Project Plan - µTomography

Project name	Stakeholder	Project managers
Precise Positioning and Scanning for Microwave Imaging	Nikola Petrovic	**Software Manager:** Victor Aziz **Hardware Manager:** Emanuel Bjurhager

1 Staffing and Roles

Name	Title	Responsibilities
Victor Aziz	Software Manager	Responsible for making sure that project meets software requirements. 3D-reconstruction
Emanuel Bjurhager	Hardware Manager	Responsible for making sure that project meets hardware requirements. Responsible for keeping OpenProject server up and running.
Amanda Rautio	Software Member	Responsible for project GitHub repository. GUI
Ingrid Heien Bjonge	Software Member	YuMi robot operator
Jonathan Holm	Software Member	3D-reconstruction
Aref Bahtiti	Hardware Member	Responsible for the 3D modeling and PCB design

Table 1: Staffing and roles

2 Mission

2.1 Background

Breast cancer is one of the most common types of cancer and predominantly affects women. Around 30% of the diagnosed cancer among women is breast cancer, and in Sweden alone, according to the Swedish Cancer Society, approximately 20 women get diagnosed with it every day [1]. Often, the cancer is close to symptomless in its preliminary stages, making it hard to detect. But if found early, the likelihood of eliminating the cancer is high. Commonly, breast cancer is found with mammography [2], where X-ray images are taken of the breast. This process requires the breast to be compressed, which may feel uncomfortable or cause pain for the patient. The X-ray used in mammography exposes the patient to ionizing radiation, which, while being in tiny doses, still pose as a potential risk for the patient. Mammography has limited capacity in identifying tumors without a characteristic mass, often seen in lobular breast cancer or tumors without calcification [3]. Other solutions, such as MRI and ultrasound, also have limitations. Therefore, there is a need for novel solutions that can detect breast cancer early.

Microwave tomography (MWT) is a biomedical imaging technique where microwaves are used to illuminate a target from multiple angles and where the collected data is used to create cross-sectional images. Microwave imaging

2.1 Background

makes it possible to detect cancerous tumors as healthy and cancerous tissue respond differently to electrical fields in the microwave spectrum, making them distinguishable from one another in the produced images. MWT poses as a potential competitor to mammography, as it is non-intrusive, comfortable and without ionizing radiation, making it suitable for both detection and recurrent monitoring during treatment [3].

Innovation and development in the field of MWT is the focus of an ongoing project at Mälardalens University. Previously in the project, a robot-controlled data acquisition system for microwave imaging was developed and validated [4]. The system consisted of a robotic arm, two monopole antennas, a water tank in which the object to be scanned and the antennas were placed, and a MATLAB interface for controlling the data acquisition. During the scanning, both the transmitting and receiving antennas would be immersed in the water tank, where the transmitting antenna was in a fixed position while the receiving antenna was fixed to the robotic arm, which could move along the surface of the object in a pre-programmed pattern. Because the receiving sensor only moved in a pre-programmed pattern with no consideration for the object's placement, the object itself had to be positioned in relation to the robot's coordinate system with high accuracy. When validated through comparison between measured and simulated data, the system showed promising results.

Since then, different prototypes of arm designs have been developed and tested, and improvements to the transmitters have been made, making them suitable for a dry set-up. These transmitters are now a microwave sender that is meant to be placed under the object, and a receiver that should be moved over the object, measuring the microwave signals at different parts of the object. To achieve this, a robotic system that can move the transmitters over the object at a high degree of freedom and place them at specified distances from the object with high precision, as the characteristics of the microwave signal change greatly depending on the distance to the object. Additionally, a 3D model of the object, accompanied with a graphical user interface needs to be created to aid with the positioning and user interaction to control scanning area, distance and patterns.

Three-dimensional (3D) reconstruction is a mathematical representation of a real-world object. 3D scanning and reconstruction have become important in the medical industry and is used to improve treatment [5]. A method for 3D scanning will scan the surface of an object and generate a point cloud. A point cloud is a set of data points in space. The reconstruction method will use the point cloud to approximate the 3D surface of the object. The 3D model can be created with no physical contact with the object by using a non-contact sensor technology, such as LIDAR.

When working with data collected from practical applications, there will certainly be noise present in the data. Reconstruction of objects digitally is no exception and can make a representation look nothing like the actual object that was scanned if it is not dealt with [6]. Speckle noise and reflections are some of the largest contributors to the noise in image reconstruction [7]-[8]. Many proposed solutions to the problem have been tried, ranging from using filters on the signal to extract the desired data to smoothing data using different mathematical functions [9].

3D reconstruction is widely used in multiple fields, which creates a wide variety of algorithms. Each algorithm has it is own pros, cons and prior assumptions about the scannable object and the data [10] [11] . In summary, two aspects characterize the solutions, the prior knowledge about the scannable object and the information collected in the acquisition phase[12]. A solution, as in [13] requires information about the sampling process while another solution [14] needs surface normal and sample point neighbor information[15].

A popular algorithm Crust[16] considers the general case of unorganized sets of data points and requires no additional information about the surface normal or the sampling process. Given a priory knowledge of smooth surface and high-density sampling, The Crust algorithm is theoretically proven to produce a surface that is topologically equivalent to the real surface[17]. The crust algorithm does not have any problem with some noise or outlier in the data but it cannot handles a high noisy data or sharp edges. It also requires a post-processing stage to get rid of invalid parts of the surface[16]. The crust algorithm uses multiple computational geometry basic techniques such as Voronoi diagrams, Delaunay Triangulation and Medial Axis. In the following section, The basic techniques are described in summary to define some terminology. The mathematical descriptions and prof are better described in [18].

The Voronoi diagram shown in figure 1 is a map of a surface created from sample points called sites that have specific coordinates. The sites are separated by edges which create different regions or cells for every site. A vertex is when 3 Voronoi cells meet at a point. The important purpose of the Voronoi diagram is that in a specific site region, all other coordinates are closest to the region site than to any other site.

On the boundary of the Voronoi diagram representation, there is 2 types of regions, the bounded and unbounded regions. The bounded regions are where the edges of that region converge to an intersection while unbounded regions' edges do not intersect. A contour shape is created by joining all the unbounded regions. The contour is called a convex hull.

A Delaunay triangulation is also a surface map representation that instead of dividing the surface into regions, the convex hull is divided into triangles see figure 2. The unique property of Delaunay triangulation is that every Circumscribed circle around each triangle on the surface is empty e,g The circle does not contain any other point from the points set.

Finally the medial axis shown in figure 3 is a set of points that represents the skeleton of the shape.In a sufficiently sampled dense set of point, the Voronoi vertices approximate the medial axis of a shape.

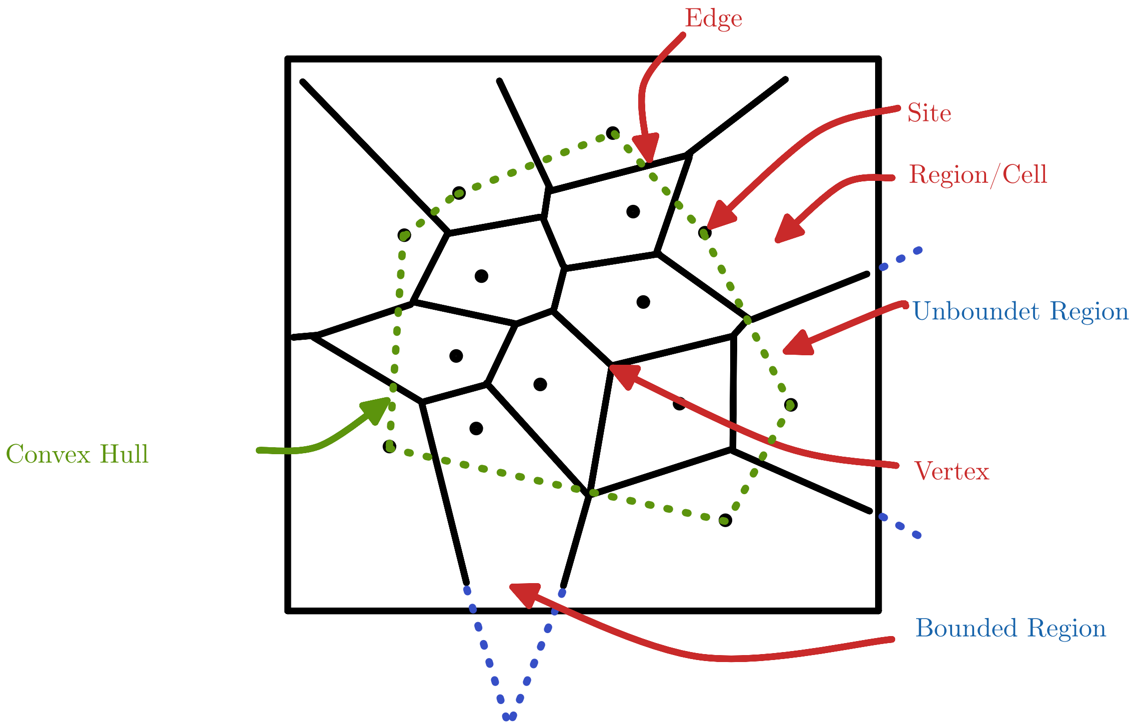

Figure 1: The Voronoi diagram termonology

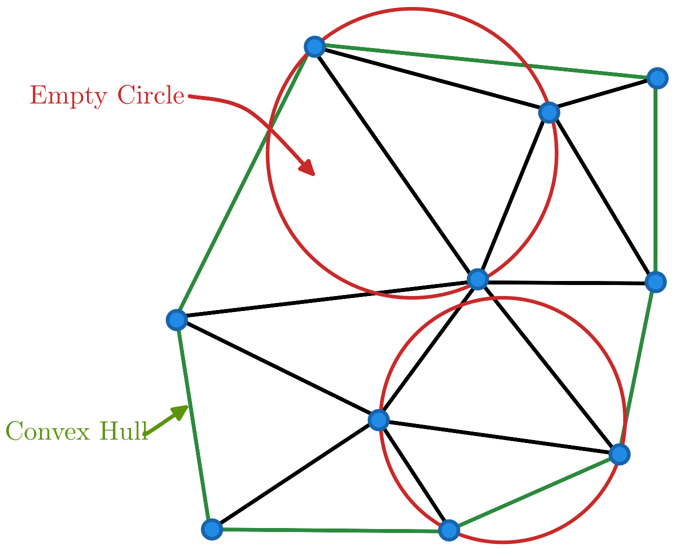

Figure 2: The delaunay triangulation that devide the green convex hull in black triangles and the circumscribed empty circle in red of 2 triangles that does not contain any other blue points.

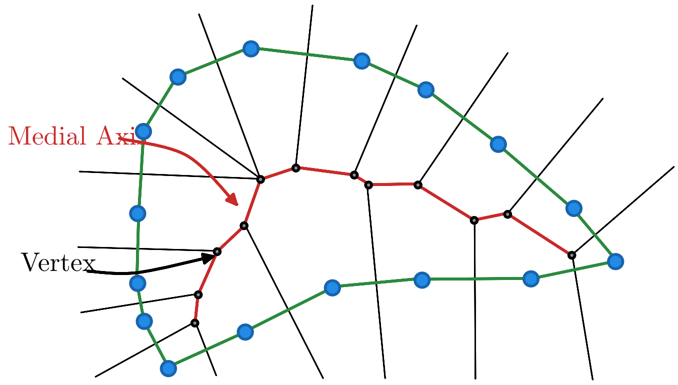

Figure 3: The medial Axis in red is created by connecting the black vertices of the voronoi diagram.

2.2 State of the Art and State of Practice

A research group based at the University of Calgary [19]; was able to recreate a breast surface through point laser scanning and microwave imaging. The laser scanning was performed with a laser with an accuracy lower than 400 μm. Tilting the laser at a 15 °angle was also tested to improve the curve estimation of the breast. The laser point data was later fed into the PowerCrust algorithm to get a surface estimation. Both methods were performed with the breast submerged in a liquid. The paper concluded with a result that showed laser were superior to microwave imaging. Another solution to get a accurate 3D-estimation of a object was conducted by a group based in the Technical University of Braunschweig [20]. By combining the information of both laser and a camera the error could be reduced down to 1mm off from the actual model. The laser was sweept over the object while a color camera is used to detect the laser strip on the object the frames was then interpolated to get surface estimation.

A research group from the same university [21] successfully created a method for automatically scanning for breast cancer. Their 3D reconstruction was done using a laser triangulation sensor mounted on a four-degrees-of-freedom robotic arm, which measured the breast in the horizontal plane. The 3D scanning protocol was based on scanning the breasts at different heights in the Z-plane to get a representation of the contour at different angles in the X, and Y plane. Creating a point cloud representing the contour of the breast at different angles. The data collected was interpolated and then used to get an image of the entire breast. The reconstruction was then used as a reference when controlling the robotic arm, which had a sensor for detecting anomalies in the breast tissue. The paper concluded that their surface reconstruction using laser triangulation was quick and successful.

Another research group [22], also worked with breast cancer detection, but in contrast to the group based in Calgary, this 3D reconstruction technique used a webcam to estimate the surface of the breast. The camera took 12 pictures of the breast in the azimuth plane; ranging from 0 to 165 °angles. By using edge detection, a curve of the breast contour could be approximated. This procedure was repeated around the Z-axis in 0.5mm intervals in the X, Y-plane. By combining all the breast contour estimations, a 3D surface could be estimated. The greatest surface error was 2mm compared to the real breast. However, the Z-axis was elongated in the estimation, which caused the position of the tumor to be off by around 10mm in the z-direction.

The use of robotics in the field of medicine has seen an increase over the last decade. Their areas of application range from using the robots for normal checkups to being used in the surgical room to help the surgeon [23]. ABB is one of the world's leading companies in the design of robotic arms that meet a high standard of precision. One example of such a robot is the Single-Arm YuMi (SAY) robot which is a seven-axis robotic arm, the seventh axis giving it redundancy, resulting in the freedom of performing more complex movement than a six axis robot. The arm has a reach of around 56 cm mimicking a human arm, with a pose repeatability of 0.02 mm [24]. The robot has been certified for use close to and in contact with humans, and it has even been successfully implemented and used in the medical field, performing tasks like distributing medicine to patients [25].

A multitude of different hardware and software setups for microwave imaging have been developed since the technology first emerged. In the early 2000s Meaney et al. [26] were one of the first to develop a clinical prototype for microwave imaging of a breast. The system comprised 16 monopole antennas arranged in a circular array configuration, where the antennas were submerged in a saline bath, and the patient was laid on a table above the tank with the breast hanging into the fluid. Since then, a large quantity of systems have emerged with similar designs. Using multiple transmitters in a circular array could still be regarded as state-of-the art today [27], since it is still used by the Wavelia system.

The Wavelia system [28] is a microwave breast imaging device developed by MVG Industries and currently under clinical investigation. Similarly to the system developed by Meaney et al., the Wavelia system also comprises multiple antennas arranged in a circular array, where the patient lies prone on a table with the breast hanging into the coupling fluid. But the new system differentiates itself by using 18 equally spaced wideband Vivaldi-type probes, placed outside of the fluid filled cylinder. These probes are rotated vertically around the breast, illuminating it in 5 mm intervals. The microwave breast imaging system is also paired with an optical breast contour detection (OBCD) system. The OBCD system allows the external surface of the breast to be reconstructed and the breast volume to be calculated with the help of a 3D stereoscopic camera, placed below the examination table. As of now, the system has shown good results, both when detecting dielectric contrast between tumor phantoms and synthetic breast models, and in clinical studies with human subjects. However, the current generation of the system cannot detect lesions less than 10mm, and is unsuitable for patients with smaller breasts, as the breast must have enough mass to create a pendulous reach when lying prone. The system is also limited in detecting abnormalities near the underlying chest muscles, as there is 2-4cm between the uppermost scanning position and the chest wall. Using coupling fluid is also not preferred because it is can be seen as unhygienic and requires the patient to clean their breasts after examination.

Currently, no evidence has been found that microwave tomography is used in practice, as it is still a method under research. The Wavelia system mentioned above is one of the systems closest to a finished product, currently undergoing clinical trials. Therefore, in the area of breast tumor detection, mammography is the state of practice.

3 Purpose and Goal

3.1 Purpose

The purpose of this project is to help the stakeholders take their research further, to test new antenna designs, and to take the research closer to clinical trials by developing a new antenna positioning system. Furthermore, their research goal is to discover and invent new techniques for detecting Object Under Study (OUS) cancer at an early stage without exposing the patient to ionizing radiation.

3.2 Goal

The goal of the project is to build a system that can automatically do measurements of a phantom OUS.

4 Requirement specification

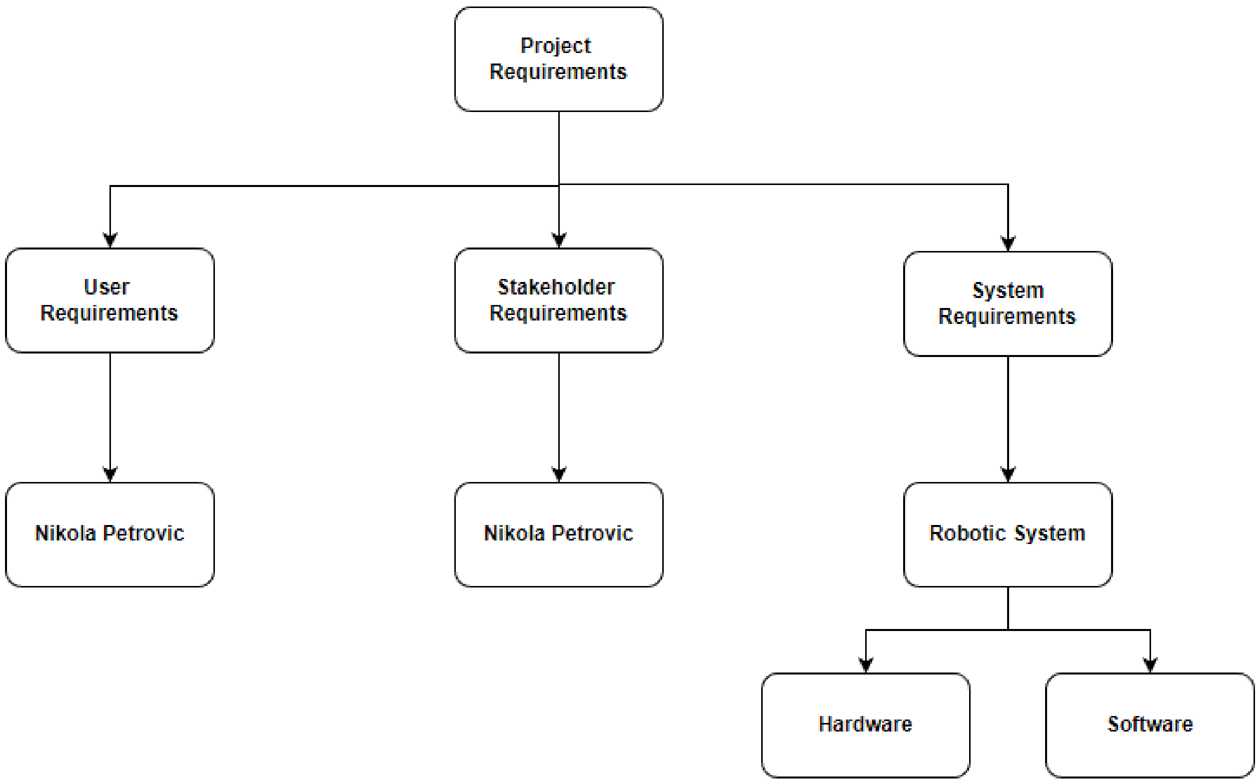

Figure 4: A requirement tree that shows the requirements of the project. The project requirements can be divided into three categories: user, stakeholder and system requirements.

4.1 Project requirements

- The project shall be completed before January 13 2023.

- The project shall be transferred to MDU robotics project on GitHub on completion of the project.
- The project shall use GitHub for version control.
- The project shall be planned and time managed using the project server.

4.2 Stakeholders requirements

These are the requirements as specified by the stakeholders.

- Develop the hardware for a robotic system that can move at least one applicator around an OUS with all required degrees of freedom.
- Implement a surface scanning and/or positioning system to support exact (± 0.5 mm) placement of the antenna at a required distance d away from the OUS ($0 < d < \lessapprox 10$mm).
- Develop the necessary control software to move the transmitter to an arbitrary position and to run a pre-defined measurement sequence.
- Develop a graphical user interface to control the measurement system.

4.3 User requirements

The stakeholder will be the operator of the system, and for that reason be the user of the system. As a result, the user requirement and the stakeholder requirement will be the same. There will be no patients or other humans involved.

4.4 Product requirements

4.4.1 Hardware requirements

The hardware can be divided into multiple subsystems: receiver end-effector, sender end-effector, receiver robot arm and sender fixture.

- The receiver end-effector shall be designed to have a mount for the microwave receiver and one distance measurement sensor.
- The sender end-effector shall be designed to have a mount for the microwave sender.
- The receiver robot arm shall be able to place the microwave receiver approximately normal to the OUS, with a distance of 0mm to 10mm.
- The receiver robot arm shall have an accuracy better than ± 0.5 mm.
- The sender platform shall be able to place the microwave sender between 0mm and 10mm from the OUS.
- The sender platform shall have an accuracy better than ± 0.5 mm.

4.4.2 Software requirements

The software can be divided into the following subsystems: 3D reconstruction, trajectory planning, Graphical user interface (GUI) and data acquisition.

- The 3D reconstruction algorithm shall be able to estimate the OUS surface and create a 3D model based on the measurement data provided by the sensor.
- The GUI should display information about the system with a visualization of the OUS.
- The GUI shall let the user configure the scanning region, distance, and density.
- The trajectory planning algorithm shall calculate at which locations and in what order the receiver robot arm should stop to let the microwave receiver take measurements, based on configurations made in the GUI by the user.
- Trajectory shall be calculated to ensure the receiver robot arm does not move in a way that will potentially damage the cables or collide with the OUS or the environment.

5 Development plan

5.1 Tools

All computers are running Windows 10 or 11 [29][30]. OpenProject [31] is used for task management within the group. Microsoft Teams will be used as the communication tool within the project group and to provide and receive information from stakeholders [32].

5.1.1 Hardware Tools

Single-Arm YuMi
T he robot used in this project is provided by ABB and will be a Single-Arm YuMi (SAY). It is one of ABB's most agile and compact collaborative robots today [24]. In contrast to typical industrial robots that need to be protected with various safety measures, collaborative robots, also known as cobots, are safe to use in contact with humans. The SAY has seven different axes, as opposed to the six different axes found on regular industrial robots made by ABB. The six axes give the robot freedom to move to every position in space, but the seventh axis allows the robot to move to all positions with different joint configurations. This makes it easier to avoid contact with the environment.

Arduino Mega 2560
Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It contains 16 analog inputs, 4 hardware serial ports (UARTs), a 16 MHz crystal oscillator, 54 digital input/output pins (of which 15 can be used as PWM outputs), a USB connector, a power jack, an ICSP header, and a reset button. It comes with everything needed to support the microcontroller; to get started, just plug in a USB cable, an AC-to-DC adapter, or a battery. The high number of digital pins, ethernet connectivity and ease of use make this type of microcontroller a good choice for this project [33].

Opto NCDT 1302 Laser Distance Sensor
For frequent measuring jobs, a low-cost laser sensor called the miniaturized opto NCDT 1302. Its integration is made possible by the exceptionally compact design. Despite its compact size, the 1302 series offers accurate measurement results and is appropriate for automation and machine integration technology. The sensor generates an analog signal because it includes an integrated analog output. The sensor will be employed in this project since it has a high degree of precision and can measure distances between 20 and 200 mm.

Cables and connectors
The types of cables and connections used in this project will depend on its requirements and behavior, but as a general rule, it will require a few Ethernet cables for the robot arm and the microcontroller, as well as a few cables and connectors for the power connection. It's also important to take into account the microwave antenna cables and the laser sensor cable.

Microwave Sender/receiver
The stakeholders provide a microwave sender and receiver, which should be able to be installed on the robot arm and sender fixture using 3D-printed holders. The holders will hold all the sensors and antennae.

Computer
The computer is the central control device that will link all of the parts—sensors, microcontroller, and robot hand—together. The computer ought to meet the needs that each application and system have.

Power supply
Power is required for the robot arm, sensors, microcontrollers, and computer. The laser sensor requires a 24 volt power source, the microcontroller a 5 volt supply, and some of the components a 230 volt supply. To properly power all components, we therefore require some voltage regulators and step-down circuits.

3D reference models
The OUS has to be created using average human breast size as a guide. Two models will be created, one of which is a symmetrical design with a spherical and cylindrical shape. In addition, a different one will be created to mimic the intricate contour of a real woman's breast. These models ought to be fastened to a stationary holder in the robot arms' work area.

Original Prusa I3 MK3 3D-printer
Prusa I3 MK3 3D-printer has been designed by Josef Prusa. It is the replacement for the well-liked Prusa I3 MK2S. A removable build plate, an auto-leveling sensor, and a Bowden extruder are a few of the printer features. This printer's workspace measures 25 x 21 x 21 cm and can only use 1.75 mm PLA/ABS filament [34]. The initial prototypes required for creating the project's hardware will be produced with this printer.

5.1.2 Software tool

MATLAB
For easy implementation of the surface reconstruction, computation of trajectory path points and plotting of the result, MATLAB [35] was the chosen method. MATLAB has an intuitive programming style and supports state-of-the-art algorithms using toolboxes. The group members are also comfortable in the use and language of MATLAB which was therefore the ideal programming environment for the project.

RobotStudio & RAPID

RobotStudio is a program developed by ABB that features offline programming, modeling, and simulation of robot cells. RAPID is a high-level programming language that is used as the basic programming language in RobotStudio, and is used to control ABB industrial robots. All robot movement will be programmed using RAPID, and will be tested in a simulation using RobotStudio.

GitHub
Github [36] is used for version control and the git branching is handled with the Gitflow workflow [37]. In Gitflow, the main branch is protected and only contains completed and reviewed code, while development is done on a development branch. Each time a new feature is being developed, it is done on a child branch from the development branch, a so-called feature branch, and merged back into the development branch once the feature is completed. Hence, no code is written on either the main or development branch, and is only added by merging. This ensures the possibility for isolated experiments, more efficient collaboration and gives a good overview on what is currently being worked on. Once a development branch is finished a release branch is created where the code is reviewed before merging into main. Since the software aspects in this project can be divided into four independent parts; 3D-surface reconstruction, robot control, GUI and 3D-CAD modeling, each of these parts has its own independent development branch.

SOLIDWORKS
SOLIDWORKS CAD is a mechanical design automation tool, enables designers to swiftly sketch out concepts, play with features and measurements, and create models and thorough drawings. When it comes to motion simulation and aerodynamics simulations, it is a highly useful tool [38]. This tool will be used in this project to design the end-effector, which contains all of the sensors and measuring components.

KiCad
KiCad (EDA) is an open-source software program for electronic design automation. The software handles PCB Layout with Gerber output and schematic capture. The program is GNU GPL version 3 licensed and functions on Windows, Linux, and Mac OS. The KiCad project aims to offer the greatest cross-platform electronics design program available for industry professionals[39]. KiCad will be used in this project to design the necessary PCBs.

Visual Studio code
Visual Studio code is a Linux, Windows, and macOS-compatible standalone source code editor.This compiler can be used by web developers and it supports almost any programming language [40]. This tool will be used to program the microcontroller.

Multisim
Multisim software will be used to quickly see and understand the behavior of electronic circuits, combining an interactive schematic interface with industry-standard SPICE simulation. Its user-friendly interface aids educators in reinforcing circuit theory and enhancing theory retention throughout the engineering curriculum [41].

5.2 Project management methodology

A heavily simplified version of Scrum will be used. The work will be divided into sprints. Each sprint is a multiple of one week. For example, a quick sprint is 1 week, while a long sprint might be 2 or 3 weeks. Every Monday morning, the sprint for the week will be decided within the group. If there currently is a long sprint in progress, then the current sprint will be briefed to make sure all project members understand what is expected for the upcoming week. At the end of each sprint, there will be a short evaluation among the project members to find potential weaknesses or problems with the sprint and to make sure the upcoming sprint works better. The current work, upcoming work, and the work that has been completed are transparent to all project members and stakeholders through the project server. Other aspects of Scrum will not be used.

6 Documentation Plan

Documentation of the project will be found in the GitHub repository, to which the stakeholders have read access. In the repository, each developed feature will include a short description of: why the feature was needed, its functionality and how it connects or relates to other features. This description should be written on the feature's completion with Markdown and can be found in the documentation folder. A template of how the documentation should be written is provided to the team members. The reports written during the project will also be found in the documentation folder after their respective deadlines. Additionally, written code will be well commented. The GitHub repository will contain a README file containing a brief description of the project, contact information of the contributors, prerequisites and installation instructions at the completion of the project. On project completion, the repository will be moved into the MDU Robotics GitHub Organization.

All meetings within the group and with the stakeholders will be documented by the appointed person, which will rotate according to a schedule. The meeting transcripts will be uploaded to git in the documentation folder.

The stakeholders can at any time access the current WBS, work packages, project status and Gantt chart through project.bjurhager.net.

7 Testing Plan

As the project is divided into different smaller sub-tasks, each sub-task will be tested individually to make sure all parts of the system works independently. As the system is put together, verification will be done to make sure the entire system meets the requirements.

7.1 Stakeholders requirements validation

These are the requirements as specified by the stakeholders.

- *Develop the hardware for a robotic system that can move at least one applicator around an OUS with all required degrees of freedom.*
  Will be verified by jogging the robot around the OUS to see if it can reach all points without collision with the environment or the OUS.
- *Implement a surface scanning and/or positioning system to support exact (±0.5 mm) placement of the antenna at a required distance d away from the OUS ($0 < d < \lessapprox 10mm$).*
  Will be verified by moving the robot to a decided point with a d distance, and measure the distance between antenna and OUS, and compare it to the d distance.
- *Develop the necessary control software to move the transmitter to an arbitrary position and to run a pre-defined measurement sequence.*
  Will be verified by choosing the desired measuring area and see if the robot measure the chosen area.
- *Develop a graphical user interface to control the measurement system.*
  Will be verified by running tests on each of the GUI's intended functions to see if the expected results are obtained.

7.2 Product requirements validation

7.2.1 Hardware requirements validation

- *The receiver end-effector shall be designed to have a mount for the microwave receiver and one distance measurement sensor.*
  The receiver end-effector will have a mount for the microwave receiver.
- *The sender end-effector shall be designed to have a mount for the microwave sender.*
  The sender end effector will have a mount for the microwave sender.
- *The receiver robot arm shall be able to place the microwave receiver approximately normal to the OUS, with a distance of 0mm to 10mm.*
  The OUS will be placed well within the workspace of SAY. The robot can reach any point with any orientation within its workspace. This will be tested by trying to move the robot around the OUS.
- *The receiver robot arm shall have an accuracy better than ±0.5 mm.*
  The SAY have an accuracy better than ±0.5.
- *The sender platform shall be able to place the microwave sender between 0mm and 10mm from the OUS.*
  The sender platform's distance to the OUS will be measured using a ruler to make sure it can place the microwave sender between 0mm and 10mm from the OUS.
- *The sender platform shall have an accuracy better than ±0.5 mm.*
  This will be tested by moving the sender platform up and down between a few points and measuring with the laser how close to the desired point it can place itself.

7.2.2 Software requirements validation

The software can be divided into the following subsystems: 3D reconstruction, planning, GUI and data acquisition.

- *The 3D reconstruction algorithm shall be able to estimate the OUS surface and create a 3D model based on the measurement data provided by the sensor.*
  By 3D printing a model with high accuracy and known tolerances, the source 3D model from which the 3D print was made can be used as a ground truth. The difference between the source 3D model and the 3D reconstruction should not differ more than the manufacturing tolerance in the ideal case. By comparing the source 3D model to the reconstructed 3D model, if the difference is greater than the manufacturing tolerance, then it must be due to 3D reconstruction error, or measurement error. This difference will be used to estimate how good the 3D reconstruction is.

- *The GUI should display information about the system with a visualization of the OUS.*
  This will be verified by looking at the GUI and making sure everything that needs to be there is there.
- *The GUI shall let the user configure the scanning region, distance, and density.*
  All GUI features will be tested by pressing buttons and changing parameters and making sure the desired change is actually done.
- *The trajectory planning algorithm shall calculate at which locations and in what order the receiver robot arm should stop to let the microwave receiver take measurements, based on configurations made in the GUI by the user.*
  By running the algorithm multiple times with different configurations, the physical locations scanned can be counted. If the robot goes to all desired points as configured in the GUI, in a good order, stops to let the receiver take measurements, and never rotates more than the cables can handle nor collides with the environment, then it works as it should.
- *Trajectory shall be calculated to ensure the receiver robot arm does not move in a way that will potentially damage the cables or collide with the OUS or the environment.*
  By testing different configurations and doing scans. If all of them work without damaging the cables for colliding, then it works as it should. It is impossible to test the entire state-space, therefore a few different configurations will be used to test if this seem to work as it should.

8 Risk analysis

Risk	**Cause**	**Action**
Incorrect or noisy data	Problem with sensor and/or data communication	Locate source, repair or replace faulty parts
Communication problems between RobotStudio and MATLAB	Issues with data transfer between different RobotStudio and MATLAB	Using or trying a different protocol for the communication. Creating a transport layer using some other program.
Inaccuracies with ABB robot positioning and motion control	The robot has not gone through the ABB calibration procedure/ old motors in the SAY	Try to compensate in software, or try to get ABB to calibrate the robot.
Inaccurate 3D model	Unforeseen issue with reconstruction algorithm, bugs, not enough sensor data, noise	Find root of problem, try to optimize, add another sensor if necessary
Miss of deadline or not fulfilling requirements	Poor time management	Consequent with time management and project status updates.
Physical system accuracy does not meet requirements	Poor design	Redesign cause components
Heavy receiver end-effector causing issues with ABB robot	Receiver end-effector too heavy	Try to redesign receiver end-effector
Component delivery issues	Global shortages	Try to find another component at another supplier
Component breaks	incorrect design or problem with component	Find another component and figure out why it broke, fix design
Blackout	Current world situation	Try to work on laptops, or at home
Internet issues	Problems with network	Wait, try WiFi, if it continues long term, use 4G or work from home
Cannot get into building	Students does not have keys to buildings	Wait, if no one opens before 09:00, go home and work from home

Table 2: Risk Analysis

9 Scope

The scope can be divided into three categories, paper work, hardware, and software. Paper work is the different Canvas assignment and other writing tasks. Hardware is the hardware implementation and software is the software implementation.

9.1 Paper Work

SUBJECT	TYPE	STATUS	PRIORITY	ASSIGNEE	FINISH DATE
Planning	PHASE	In progress	Normal	-	2022-09-30
Execution	PHASE	Scheduled	Normal	-	2022-12-17
Project Presentation	MILESTONE	New	Normal	-	2022-12-16
Hardware	TASK	New	Normal	-	2022-12-17
Paper work	TASK	New	Normal	-	2022-12-16
Poster	TASK	New	Normal	-	2022-10-07
2.0 - Progress report: 1	TASK	New	Normal	-	2022-10-28
2.1 - Peer-Review: 1	TASK	New	Normal	-	2022-11-04
3.0 - Progress report: 2	TASK	New	Normal	-	2022-11-25
3.1 - Peer-Review: 2	TASK	New	Normal	-	2022-12-09
Final Poster	TASK	New	Normal	-	2022-12-09
Project report draft	TASK	New	Normal	-	2022-12-16
Closure	PHASE	Scheduled	Normal	-	2023-01-13
4.0 - Project report (Finalization)	TASK	New	Normal	-	2023-01-13
GitHub handover	TASK	New	Normal	-	2023-01-13

Figure 5: WBS of paper work of the project

9.2 Hardware

9.2 Hardware

SUBJECT	TYPE	STATUS	PRIORITY	ASSIGNEE	FINISH DATE
Execution	PHASE	Scheduled	Normal	-	2022-12-17
Project Presentation	MILESTONE	New	Normal	-	2022-12-16
Hardware	TASK	New	Normal	-	2022-12-17
Robot arm	TASK	New	Normal	-	2022-12-17
Remove end effector	TASK	New	Normal	-	2022-10-28
Investigate work space	TASK	New	Normal	-	2022-11-04
Test	TASK	New	Normal	-	2022-12-17
Small robot "Arm"	TASK	New	Normal	-	2022-12-16
Design	TASK	New	Normal	-	2022-11-18
Build, wire and solder	TASK	New	Normal	-	2022-12-02
Arduino + programming	TASK	New	Normal	-	2022-12-02
Mount on table	TASK	New	Normal	-	2022-12-09
Order components	TASK	New	Normal	-	2022-11-11
Test	TASK	New	Normal	-	2022-12-16
End effector reciever	TASK	New	Normal	-	2022-11-11
3D print antenna replica	TASK	New	Normal	-	2022-10-07
Design housing and mounts	TASK	New	Normal	-	2022-10-21
Arduino ethernet comminucation	TASK	New	Normal	-	2022-10-21
Mount on robot	TASK	New	Normal	-	2022-11-11
Distance sensor communication	TASK	New	Normal	-	2022-10-14
Build, wire and solder everything	TASK	New	Normal	-	2022-10-28
Test	TASK	New	Normal	-	2022-11-04
Order components	TASK	New	Normal	-	2022-10-07
End effector sender	TASK	New	Normal	-	2022-12-16
Design housing and mounts	TASK	New	Normal	-	2022-11-25
3D print antenna replica	TASK	New	Normal	-	2022-11-25
Mount on small robot	TASK	New	Normal	-	2022-12-09
Build, wire and solder	TASK	New	Normal	-	2022-12-02
Test	TASK	New	Normal	-	2022-12-16
Miscellaneous	TASK	New	Normal	-	2022-11-16
Power supply	TASK	New	Normal	-	2022-11-16
Networking equipment	TASK	New	Normal	-	2022-11-16
Fixture for models	TASK	New	Normal	-	2022-11-16
3D reference models	TASK	New	Normal	-	2022-11-16

Figure 6: WBS of hardware of the project

9.3 Software

SUBJECT	TYPE	STATUS	PRIORITY
BackLog	LIST	New	Normal
Perform a 3D Sanning with Yumi and Laser Sensor	LIST	New	Normal
Sensor Calibration (Matlab)	USER STORY	Planning	Normal
Sample Data From Scannable Object	USER STORY	Planning	Normal
Laser Scanning Protocol (Matlab)	USER STORY	Planning	Normal
Save Yumi and sensor data (Matlab/Yumi)	USER STORY	Planning	Normal
Move Yumi Follow Scanning Protocol (Robot Studio)	USER STORY	Planning	Normal
Show calibration process in GUI (Matlab)	USER STORY	Planning	Normal
Send and receive MATLAB/Robot Studio (UDP, TCP, File)	USER STORY	Planning	Normal
Surface Reconstruction from Scanned Data	LIST	New	Normal
Create simulated Data	USER STORY	Planning	Normal
Test different simulated noise	USER STORY	Planning	Normal
Create theoretical Scanning protocol based on Power Crust ...	USER STORY	New	Normal
Convert Sensor Value To Points in Yumi space (Matlab)	USER STORY	Planning	Normal
Implemen PowerCrust Algorithm (Matlab)	USER STORY	Planning	Normal
GUI Show process / Surface (Matlab)	USER STORY	Planning	Normal
Perform a Automated Microwave Measurements	LIST	New	Normal
GUI User Choose Area (Matlab)	USER STORY	Planning	Normal
Create Scanning points from Area (Matlab)	USER STORY	Planning	Normal
Move Yumi to Location (Robot Studio)	USER STORY	Planning	Normal
Verify Yumi position (No idea)	USER STORY	Planning	Normal
System Testing and Verification	LIST	New	Normal
Prepare Presenation	LIST	New	Normal

Figure 7: WBS of Software of the project

10 Communication Plan

Communication will primarily happen physically and through Teams[32]. OpenProject[31] will be used to communicate current status and what needs to be done next. The communication plan helps specify how, when, and to who communication should happen.

Item/Event	Purpose	Audience	When	How	Responsible
Sprint planning	Plan the next sprint	Sprint members	Before every sprint	Physical meetings	Project manager
Daily status	Plan the day and check progress	Project members	Every morning around 09:00	Physical Meetings	Project managers
Sprint evaluation	Evaluate the sprint to improve future sprints	Project members	After every sprint	Physical Meetings	Project managers
Stakeholder meeting	Keep stakeholder updated	Project members and stakeholders	Weekly	Physical Meetings	Project managers and stakeholders
Team celebration	Celebrate success	Project members	After completed milestones	Physical Meetings	Project members
Minor issue	Solve minor issues	Rubber duck	If minor issues occur	Explain problem step by step for Quack or Quackie (rubber ducks)	Project members
Minor issue	Solve minor issues	Project members most related to task	If minor issues occur and rubber ducks could not solve it	Ask neighbor for help	Project members
Major issue	Solve major issues	Project members	If major issues occur	Wait for next meeting to discuss possible solutions with group	Project members
Content or information to share	Communicate with project member	Project member(s) that can benefit from the content	If there is content that can benefit someone else	Send content to person(s) on Teams that need the content	Project members
Content to share in group chat	To inform group about something everyone needs to know	Project members	If there is content that can benefit the whole group, or there is something everyone needs to know	Send content in group chat on Teams	Project members
Check status of project	To keep project members and stakeholders updated about current state of project and what needs to be done	Project members and stakeholders	Preferably at least once a week	Check project.bjurhager.net	Project members

Table 3: Communication plan

11 Proposed solution

A SAY with seven degrees of freedom provided by ABB will be used to move the end-effector containing the microwave receiver. The SAY robot arm is a state-of-the-art solution for the problem of moving the microwave imaging sensor and scanning sensor in three dimensions while also imposing an end-effector orientation. The system consists of five major parts, and every part has its own problem and solution.

11.1 Scanning an object and acquiring data.

The end-effector on the SAY will be equipped with a Opto NCDT 1302 Laser Distance Sensor (see 5.1.1) that will be used to create a point cloud of the object . The laser data is communicated to the program with the help of a microcontroller (see 5.1.1) The data collected is then used to reconstruct the scanned surface. As the quality of the data collected with this sensor on the objects of interest in this project is unknown. The distance sensor will be moved along a predefined scanning protocol, where the scanning of the object will be done in multiple iterations. Firstly, a general scan on a large distance from the object is performed to find the object in the space, which then iteratively becomes closer and more adapted to the object's surface to improve the quality of the data. The laser distance measurements are done to get an estimation of the distance between the SAY and the object being scanned, the combined information, position of SAY and the laser distance measurement resulting in an approximation of the object's placement in space.

11.2 Surface reconstruction using the acquired data.

After the data has been collected surface reconstruction method is performed using the PowerCrust algorithm. Which has been proven to produce promising result in the area of surface reconstruction of breast and breast phantom reconstruction using laser point data [19], [21].

11.3 Accurate positioning for automated microwave measurements

Because of the excellent pose repeatability claimed to be achieved by the SAY [24], the accuracy of the positioning is heavily reliant on the accuracy of the 3D-surface reconstruction, which will give the robot information about the coordinates and rotation to achieve desired position. This positioning information is extracted from the 3D-model by translating chosen coordinates on the 3D-model to the coordinate system of the SAY. The rotation is provided by calculating the normal of the area on the 3D-model surface of the chosen coordinates. All calculations for the positions will be done in MATLAB [35] and communicated to the robotic arm through a TCP connection [42]. The SAY supports commands to move to given coordinates and rotations, this will be used to position the end-effector. Additionally, the SAY has a feature of specifying restricted areas that should not be entered by the arm. Instead, the robot will automatically find configurations to move around and avoid this area, if possible. This system will be used to ensure that the arm does not make contact with the object.

11.4 Graphical user interface.

On top of all parts of the system, there should be a graphical user interface that will provide communication between the user and the system. It should also provide configuration for the system developer to make it easier to acquire data and test the system.

In the initial scanning section, the graphical interface will help the developer choose a scanning protocol for the unknown object. This helps test different protocols with different amounts of data. The GUI also interactively shows the reconstruction results as a 3D model. In the microwave measurements phase, the interface uses the interactive 3D model to select points or regions to scan.

11.5 Hardware

The sender fixture will be a small platform that can be adjusted up and down based on input commands from the GUI. It will use linear rods, lead screws and stepper motors for accurate linear movement.

The end effectors will be 3D printed and hold all needed components. The sender end effector will most likely only contain the microwave sender. The receiver end effector will most likely contain: the microwave receiver, a distance laser sensor and maybe a camera.

As of now the idea is to power the system using a 24V power supply, and use TCP/IP over Ethernet for data communication. Most components can be powered using 24V but those that cannot can be powered using a DC/DC step down converter.

Some kind of fixture will be used to hold the OUS models and at least two different 3D printed models will be used to test the system.

12 Planning

12.1 Paper work

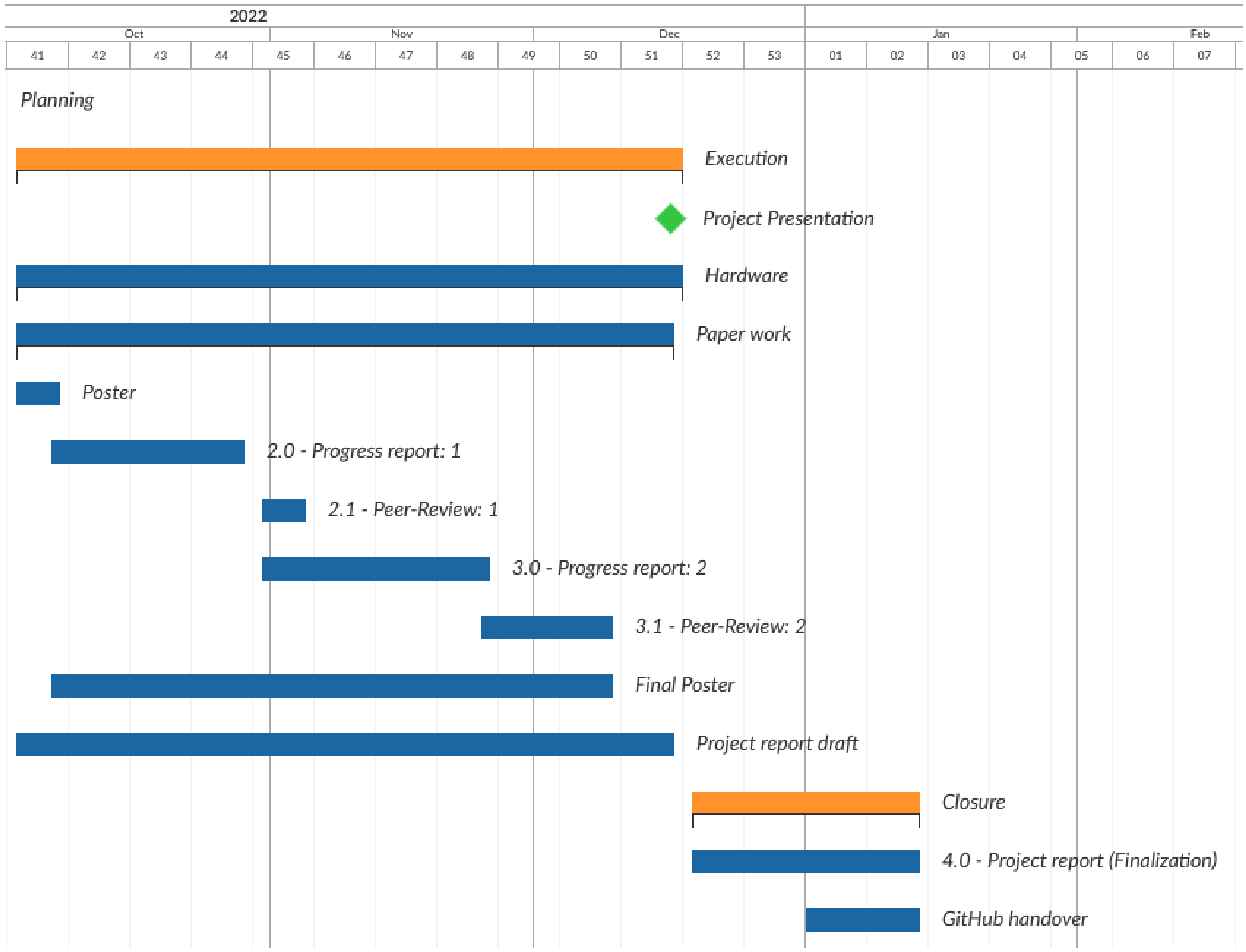

Figure 8: Gantt chart of paper work of the project.

12.2 Hardware

12.2 Hardware

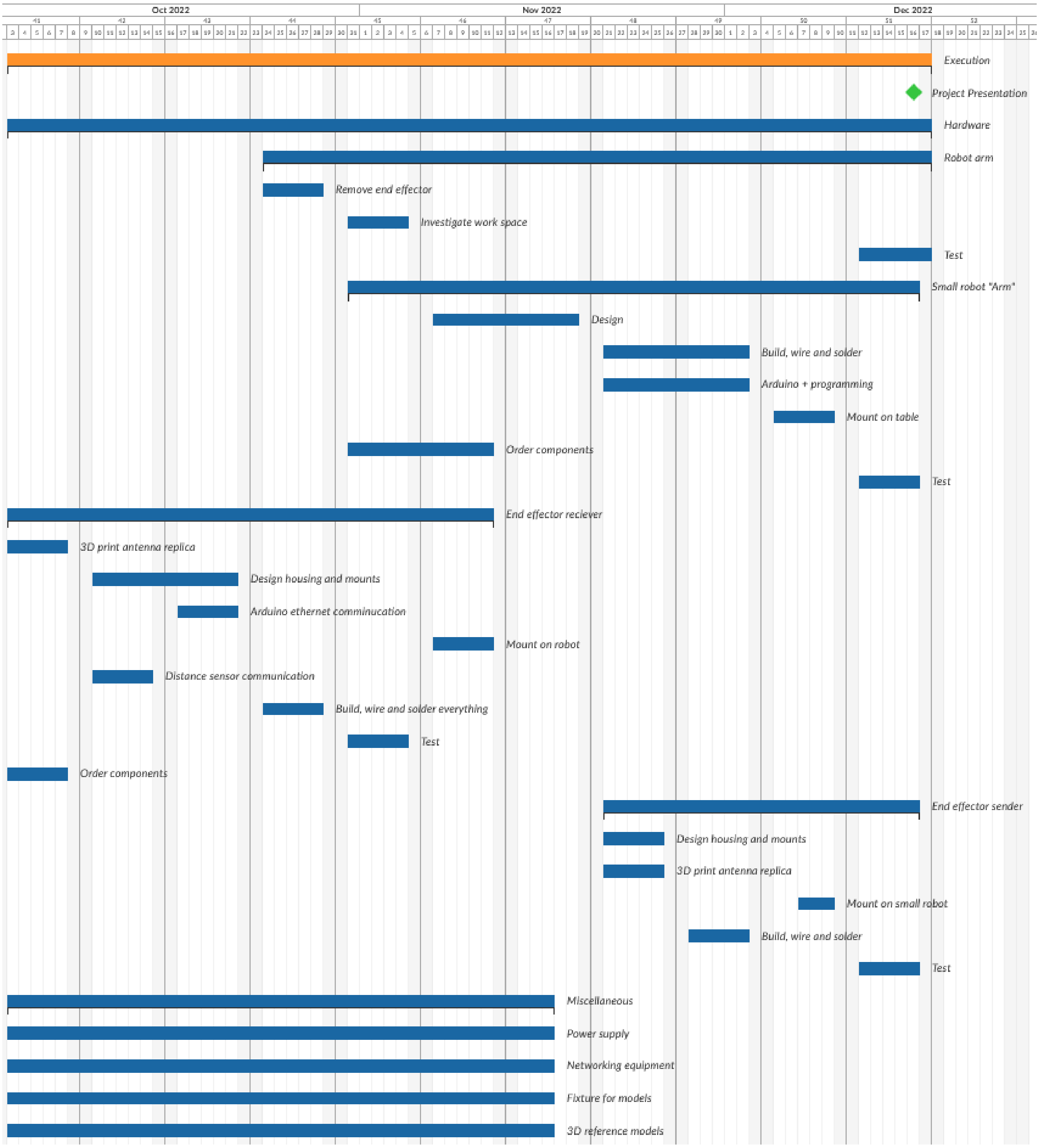

Figure 9: Gantt chart of hardware of the project.

12.3 Software

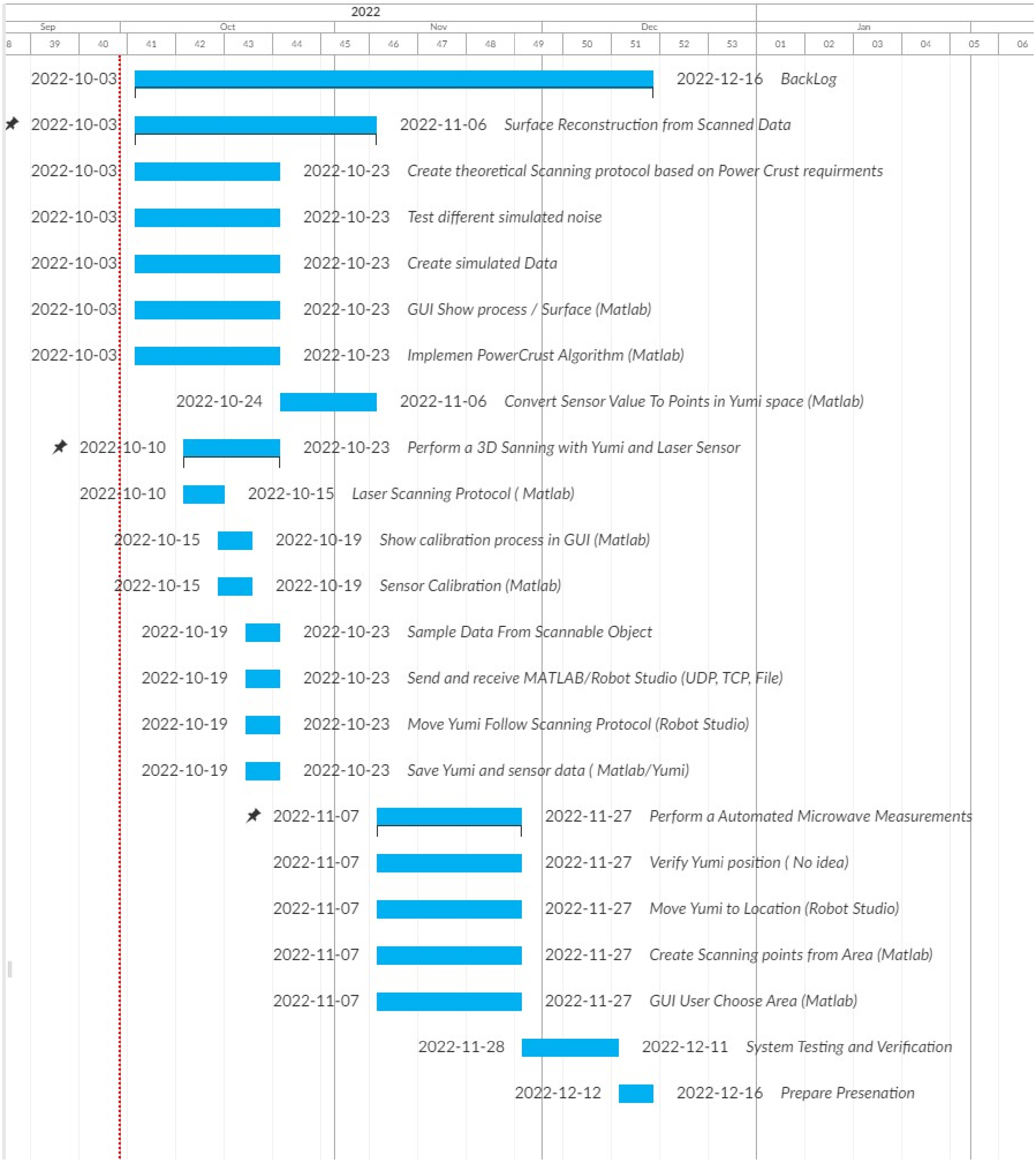

Figure 10: Gantt chart of software of the project.

13 Limitations

- The team **won't** produce a finished product.
- **No** patient beds will be delivered under the project.
- **No** physical control panel will be delivered as part of the project.
- The team **won't** be working on the microwave imaging antenna technology.
- Humans will **not** be used in the product's testing.

- It **cannot** be guaranteed that all breast forms, sizes and colours works equally well or works at all.
- The finished product **lacks** a certification for either human or medical usage.
- The product does **not** have any form of energy saving.
- The product **lacks** a certification for EMC and EMI.
- It is **not** guaranteed that the product is safe.
- It is **not** guaranteed that the product is free of bugs and works well in all circumstances.

The project's budget, deadlines, the scope/project plan, required resources, and, last but not least, the project's quality all need to be taken into consideration. The budget is about 20,000 SEK, although it might be increased if required. The project's timeline is constrained to begin on August 29, 2022, and must be handed over by January 13, 2023. Many dangers can impact the project. Many hazards, such as depleted resources, operational blunders, poor performance, ambiguity, component shortages, and high expenses, may be encountered. When all these restrictions are considered, the project's final quality may be altered in a positive or negative way.

14 Handover Plan

The hardware components will be picked up by the stakeholders in C2 at the end-date, 13th of January 2023. Stakeholders will communicate with ABB if they can continue to lend the SAY robot used in this project. In that case, the robot will be included in the hardware handover, otherwise the robot will be returned to ABB. Because the stakeholders already have full access to software and documentation through the GitHub repository during the project, no specific handover of software and documentation to stakeholders is needed. The repository will also be uploaded to the MDU (Mälardalen University) Robotics GitHub Organization at the end-date of the project. The stakeholders will also be shown a demonstration of how to operate and use the system.

15 Individual Contributions

15.1 Emanuel Bjurhager

Created the document, rearranged document section to fit task, created and made sure all needed sections exists. Wrote Tools section. Created WBS and Gantt (except software), fixed title, helped Aref narrow down requirements and make them as specific as possible to aid with verification later on based on how the book suggest we do it. Wrote first version of proposed solution. Fixed errors, warnings and other problem with libraries and syntax. Partly wrote documentation plan. Created/wrote Communication plan + table. Changed all Yumi or similar in document to defined acronym. Wrote current state section. Added missing information in testing plan section. Verified that all sections meet our understanding of the canvas requirements. Added some risks to risk section. General grammar, spelling and other fixes.

15.2 Victor Aziz

Wrote a part of background about different algorithm solution of surface reconstruction and described computational geometry basic techniques.Created Scope and planing for software.

15.3 Amanda Rautio

Wrote parts of background and state of the art. Wrote about GitHub and Gitbranching in software tools section. Wrote Documentation plan and handover plan. Corrected grammar, wording and phrasing throughout the report. Edited proposed solution and added state of practice.

15.4 Ingrid Heien Bjonge

Wrote parts of background. Wrote parts of hardware tools and software tools. Wrote parts of requirements and requirements validation. Corrected spelling and sentences through the text.

15.5 Jonathan Holm

Wrote part of the background, proposed solution, state of the art, testing plan and software tool. Wrote risk analysis. Organized the rapport into sections, checked spelling and sentences.

15.6 Aref Bahtiti

Wrote parts of the Software tools(Solidworks, Kicad, Visual studio and Multisim). Wrote Requirements and created the requirements figure in addition to limitations. Wrote the hardware tools section as well.

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