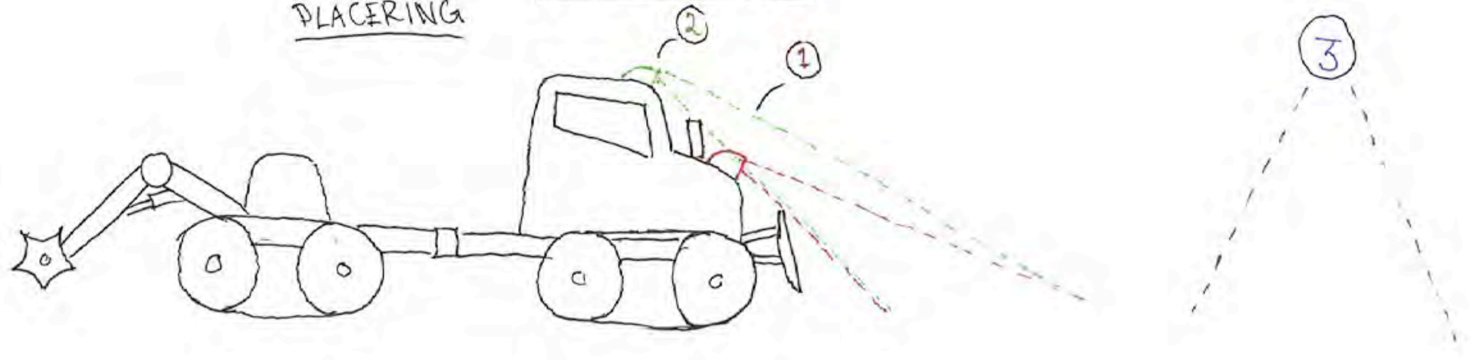




- MEKANISK
- MINDRE KOMPLEX
- MARK PENETRERANDE
- BEGRÄNSAT OMRÅDE
- MÖJLIG ATT KOMBINERA MED ANDRA TEKNIKER

KONCEPT TOF

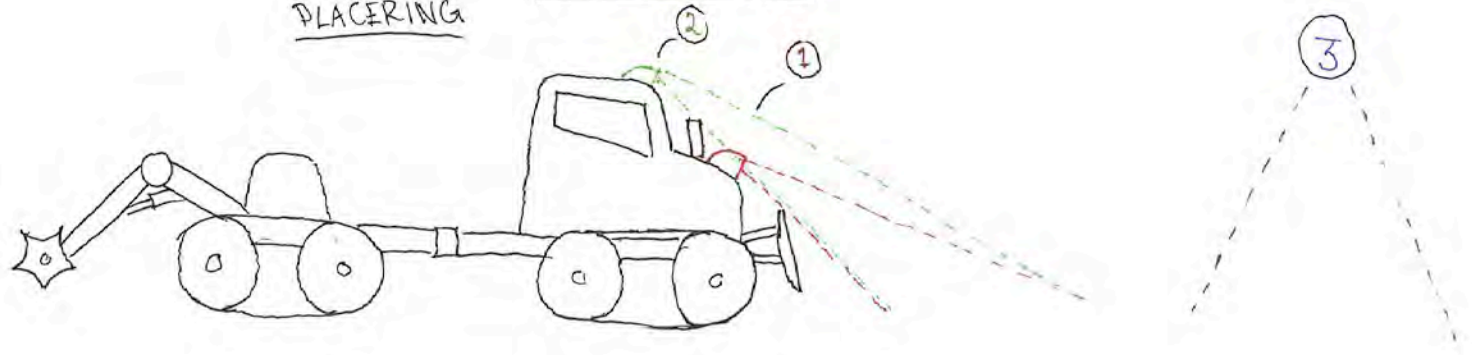
PLACERING



- KOMPLEX
- SVÅR SIGNAL
- STOR YTA
- MÖJLIG ATT KOMBINERA MED ANDRA TEKNIKER

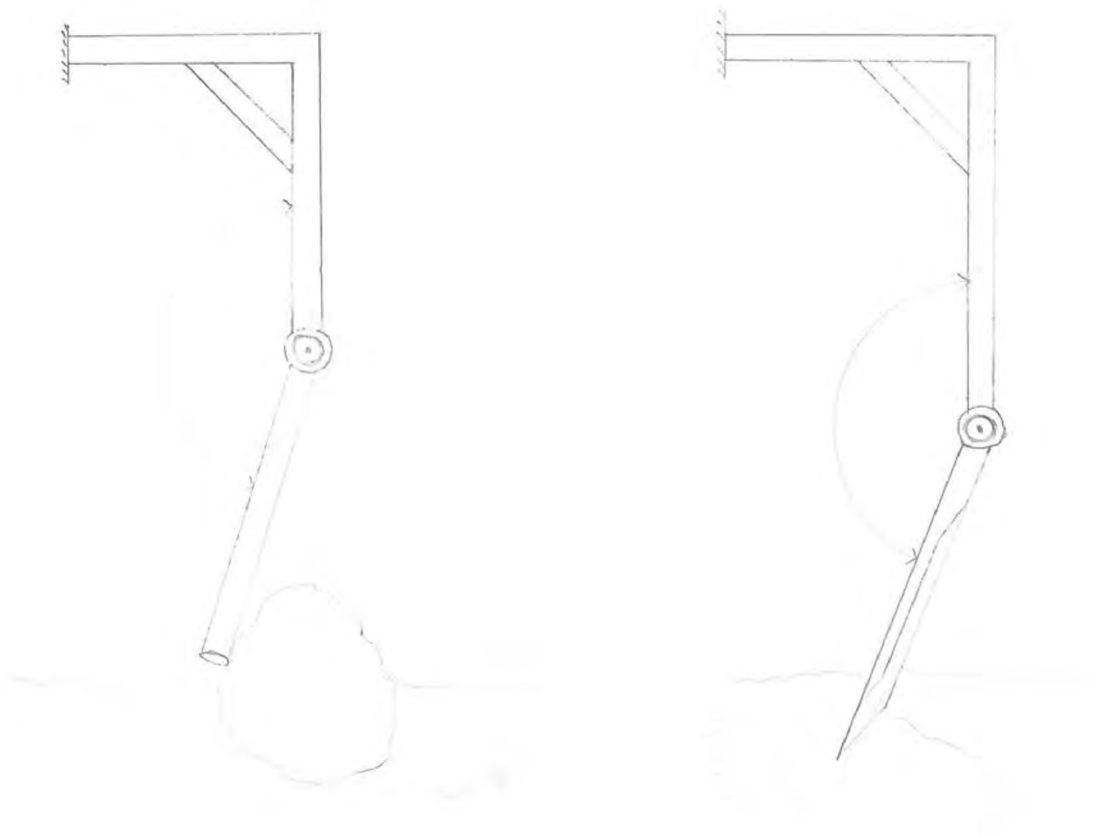
KONCEPT TOF

PLACERING



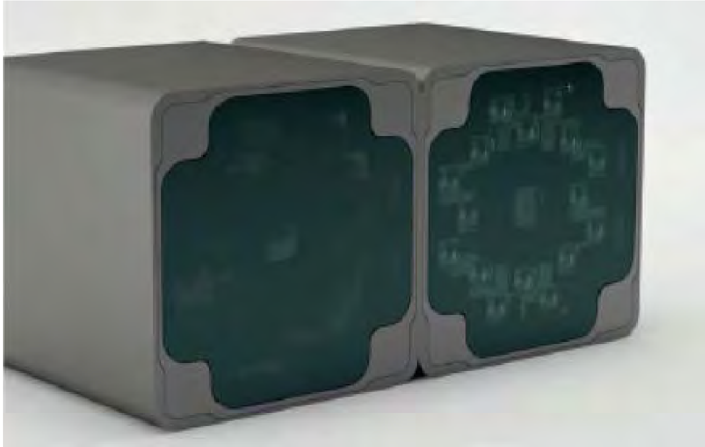
- KOMPLEX
- SVÅR SIGNAL
- STOR YTA
- MÖJLIG ATT KOMBINERA MED ANDRA TEKNIKER

Loaded arm



Appendix E

ToF Camera



Description

The camera transmits active light and measure the time it takes the reflected light to reach the camera. In this way, the distance of each point in the image is calculated and a three-dimensional image is obtained.

Infra red light is transmitted from light or laser diodes that are mounted in the immediate vicinity of the camera lens. The lens collects the reflected light and removes the background light with a band-pass filter. For each pixel in the image the time of the light to reach the reflected object is calculated and the distance is determined by the speed of the transmitted light.

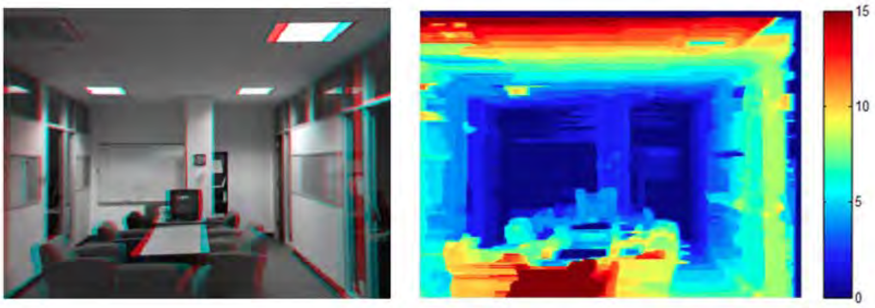
Source

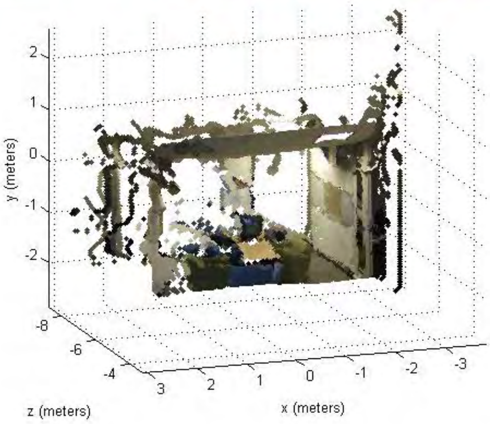
Hansard, M et. al (2012) *Time-of-Flight Cameras: Principles, Methods and Applications*

Hussman & Liepert (2007). *Robot Vision System based on a 3-D-ToF Camera*

Placement	Pros and cons	
	Pros	**Cons**
On roof or in front of machine.	+ Few components + No moving parts + Instant 3-D-mapping + High performance + Can be implemented for autonomous steering of vehicle	- Can not detect objects below ground surface - Can not, from the box, distinguish between obstacle and other terrain - Requires extensive programming - Direct sun light disrupts data - Rain and dust compromises signal - Can not detect obstacles covered by slash or vegetation

Stereo Vision





Description

Two digital cameras mounted next to each other taking pictures simultaneously. These images are processed with advanced algorithms and can with image-processing tools give a three-dimensional mapping of the terrain in front of the vehicle.

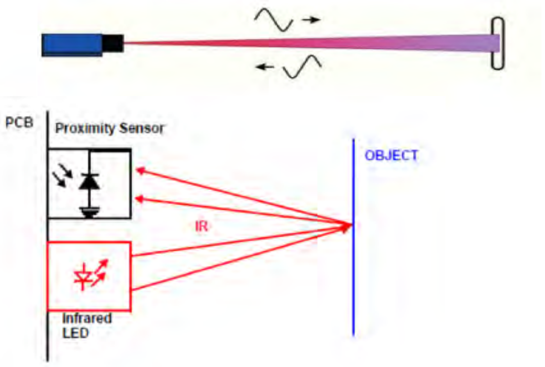
Source

http://www.mathworks.se/discovery/stereo-vision.html

T Kemppainen & A Visala, 2012 "*Stereo Vision Based Tree Planting Spot Detection*" Aalto University, Finland

Placement	Pros and cons	
	Pros	**Cons**
On roof or in front of machine.	+ Inexpensive + No moving parts + Can be implemented for autonomous steering of vehicle	- Requires extensive calculations = affects performance - Rain and dust compromises signal - Can not operate in darkness - Can not distinguish between obstacle and other terrain -

Laser/IR-laser



Description

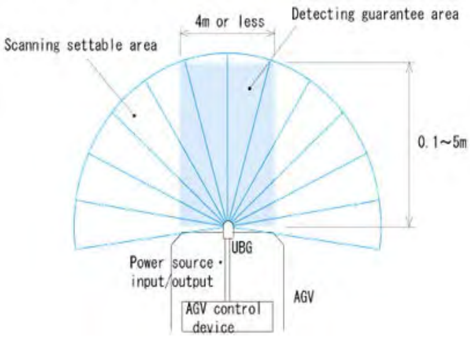
Laser and IR is essentially the same thing, light. Many lasers use a pulse of IR light, which is light outside the visible spectra. Distance is calculated through phase or time difference of the transmitted pulse to reach the object and travel back to the meter.

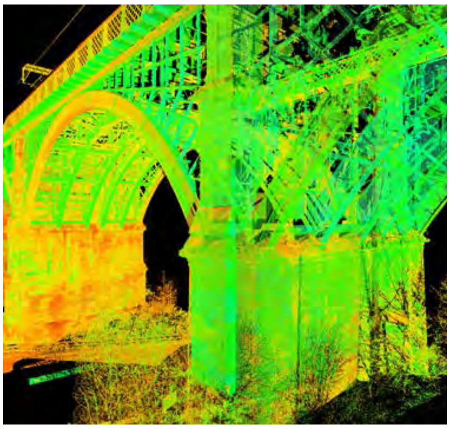
Source

Airborne and terrestrial laser scanning Author: Edited By George Vosselman, Hans-Gerd Maas.Pages: 336 Publisher: Whittles Publishing Published: Jan 1, 2010 eISBN-13: 9781849950138 Show more Chapter 1

Placement	Pros and cons	
	Pros	**Cons**
One or more meters mounted on roof or in front of machine.	+ Insensible to sun light	- Sensitive for dirt, grass and rain.
	+ Inexpensive	- Can not detect objects below ground surface
	+ No moving parts	- Can not distinguish between obstacle and other terrain

Laser scanner





Description

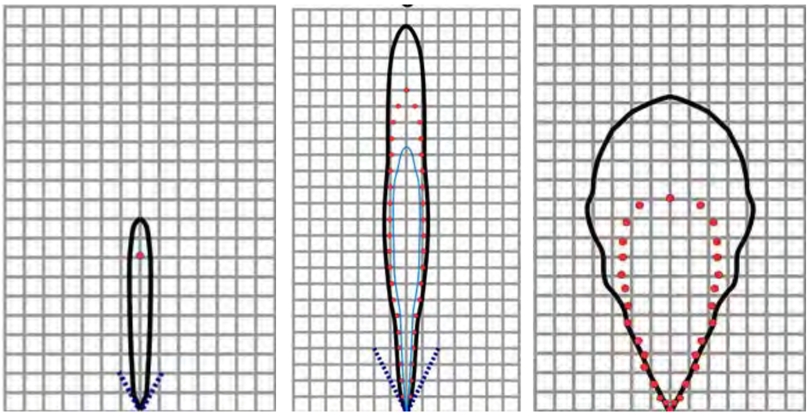
Operates in the same way as a laser meter but scans a greater area measuring distance to all objects in front of the sensor. To get tree dimensional data the sensor needs to be tilted or swept.

Source

Airborne and terrestrial laser scanning Author: Edited By George Vosselman, Hans-Gerd Maas.Pages: 336 Publisher: Whittles Publishing Published: Jan 1, 2010 eISBN-13: 9781849950138 Show more Chapter 1

Placement	Pros and cons	
	Pros	**Cons**
On roof or in front of machine.	+ The same as for IR/Laser with the advantage of a wider field of view + Can be implemented for autonomous steering of vehicle	- Same as for IR/laser - Can not detect objects below ground surface

Ultrasonic sensors



Description

Ultrasound is sound waves with a frequency higher than the audible spectra for the human ear. The high frequency, short wave length, allows reflection from small surfaces. By measuring the time for the sound wave to travel back and forth from an object it is possible to calculate the distance.

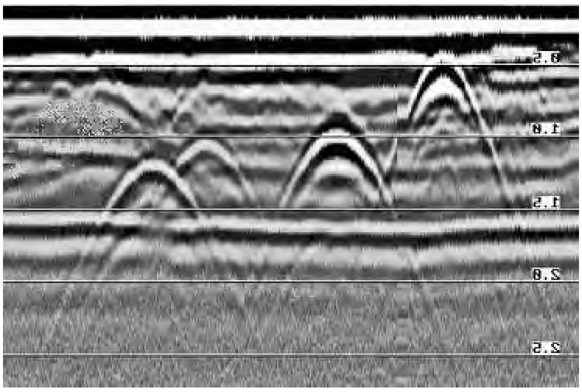
Source

http://www.olympus-ims.com/data/File/panametrics/UT-technotes.en.pdf

http://www.ia.omron.com/support/guide/50/further_information.html

Placement	Pros and cons	
	Pros	**Cons**
One or more in front of machine or in the middle.	+ Inexpensive + Sampling rate + Not sensitive to vibrations or percussions	- Can not detect objects below ground surface - Can not distinguish between obstacle and other terrain - Difficult to know what caused the reflection, angel of sensors must be known

GPR



Description

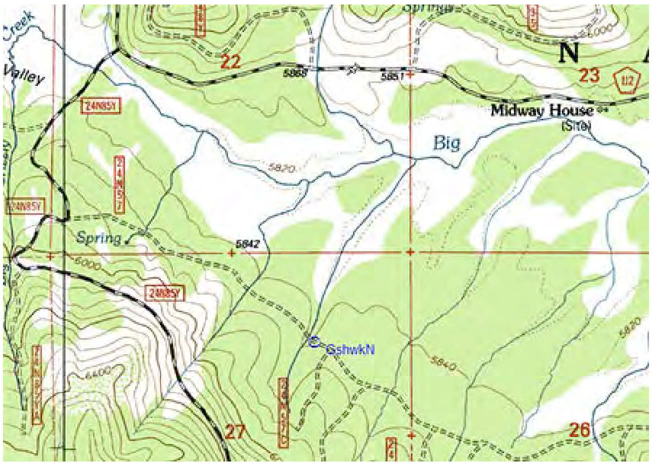
Electromagnetic waves are sent out from a transmitter and reflected by an object back to a receiver. The electromagnetic waves velocity through the soil varies both with the type of soil and the soil moisture. Soil type should cause fewer problems than soil moisture when humidity is more likely to vary over a cutting area than soil type. Complete systems area available for purchase from local producers, however, its by far the most expensive technology of those that are current. For this application an airborne antenna is required.

Source

http://www.malags.com/innovation/gpr-explained]

Placement	Pros and cons	
	Pros	**Cons**
In the middle or in front of machine.	+ Can detect obstacles below ground surface + Non destructive technique + Sampling rate	- Expensive - Sensitive technology - Calibration problems, at varying wave velocity - Complex data processing - Must be calibrated according to soil type

GPS



Description

The idea of the concept is to log the position of the harvested trees and in return obtain the position of the stumps. This data will then be transferred to the later scarification in order to avoid unnecessary ground impact.

By using GPS it is possible to reach an accuracy of +/- 2.5 cm via RTK signal SWEPOS, when in contact with enough satellites.

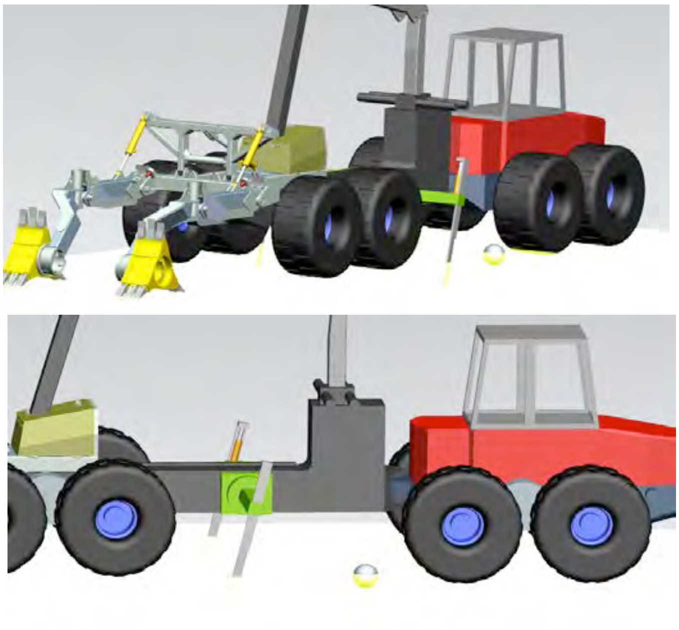
Source

https://scholar.vt.edu/access/content/group/464c632e-71-D9-4210-82c7-735ed5ff9e6f/WorkbookPrintingFolder-Final/3.01%20Intro%20to%20GPS_PPT%20handout.pdf

http://swepos.lmv.lm.se/natverksrtk/netvrtktjanst.htm

Placement	Pros and cons	
	Pros	**Cons**
--	+ Coordinates of stumps/(obstacles) before scarification + Ability to establish drive map + Implement in existing systems?	- Relatively expensive - Reception - Varying accuracy

Svärd



Description

An oblong “sword” is mounted between the boggie axles. The “sword” penetrates the ground by hydraulic cylinders that compensates for variations in terrain and ensures desiderate reach of depth. The arm that the “sword” is mounted on is loaded with a radial force great enough to keep the “sword” in the ground. When an obstacle come in contact the “sword” indicates an angular change, due to that the contact force will overcome the radial force.

Placement	Pros and cons	
	Pros	**Cons**
Between boggie axels	+ Inexpensive	- Ground impact
	+ Can detect obstacles below ground surface	- Mechanical Wear
	+ Easy to implement compared to other solutions	- Can not determine size of obstacles
	+ Independent of velocity	- Narrow field of view
		- Ensure depth of ground penetration

Vibrating probe

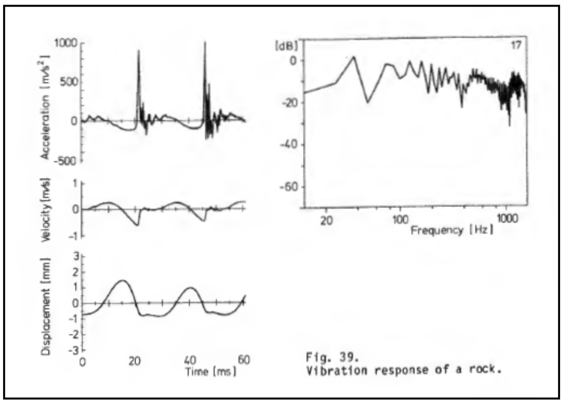


Fig. 39.
Vibration response of a rock.

Description

A sled with a rotating imbalance in contact with the ground is dragged along the machine. An accelerometer measures the vibrations of the sled making it possible to see changes in the ground properties. By analysing the vibration characteristics it is possible to determine whether the sled is on top of an obstacle or not.

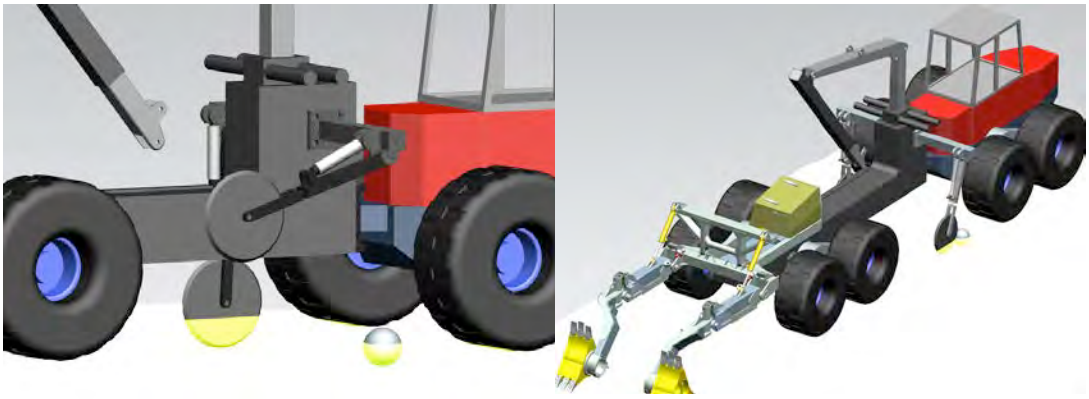
Source

Jorma Lammasniemi (1983), “*A vibrator probe for planting position sensing for a tree planting machine”*

Technical Research Centre of Finland

Placement	**Pros and cons**	
	Pros	**Cons**
Between boggie axels.	+ Can detect obstacles slightly below ground surface + Small impact on terrain + Independent of velocity + Clear output	- No information about depth of obstacle - Bulky - Mechanical Wear - May be covered by patents

Disk

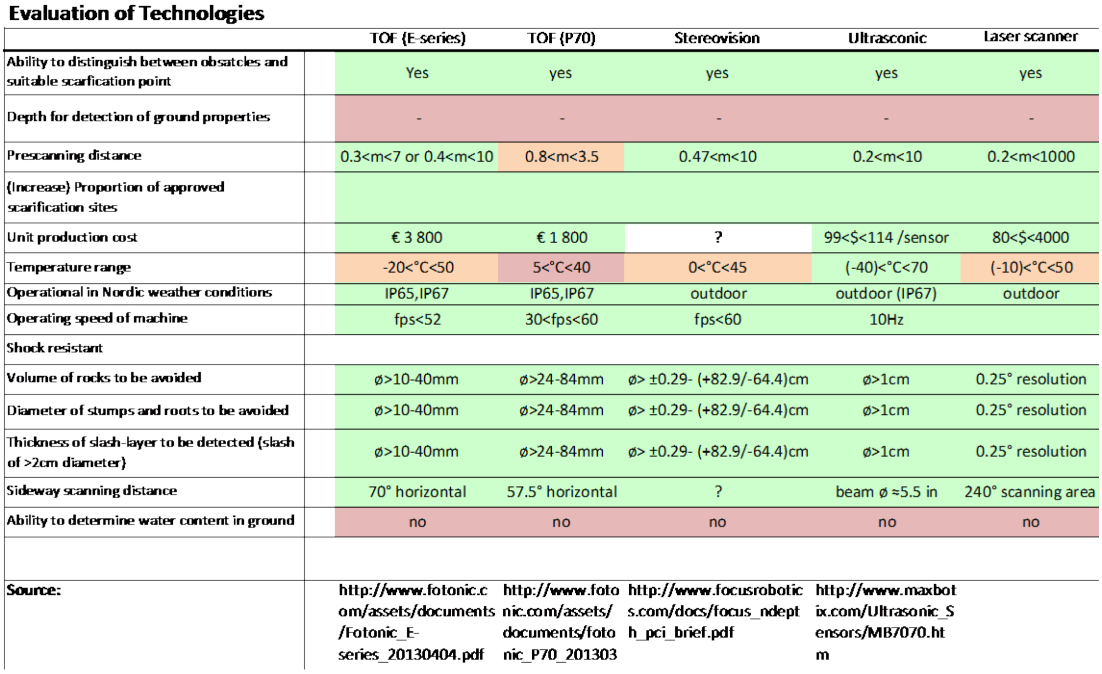


Description

A disc mounted on a jointed arm penetrates the ground surface. Hydraulic cylinders compensate for variations in terrain and ensures desiderate depth of penetration. When contact with obstacle occurs the disc will climb over causing an angular change.

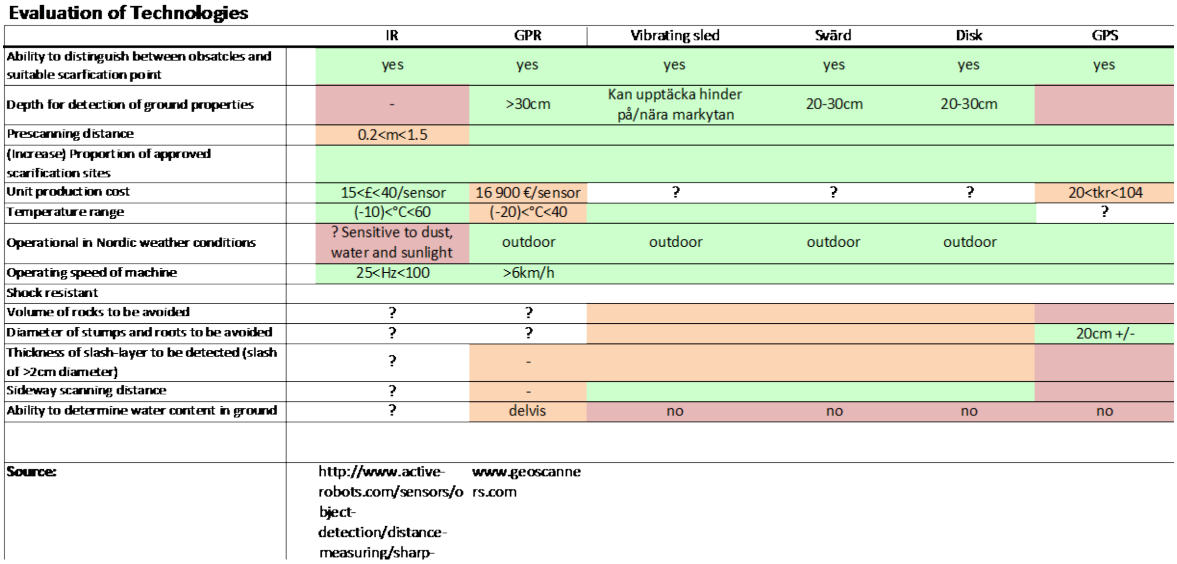
Placement	**Pros and cons**	
	Pros	**Cons**
Between boggie axels.	+ Inexpensive	- Ground impact
	+ Can detect obstacles below ground surface	- Mechanical Wear
	+ Easy to implement compared to other solutions	- Can not determine size of obstacles
	+ Independent of velocity	- Narrow field of view
		- Ensure depth of ground penetration

Appendix F



Evaluation of Technologies

	TOF (E-series)	TOF (P70)	Stereovision	Ultrasconic	Laser scanner
Ability to distinguish between obsatcles and suitable scarfication point	Yes	yes	yes	yes	yes
Depth for detection of ground properties	-	-	-	-	-
Prescanning distance	0.3<m<7 or 0.4<m<10	0.8<m<3.5	0.47<m<10	0.2<m<10	0.2<m<1000
(Increase) Proportion of approved scarification sites					
Unit production cost	€ 3 800	€ 1 800	?	99<$<114 /sensor	80<$<4000
Temperature range	-20<°C<50	5<°C<40	0<°C<45	(-40)<°C<70	(-10)<°C<50
Operational in Nordic weather conditions	IP65,IP67	IP65,IP67	outdoor	outdoor (IP67)	outdoor
Operating speed of machine	fps<52	30<fps<60	fps<60	10Hz	
Shock resistant					
Volume of rocks to be avoided	ø>10-40mm	ø>24-84mm	ø> ±0.29- (+82.9/-64.4)cm	ø>1cm	0.25° resolution
Diameter of stumps and roots to be avoided	ø>10-40mm	ø>24-84mm	ø> ±0.29- (+82.9/-64.4)cm	ø>1cm	0.25° resolution
Thickness of slash-layer to be detected (slash of >2cm diameter)	ø>10-40mm	ø>24-84mm	ø> ±0.29- (+82.9/-64.4)cm	ø>1cm	0.25° resolution
Sideway scanning distance	70° horizontal	57.5° horizontal	?	beam ø ≈5.5 in	240° scanning area
Ability to determine water content in ground	no	no	no	no	no
Source:	http://www.fotonic.com/assets/documents/Fotonic_E-series_20130404.pdf	http://www.fotonic.com/assets/documents/fotonic_P70_201303	http://www.focusrobotics.com/docs/focus_ndepth_pci_brief.pdf	http://www.maxbotix.com/Ultrasonic_Sensors/MB7070.htm	



Evaluation of Technologies

	IR	GPR	Vibrating sled	Svärd	Disk	GPS
Ability to distinguish between obsatcles and suitable scarfication point	yes	yes	yes	yes	yes	yes
Depth for detection of ground properties	-	>30cm	Kan upptäcka hinder på/nära markytan	20-30cm	20-30cm	
Prescanning distance	0.2<m<1.5					
(Increase) Proportion of approved scarification sites						
Unit production cost	15<£<40/sensor	16 900 €/sensor	?	?	?	20<tkr<104
Temperature range	(-10)<°C<60	(-20)<°C<40				?
Operational in Nordic weather conditions	? Sensitive to dust, water and sunlight	outdoor	outdoor	outdoor	outdoor	
Operating speed of machine	25<Hz<100	>6km/h				
Shock resistant						
Volume of rocks to be avoided	?	?				
Diameter of stumps and roots to be avoided	?	?				20cm +/-
Thickness of slash-layer to be detected (slash of >2cm diameter)	?	-				
Sideway scanning distance	?	-				
Ability to determine water content in ground	?	delvis	no	no	no	no
Source:	http://www.active-robots.com/sensors/object-detection/distance-measuring/sharp-	www.geoscanners.com				

Appendix G

FOTONIC

FOTONIC C-SERIES

3D CAMERAS WITH COLOR PERCEPTION

High resolution color images, combined with 3D data from a Fotonic time of flight camera, gives even more dimensions to 3D. The C-series cameras follow the Fotonic concept of high reliability in performance and a robust design.

The C-series combines all of the E-series performance as low motion artefacts, sunlight resistance with a color image calibrated on to the 3D depth data. This combination gives better resolution in x,y and enables the user to use color information in the imageprocessing/ algorithm development.

All cameras are IP65 and IP67, and the window of Gorilla glass is interchangeable. The powerful ARM processor from Texas Instrument together with the Linux OS, enable you to easily run your software on board. The C-Series are truly smart cameras, with robust real vision.

"Our aim is to build the best 3D smart cameras based on commercially available sensors."
Gösta Forsén, Fotonic

C-series cameras are possible to configure by choosing different Field of view.

You can also add our HD enclosure for extremely harsh environments. The HD enclosure adds nozzels which can be used for continuous cleaning of the camera window with water/air.

OPTIONS

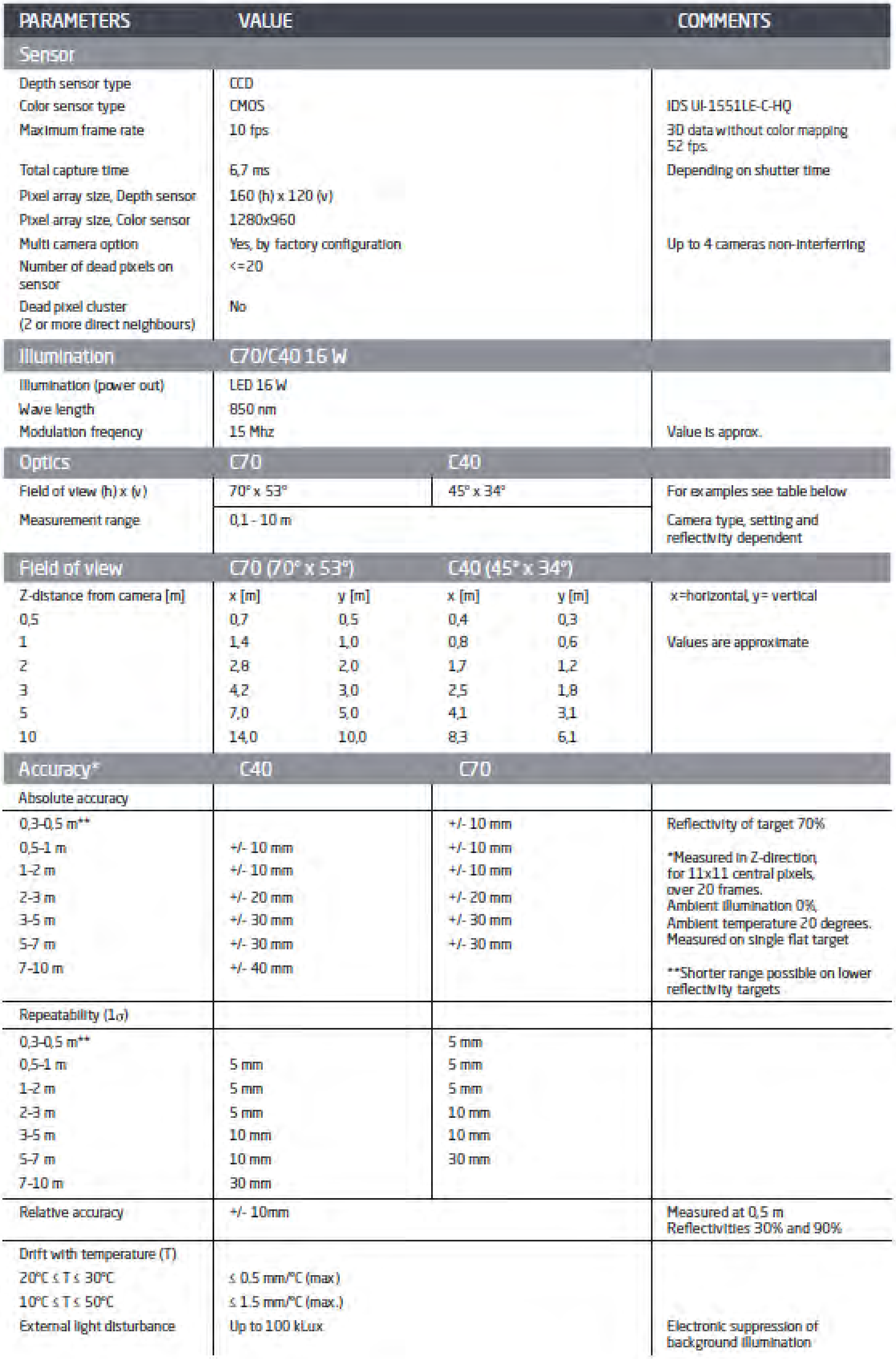
FOV:

C70 - 70deg horizontally

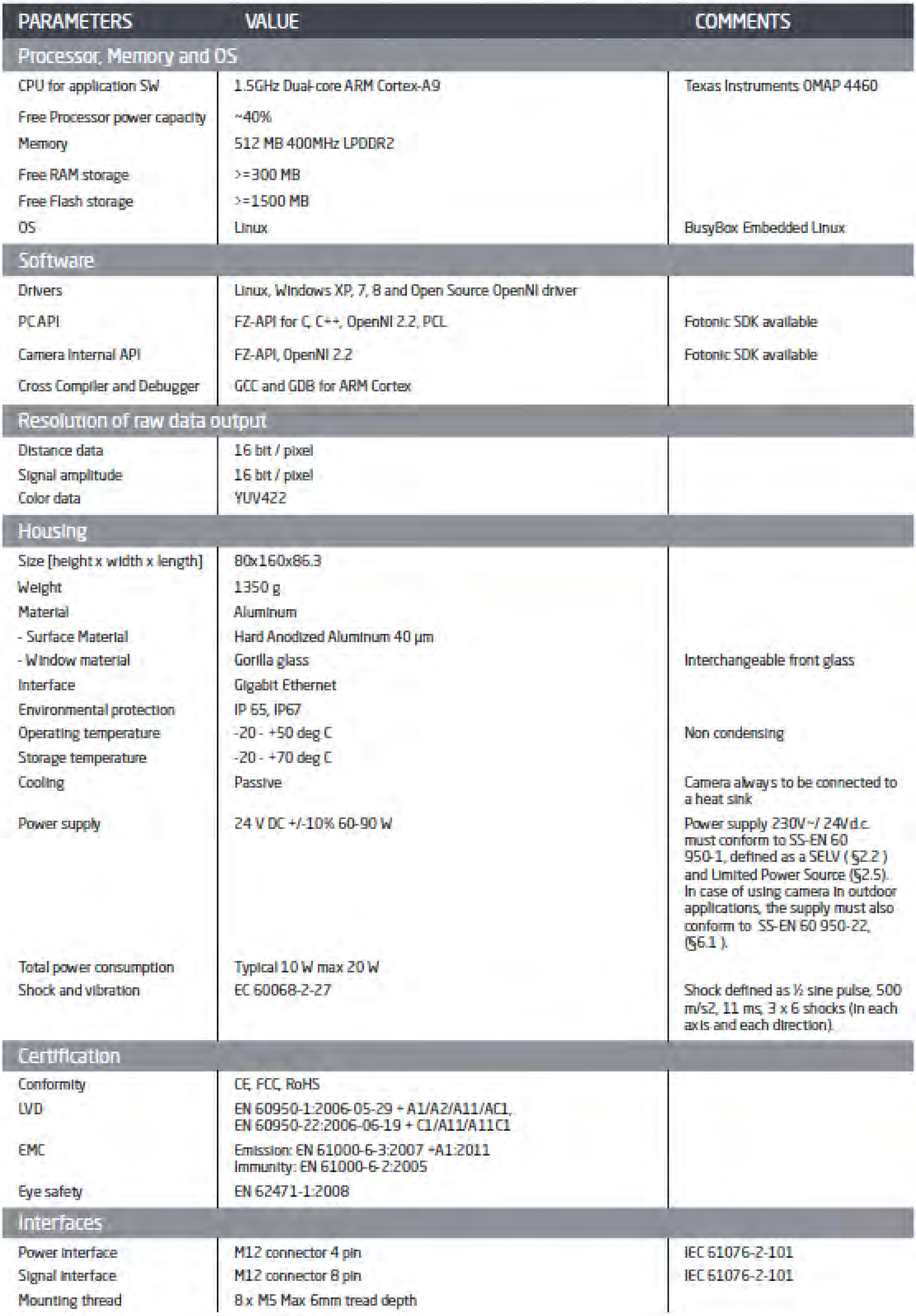
C40 - 40deg horizontally

Technical information ›

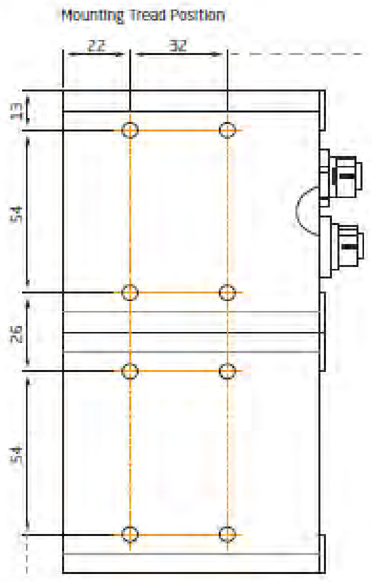
2013:2



PARAMETERS	VALUE				COMMENTS
Sensor					
Depth sensor type	CCD				
Color sensor type	CMOS				IDS UI-1551LE-C-HQ
Maximum frame rate	10 fps				3D data without color mapping 52 fps.
Total capture time	6,7 ms				Depending on shutter time
Pixel array size, Depth sensor	160 (h) x 120 (v)				
Pixel array size, Color sensor	1280x960				
Multi camera option	Yes, by factory configuration				Up to 4 cameras non-interferring
Number of dead pixels on sensor	<=20				
Dead pixel cluster (2 or more direct neighbours)	No				
Illumination	**C70/C40 16 W**				
Illumination (power out)	LED 16 W				
Wave length	850 nm				
Modulation freqency	15 Mhz				Value is approx.
Optics	**C70**		**C40**		
Field of view (h) x (v)	70° x 53°		45° x 34°		For examples see table below
Measurement range	0,1 - 10 m				Camera type, setting and reflectivity dependent
Field of view	**C70 (70° x 53°)**		**C40 (45° x 34°)**		
Z-distance from camera [m]	x [m]	y [m]	x [m]	y [m]	x=horizontal, y= vertical
0,5	0,7	0,5	0,4	0,3	
1	1,4	1,0	0,8	0,6	Values are approximate
2	2,8	2,0	1,7	1,2	
3	4,2	3,0	2,5	1,8	
5	7,0	5,0	4,1	3,1	
10	14,0	10,0	8,3	6,1	
Accuracy*	**C40**		**C70**		
Absolute accuracy					
0,3-0,5 m**			+/- 10 mm		Reflectivity of target 70%
0,5-1 m	+/- 10 mm		+/- 10 mm		*Measured in Z-direction, for 11x11 central pixels, over 20 frames. Ambient illumination 0%, Ambient temperature 20 degrees. Measured on single flat target
1-2 m	+/- 10 mm		+/- 10 mm		
2-3 m	+/- 20 mm		+/- 20 mm		
3-5 m	+/- 30 mm		+/- 30 mm		
5-7 m	+/- 30 mm		+/- 30 mm		
7-10 m	+/- 40 mm				**Shorter range possible on lower reflectivity targets
Repeatability (1σ)					
0,3-0,5 m**			5 mm		
0,5-1 m	5 mm		5 mm		
1-2 m	5 mm		5 mm		
2-3 m	5 mm		10 mm		
3-5 m	10 mm		10 mm		
5-7 m	10 mm		30 mm		
7-10 m	30 mm				
Relative accuracy	+/- 10mm				Measured at 0,5 m Reflectivities 30% and 90%
Drift with temperature (T)					
20°C ≤ T ≤ 30°C	≤ 0.5 mm/°C (max)				
10°C ≤ T ≤ 50°C	≤ 1.5 mm/°C (max.)				
External light disturbance	Up to 100 kLux				Electronic suppression of background illumination



PARAMETERS	VALUE	COMMENTS
Processor, Memory and OS		
CPU for application SW	1.5GHz Dual-core ARM Cortex-A9	Texas Instruments OMAP 4460
Free Processor power capacity	~40%	
Memory	512 MB 400MHz LPDDR2	
Free RAM storage	>=300 MB	
Free Flash storage	>=1500 MB	
OS	Linux	BusyBox Embedded Linux
Software		
Drivers	Linux, Windows XP, 7, 8 and Open Source OpenNI driver	
PC API	FZ-API for C, C++, OpenNI 2.2, PCL	Fotonic SDK available
Camera internal API	FZ-API, OpenNI 2.2	Fotonic SDK available
Cross Compiler and Debugger	GCC and GDB for ARM Cortex	
Resolution of raw data output		
Distance data	16 bit / pixel	
Signal amplitude	16 bit / pixel	
Color data	YUV422	
Housing		
Size [height x width x length]	80x160x86.3	
Weight	1350 g	
Material	Aluminum	
- Surface Material	Hard Anodized Aluminum 40 µm	
- Window material	Gorilla glass	Interchangeable front glass
Interface	Gigabit Ethernet	
Environmental protection	IP 65, IP67	
Operating temperature	-20 - +50 deg C	Non condensing
Storage temperature	-20 - +70 deg C	
Cooling	Passive	Camera always to be connected to a heat sink
Power supply	24 V DC +/-10% 60-90 W	Power supply 230V~/ 24V d.c. must conform to SS-EN 60 950-1, defined as a SELV (§2.2) and Limited Power Source (§2.5). In case of using camera in outdoor applications, the supply must also conform to SS-EN 60 950-22, (§6.1).
Total power consumption	Typical 10 W max 20 W	
Shock and vibration	EC 60068-2-27	Shock defined as ½ sine pulse, 500 m/s2, 11 ms, 3 x 6 shocks (in each axis and each direction).
Certification		
Conformity	CE, FCC, RoHS	
LVD	EN 60950-1:2006-05-29 + A1/A2/A11/AC1, EN 60950-22:2006-06-19 + C1/A11/A11C1	
EMC	Emission: EN 61000-6-3:2007 +A1:2011 Immunity: EN 61000-6-2:2005	
Eye safety	EN 62471-1:2008	
Interfaces		
Power interface	M12 connector 4 pin	IEC 61076-2-101
Signal interface	M12 connector 8 pin	IEC 61076-2-101
Mounting thread	8 x M5 Max 6mm tread depth	


Mounting Tread Position
22
32
13
54
26
54

Appendix H

FLIR™
The Global Leader in Infrared Cameras

ThermaCAM® E45

INFRARED CAMERA

The E45 offers a solid value for those who seek to combine good performance and affordability in our handheld E-Series line.

- Accurate Temperature Measurement
- Weighs Only 1.5 lbs.
- Interchangeable Optics
- Built-in Laser LocatIR™
- Robust Post-Processing Capabilities
- Easy-view Color LCD
- JPEG Image Storage
- Highly Affordable

Find Problems Fast

Unlike other cameras, you can use the powerful, affordable E45 in all types of harsh industrial environments to find faults in electrical and mechanical systems quickly and accurately. Store up to 200 thermal images inside the camera for post-processing and analysis on the camera or after downloading to a PC.

Most Accurate Temperature Measurement

The E45 is the most accurate lightweight, handheld IR camera on the market today. The E45 sees temperature differences as small as 0.1° C and provides 19,000 picture elements in each image.

Lightweight, Rugged & Ergonomic

The E45 is built tough for hard work in the field and in all weather conditions and industrial environments — a critical design capability. Dust and splash proof, the E45 meets IP 54 standards. Unlike other cameras that might be "lab calibrated," the E45 won't seize-up in freezing cold, extreme heat or other harsh conditions. Its exclusive Ambient Temperature Compensation (ATC) technology assures accuracy under the most challenging ambient temperature conditions.

Download and Document

Download thermal images with measurements to your PC quickly with ThermaCAM QuickView™ software and standard USB or serial cables. ThermaCAM Reporter software enables automatic report generation, capturing thermal images and text, and seamlessly integrating with standard word processing programs.

Flexible JPEG Image Storage with Post Processing

Store and recall up to 200 calibrated thermal images using the camera's on-board memory. The E45's radiometric JPEG image format allows you to go back to any image at any time to add and move spots, measure temperatures, and perform analysis you may have missed in the field.

View Sensitive Thermal Images

A maintenance-free, state-of-the-art uncooled FPA infrared detector produces crisp thermal images that reveal subtle temperature variations that can signal electro-mechanical problems. The E45 can detect problems before they become critical, helping you increase safety, reduce production downtime, and eliminate potential fires.

Pinpoint Problems with Precision

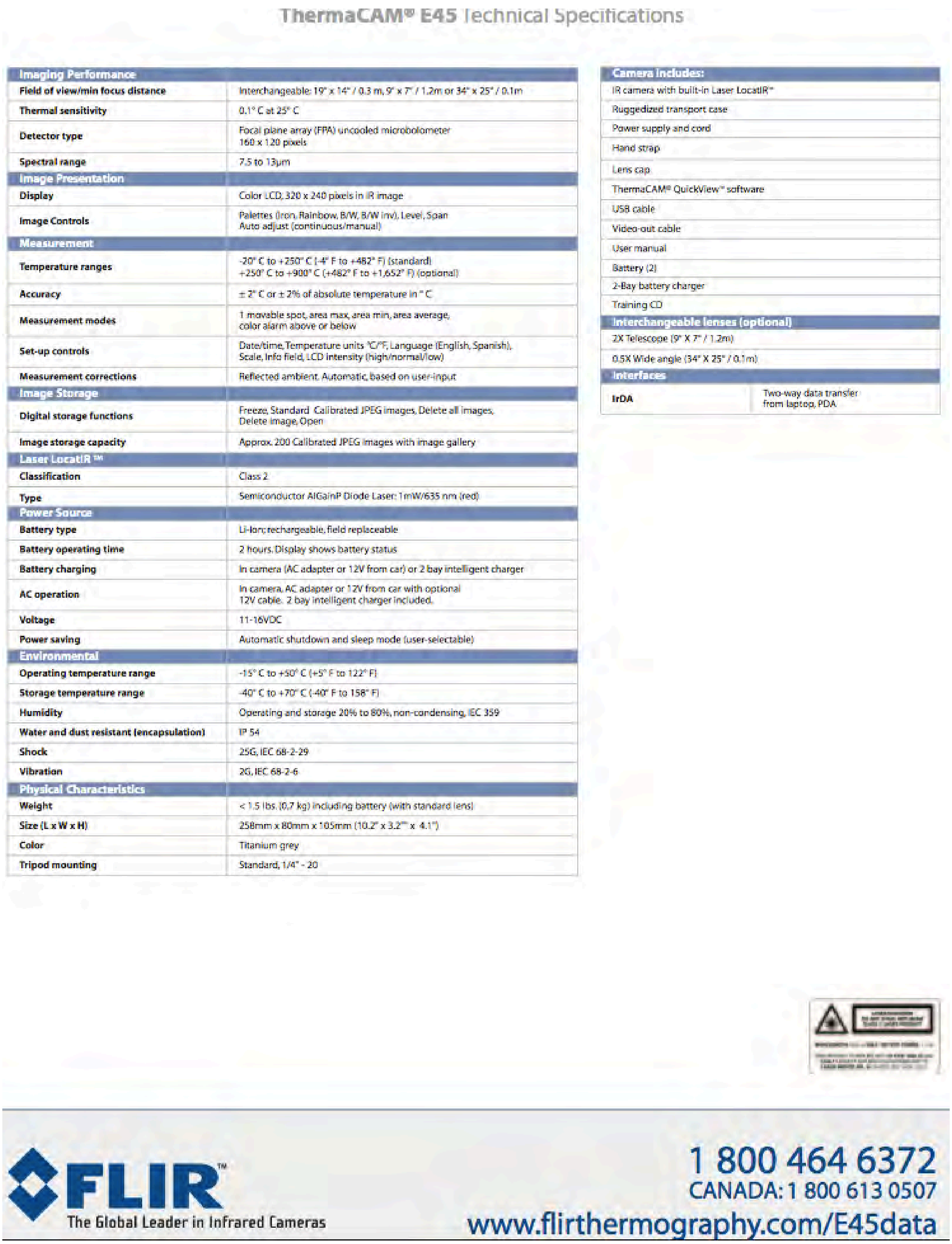
The built-in Laser LocatIR™ projects a bright red dot on the target that enables you to associate the IR image with the real physical target. This feature greatly enhances worker safety by eliminating the tendency to "finger point" at problems in potentially hazardous electrical environments.

Interchangeable Optics

Many targets in your facility cannot be imaged or measured properly without the proper optics. Optional lenses are available for the E45 to meet your application needs. A telescope lens is ideal for inspecting distant targets such as overhead power lines. A wide angle lens can more than double the standard field-of-view for evaluating large objects from a short distance, such as roofs and electrical panels.

Smart Power Management

Lightweight, longlife Li-Ion batteries assure uninterrupted inspections. The E45 includes an external 2-bay battery charger and an internal battery charger. A 12 VDC car/truck charger adapter is also available.



ThermaCAM® E45 Technical Specifications

Imaging Performance	
Field of view/min focus distance	Interchangeable: 19° x 14° / 0.3 m, 9° x 7° / 1.2m or 34° x 25° / 0.1m
Thermal sensitivity	0.1° C at 25° C
Detector type	Focal plane array (FPA) uncooled microbolometer 160 x 120 pixels
Spectral range	7.5 to 13µm
Image Presentation	
Display	Color LCD, 320 x 240 pixels in IR image
Image Controls	Palettes (Iron, Rainbow, B/W, B/W inv), Level, Span Auto adjust (continuous/manual)
Measurement	
Temperature ranges	-20° C to +250° C (-4° F to +482° F) (standard) +250° C to +900° C (+482° F to +1,652° F) (optional)
Accuracy	± 2° C or ± 2% of absolute temperature in ° C
Measurement modes	1 movable spot, area max, area min, area average, color alarm above or below
Set-up controls	Date/time, Temperature units °C/°F, Language (English, Spanish), Scale, Info field, LCD intensity (high/normal/low)
Measurement corrections	Reflected ambient. Automatic, based on user-input
Image Storage	
Digital storage functions	Freeze, Standard Calibrated JPEG images, Delete all images, Delete image, Open
Image storage capacity	Approx. 200 Calibrated JPEG images with image gallery
Laser LocatIR ™	
Classification	Class 2
Type	Semiconductor AlGaInP Diode Laser: 1mW/635 nm (red)
Power Source	
Battery type	Li-Ion; rechargeable, field replaceable
Battery operating time	2 hours. Display shows battery status
Battery charging	In camera (AC adapter or 12V from car) or 2 bay intelligent charger
AC operation	In camera, AC adapter or 12V from car with optional 12V cable. 2 bay intelligent charger included.
Voltage	11-16VDC
Power saving	Automatic shutdown and sleep mode (user-selectable)
Environmental	
Operating temperature range	-15° C to +50° C (+5° F to 122° F)
Storage temperature range	-40° C to +70° C (-40° F to 158° F)
Humidity	Operating and storage 20% to 80%, non-condensing, IEC 359
Water and dust resistant (encapsulation)	IP 54
Shock	25G, IEC 68-2-29
Vibration	2G, IEC 68-2-6
Physical Characteristics	
Weight	< 1.5 lbs. (0.7 kg) including battery (with standard lens)
Size (L x W x H)	258mm x 80mm x 105mm (10.2" x 3.2"" x 4.1")
Color	Titanium grey
Tripod mounting	Standard, 1/4" - 20

Camera includes:	
IR camera with built-in Laser LocatIR™	
Ruggedized transport case	
Power supply and cord	
Hand strap	
Lens cap	
ThermaCAM® QuickView™ software	
USB cable	
Video-out cable	
User manual	
Battery (2)	
2-Bay battery charger	
Training CD	
Interchangeable lenses (optional)	
2X Telescope (9° X 7° / 1.2m)	
0.5X Wide angle (34° X 25° / 0.1m)	
Interfaces	
IrDA	Two-way data transfer from laptop, PDA

FLIR™
The Global Leader in Infrared Cameras

1 800 464 6372
CANADA: 1 800 613 0507
www.flirthermography.com/E45data

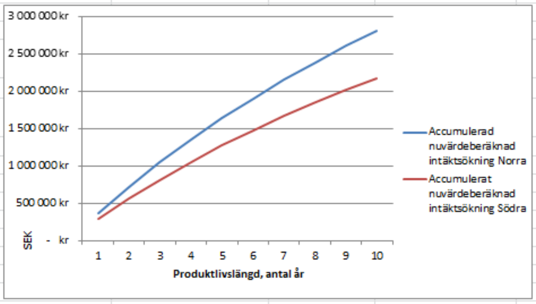
Appendix I

Investeringskalkyl 1

Baserad på antagandet att entreprenören kan ta ut ett högre pris per hektar tack vare användandet av hinderdetektering

	Antal ha markberedning/säsong	kr/ha Normal pris [2]	Normalpris + 15%	Intäkt normalpris	Intäkt normalpris +15%	Potentiell Intäktsökning/säson
Skogsentreprenör i Norra Sverige:	1500	1 780 kr	2 047 kr	2 670 000 kr	3 070 500 kr	400 500 kr
Skogsentreprenör i Södra Sverige:	1000	2 070 kr	2 381 kr	2 070 000 kr	2 380 500 kr	310 500 kr

År	Nuvärdesfaktor: (7 % kalkylränta)	Nuvärde Intäktsökning Norra	Nuvärde Intäktsökning Södra	Accumulerad nuvärdeberäknad intäktsökning Norra	Accumulerat nuvärdeberäknad intäktsökning Södra	
1	0,93458	374 299 kr	290 187 kr	374 299 kr	290 187 kr	
2	0,87344	349 812 kr	271 203 kr	724 111 kr	561 390 kr	
3	0,81630	326 927 kr	253 460 kr	1 051 039 kr	814 850 kr	
4	0,76290	305 540 kr	236 879 kr	1 356 578 kr	1 051 729 kr	
5	0,71299	285 551 kr	221 382 kr	1642129,073	1273111,304	= Tillfört värde vid en produktlivslängd på 5 år
6	0,66634	266 870 kr	206 899 kr	1 908 999 kr	1 480 011 kr	
7	0,62275	249 411 kr	193 364 kr	2 158 410 kr	1 673 374 kr	
8	0,58201	233 095 kr	180 714 kr	2 391 505 kr	1 854 088 kr	
9	0,54393	217 845 kr	168 891 kr	2 609 351 kr	2 022 980 kr	
10	0,50835	203 594 kr	157 842 kr	2 812 944 kr	2 180 822 kr	



Tänkbart försäljningspris: Minsta tillfört värde * 0,75
954833
Tänkbar tillverkningskostnad: Försäljningspris*0,5
477417

[1] Källa: Brackeforest -Föreläsning av Klas-Håkan Ljungberg(VD) & Sören Andersson(Säljare)

[2] Källa: Skogsstyrelsens och Skogforsks årliga enkät om skogsbrukets kostnader http://www.skogforsk.se/sv/KunskapDirekt/KraftsamlingSkog/Priser-och-kostnader/Kostnader/

[3] Källa: SCB lönestatistik, http://allastudier.se/jobb-o-l%C3%B6n/8112-markberedningsf%C3%B6rare-skogsbruk/

Investeringskalkyl 2

Baserad på antagandet att hinderdetektering gör skogsmaskiner semiautonoma och att en maskinförare därmed kan styra 2 eller 3 maskiner istället för en.

Personalkostnad/ maskinförare [3]	Personalkostnad/ maskinförare/år	Potentiella besparingar/år: personalkostnad/2	Potentiella besparingar/år: personalkostnad/3
23 900,00 kr	286 800,00 kr	143 400,00 kr	191 200,00 kr

År	Nuvärdesfaktor: (7 % kalkylränta)	Nuvärde besparingar (pk/2)	Nuvärde besparingar (pk/3)	Accumulerad nuvärdeberäknad besparing (pk/2)	Accumulerad nuvärdeberäknad besparing (pk/3)	
1	0,93458	134 019 kr	178 692 kr	134 019 kr	178 692 kr	
2	0,87344	125 251 kr	167 001 kr	259 270 kr	345 693 kr	
3	0,81630	117 057 kr	156 076 kr	376 327 kr	501 769 kr	
4	0,76290	109 399 kr	145 866 kr	485 726 kr	647 635 kr	
5	0,71299	102 242 kr	136 323 kr	587 968 kr	783 958 kr	= Tillfört värde vid en produktlivslängd på 5 år
6	0,66634	95 553 kr	127 405 kr	683 522 kr	911 362 kr	
7	0,62275	89 302 kr	119 070 kr	772 824 kr	1 030 432 kr	
8	0,58201	83 460 kr	111 280 kr	856 284 kr	1 141 712 kr	
9	0,54393	78 000 kr	104 000 kr	934 284 kr	1 245 712 kr	
10	0,50835	72 897 kr	97 196 kr	1 007 182 kr	1 342 909 kr