Progress report: 1 - µTomography

Emanuel Bjurhager*, Aref Bahtiti†, Amanda Rautio‡, Ingrid Heien Bjonge§, Victor Aziz¶, Jonathan Holm‖
School of Innovation, Design and, Engineering
Mälardalens University, Västerås, Sweden
Email: *ebr17003@student.mdu.se, †abi18002@student.mdu.se, ‡aro18001@student.mdu.se,
§ihe21001@student.mdu.se, ¶vaz17001@student.mdu.se, ‖jhm18006@student.mdu.se

I. Project information

Project name	Project name	Date	Project managers
Precise Positioning and Scanning for Microwave Imaging	Nikola Petrovic	2022-10-27	**Software Manager:** Victor Aziz **Hardware Manager:** Emanuel Bjurhager

Table I
General project information

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 II
Staffing and roles

II. Project progress summary

Software and hardware have different backlogs and are managed separately. The planning of both groups (hardware and software) is available for all members and stakeholders to check and comment through open projects for hardware and notion for software.

The collaboration between hardware and software occurs mostly during sprint meetings(once a week). This is done to determine what the two groups are doing, and what the groups require from each other during the upcoming period. Collaboration is working well, and we think that it is a good way to meet our needs.

Things can be changed, and software and hardware leaders are open to suggestions from team members to make the work as agile as possible.

A. Software

The project management tool used in this project is our own version of scrum-like management. The backlog is updated throughout the execution period as planned.

We have found a new area (scanning protocol) and modify some of the old areas of the backlog.

The areas currently found in the backlog are Scanning Protocol, Surface Reconstruction, YuMi Operation, GUI, Microwave measurements, and Canvas examinations.

- The scanning protocol includes tasks to create and implement a protocol to follow to acquire the data from the scannable object.
- Surface Reconstruction work on tasks to create the surface from the sampled data using the scanning protocol.
- YuMi Operation is everything related to the robotic arm movement and the collaboration between Matlab and robot Studio.
- The graphical User Interface is self-explaining.
- The microwave measurements area includes tasks to combine the Areas together to get a full system.
- Canvas Examinations and All paperwork/ Reports.

The first project plan was a rough estimation of time and the packages are updated and changed throughout the execution. We have some milestones for different periods. There is seven weeks left to presentation. In the upcoming four weeks we will finish the development and have two weeks for testing validation, the last week to prepare the presentation.

Development tasks are done according to plan. The remaining part is to test it on real data and for that we are waiting for the components and the hardware team to get the laser to work.

We have implemented parts of the system using only simulated data, and is hoping for a likewise result using the real data from the sensor

The work was divided amongst the software members where each member was responsible for one area. Even if the work was divided we have help each other along the way.

Amanda is responsible for the graphical user interface, Jonathan is responsible for the Power crust algorithm, Ingrid is responsible for YuMi and Victor is responsible for the scanning protocol.

For the future; we are planning to put together all the parts next week, using simulated data and hope that the week after will be able to try it on real data. With the 2 weeks left of the development period, we will be solving issues and try to make the system better.

As work breaks down packages and backlog is changing all the time as we progress in the project, we created a website to display all planning, and hopefully we will add more material to it so that in the end it will include everything about the project. You can see what we have done and what we are doing by checking this link[1].

1) GUI: For the GUI, a layout has been created in MATLAB app designer where it is possible to access the various features of the system. The layout features three main panels; the automatic control panel, the visual representation panel, and the manual control panel, see figure 3. In the automatic control panel, the user can establish a connection to the robot through TCP/IP and press a button to get a visual representation of the robot hand location and the object model. Because the object reconstruction algorithm and the scanning protocols are still under development, the scan button currently creates a mock object model used for testing, with the option to either use the real robot hand location in the coordinate space or a mock location depending on the testing needs. In the automatic control panel, the user can select scanning modes for the microwave scan, such as scanning the whole object, a smaller area, or selected points. In the selected area and selected points scanning modes, the user can select points by clicking on the 3D object's surface, which is sent to the robot as coordinates to move to. Furthermore, manual control of the robot through the GUI has been achieved. The user can control the robot's hand location in the Cartesian, cylindrical and spherical coordinate systems graphically in the visual representation panel and have the robot respond to the coordinate changes in real time. Additionally in the manual control, the user can adjust the step size and the minimum distance which the robot hand holds to the object, restricting the robot hand from colliding with the object, and providing better control of distance between object and hand. In both automatic and manual controls, the robot hand is always rotated so that the tooltip is angled normal towards the object's surface, which is also visually represented in the GUI by an arrow pointing in the direction of the tooltip from the robot hand marker. Furthermore, the GUI features a logging window, where progress reports and eventual error messages of processes are displayed to the user.

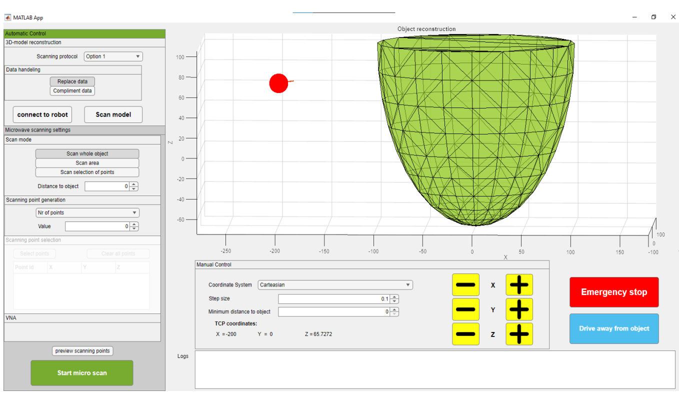

Figure 1. A screenshot of the app layout. In the app, the user can choose scanning options, interactively see the model representation of the object and the robot hand in the 3D-space and manually control the hand's position in different coordinate systems.

2) Robot control: In order to control the robot, a TCP/IP connection is created between Matlab and the robot. The connection will be used to send the coordinates and the rotation of a point in space. Through the connection, Matlab will decide the robot's destination and the rotation it will have at that position. The robot will use the connection to tell Matlab which position it is in, and the rotation of the end effector. Every coordinates that is sent is based in the breasts coordinate system. The middle and the root of the breast will be position (0,0,0). And the rotation of every coordinate is based on frame rotation from the breast coordinate system.

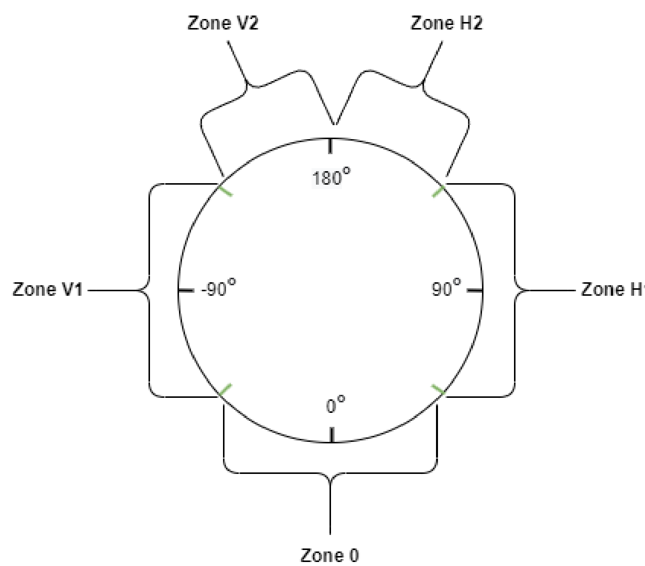

Figure 2. The five different zones in the breast phantom space

Depending on where the robot is and the desired position chosen by the Matlab code, the robot has to find a trajectory to that position. It is important that the robot do not collide with the breast phantom or the environment to reach its destination. As for now, the space around the breast is divided into five different zones (See fig 2). The robot will determine which rotation it has on joint 0 to determine which zone it is now in, and it will build its trajectory plan based on both the zone it is in and the zone it is headed to. The configuration the robot will have at the desired position will also depend on which zone the robot will be in at that position.

3) Scanning protocol: A scanning procedure was required to scan an unknown object. The robot will be instructed on where to scan the breast using this protocol. In planning, this was included in the same area as the surface reconstruction, but we found that the scanning protocol and surface reconstruction were large and divided them into different areas. We did some more literature reading and found a research paper that we think will work on our type of shape given the pre-knowledge we know about the unknown object.

The new scanning protocol are following the one used in [2]. In the mentioned paper they used the protocol on different breast shapes and compared different parameters. The result is an error of less than 0.5 mm in the upper part of the breast, which is what our project requires. Near the nipple region, they had a slightly over 1 mm error. We think that they have a higher error near the nipple area because of the higher curvature of the surface. The laser sensor needs to be pointing normally to the surface to get an accurate value in the above-mentioned study it is far from normal near the nipple area of the surface.

In another study [3], they are angling the sensor by 15 degrees to solve that problem. The 15 degrees angle gives a more normal angle to the curvature on the nipple area and still be in within the angle range for the straight part of the breast.

Our approach now is to start by implementing the basic scanning protocol used in [2]. And depending on the error size we can modify it to make it better and solve the problem of the curvature.

Some suggestions exist on how to improve it. We compared the sensor to different orientations and attempted to find the nearest point. Thus, we are normal to the surface, as we can assume that most breasts have a convex shape. Another idea is to re-scan the object after the initial scan to obtain a more normal orientation to the surface and fix the 1 mm error. It is possible to detect where the curvature starts using the data of the first scan and change the orientation to better approximate the normal of the surface in the second scan and obtain more data that can solve the problem.

4) Creating breast surface point: At every position determined by the scanning protocol, MATLAB uses the data from the laser and position of the robot to calculate the surface point of the breast in the breast coordinate system. All points comprise the point cloud used to create a 3D reconstruction of the breast.

5) Powercrust: For the 3d-reconstruction algorithm the powercrust[4] has been implemented in Matlab to fit the need for the project. The algorithm works as of now by taking in samples in 3D or 2D-space to estimate the surface trough a mesh.

The algorithm starts off by creating a boundary box around the point cloud that is fed into the algorithm. By taking the larges sample in every dimension and multiplying it by a predefined factor of 5 the cloud is contained.

This was implemented to avoid producing infinitive large Voronoi cells. The Voronoi diagram is then created by using the qhull method. From the Voronoi diagram the poles for the point cloud is determined by checking the sample in each cell and finding the vertex that is furthest from this sample, this will produce the first pole and the second is calculated by finding the negative dot product of the same distance vector. The poles is later used to produce a second Voronoi diagram, but this time a power region is assigned to the poles. The region has the radius of the distance to the closest sample point in the point cloud. This will produce a power diagram, by expanding the balls with center in the poles a graph with polar balls will be produced. The algorithm then traverse trough the graph, and labels the poles based on if they are on the inside or the outside of the point cloud. The poles on the inside will produce the surface estimation by doing triangulation.

B. Hardware

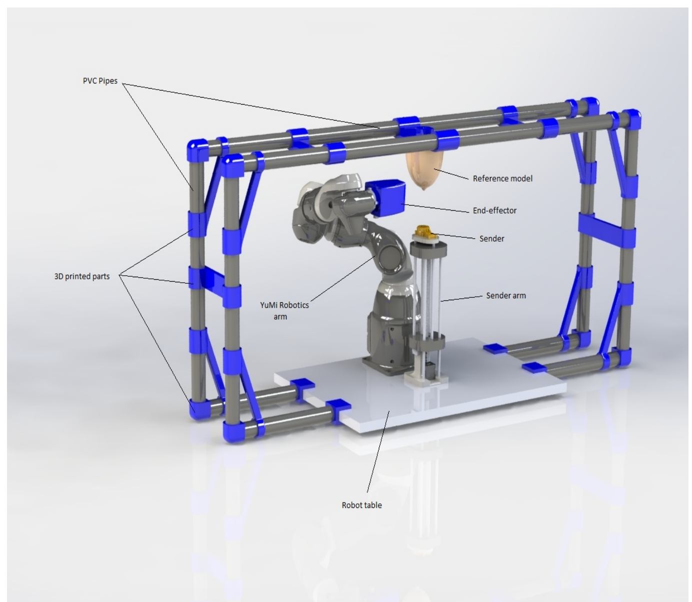

Figure 3. The system's overall initial concept is depicted in this picture. The final design may be updated or modified.

1) Receiver end effector: The measurement equipment must be mounted on the YuMi robotics arm; therefore, the laser distance sensor and microwave receiver were built inside the end-effector. The end-effector had to be redone four times because of the constraints and concerns that arose during the design phase. The dimensions and shapes of the microwave receiver and laser sensor influence the construction of the end-effector. Consequently, the end-effector has been modified to match the microwave receiver and distance laser sensor models. Other difficulties, such as the potential for collisions between the YuMi robotic arm and the end-effector, have an impact on the design. The distance between the receiver tip and the lowest point of the end-effector is crucial. To reduce the error caused by the length of the radius in a rotating joint, this distance must be as small as possible. Three of the four versions were 3D printed, tested, and modified.

2) Reference models: Two different breast 3D models were created for use in the test-scanning phase. The Brest shape is fully symmetrical at every point in the first one, which is a symmetric design. The second is an asymmetric breast model that mimics the real-shaped breast of a medium-sized female in Sweden (reference). As a first test, it is simpler to use a 3D model with a symmetric shape. An asymmetric breast model will be employed in more complex system tests. The dimensions of the symmetric model are 120 mm in diameter and 120 mm in height. The asymmetric type has a diameter of approximately 150 mm and a height of approximately 120 mm. Both variants have a similar fixture with dimensions of 30 mm in length and 30 mm in diameter.

3) Estimates of missing hardware: Plastic 3D models have been created to simulate the sender and receiver's proportions following earlier designs of the sender and receiver. These models were developed in order to gauge the robot workspace's usage and prevent damage to the real transmitter and receiver during the testing and scanning phases. A testing sender arm has been designed and 3D printed to hold the plastic sender and estimate where the sender robotics arm can be mounted.

4) System Installation Bench(SIB): A system installation bench was made using the SOLIDWORKS program. The SIB will be made of plastic to reduce the noise that metal generates and that could affect the microwave system. The breast will be hanged using PVC pipes, and some PLA 3D printed parts will be used to join the PVC pipes. The parts will be mounted on the robot table using clamps.

5) 3D printer calibration: The 3D printer could not produce good 3D prints and was suffering from layer separation issues which meant that the printed parts could not be used. The 3D printer was fixed by: updating firmware, adjusting bed flatness, correcting first layer height and calibrating nozzle temperature.

6) Distance sensor communication: Communication between the Arduino and the distance sensor was partly successful. I managed to receive distance measurements over serial but the sensor was programmed to have a shorter range than default, which means that the sensor needs to be reprogrammed to fit our use case. We are currently awaiting the hardware necessary to re-program the sensor.

7) Arduino Ethernet communication: Code was written that can successfully read and transmit data over Ethernet using UDP between an Arduino and a Mac. This will later be used to send/receive data between the Matlab computer and the different hardware components (except the YuMi).

8) 5V circuit board: A small circuit board was soldered. As input it takes 24V and ground, and as output it have one 24V, three 5V and four ground. A screw-type connector was used. This will be used to power the Arduinos and the distance sensor from a 24V power supply.

9) Small robot + sender end effector: The small robot arm has been successfully created in SOLIDWORKS and everything seem to fit together and work as it should in software. The end-effector that holds the sender antenna is also done. We are currently waiting for parts to actually start building the robot.

10) Work Packages Status: We are before plan with the sender robot arm and sender end effector. The distance sensor communication is off-track because of missing hardware. The receiver end effector as a whole is at risk of being delayed because the distance sensor communication is delayed. Other than that everything is on track. If we would get the missing hardware now, we might be able to complete the receiver end effector on time, but so far we have waited since 2022-10-13 so it might come any day now, or it will take much longer. We have not heard anything other than that it is ordered and in stock.

C. Other

1) openProject: An openProject server was setup and configured to help with project management.

III. Blockers and risks

A. Software

A blocker currently experienced by the software team is the delay of a working laser sensor. Currently, the 3D-reconstruction algorithm is being tested on simulated data, with simulated noise. There is still some uncertainty about the actual level of noise and quality of data collected from the laser during a real scan. The development is therefore approaching a stage where testing on real data needs to be done and is somewhat halted by the inability to do so. Similarly, scanning protocols for the initial 3D scan is under development, but is not able to be properly tested without the laser sensor since it does not produce any coordinate point data to analyze.
There is a risk to get a big error in position compared to the desired position when testing the system. The cause may be Yumi , Scanning protocol, Surface reconstruction, and The 3D models. The solution is that all the parts of the system are tested before we put the system together. This will help track the error back to what part of the system is contributing to the error. If yumi is the main cause of the error we are promised to get help from ABB to fix it as the current yumi we are using is a prototype and cannot guarantee the repeatability stated in the datasheet.

B. Hardware

We are currently waiting for components to continue with distance sensor communication, start building the sender robot and we are also low on plastic for the 3D printer which might be a problem later. The lacking hardware is currently blocking almost everything hardware wise. We had not anticipated that the time from order to delivery would be over 14 days for parts in stock and there is nothing we could have done differently. As of now there is still time to deliver everything as planned but the slow delivery of parts are jeopardizing the entire project.

Due to the rigidity of cables, future stages including laser cable and antenna cable may be dangerous. YuMi's robot arm has a high threshold for weight, which makes movement extremely challenging. Because of the potential for error to accumulate as the radius increases, the length of the end-effector can be problematic. The issue is that the project's components will determine how long the end-effector will be. Another concern is the 3D printer's accuracy, as any mistake in the project's crucial 3D printed components could lead to a significant error for the entire system.

IV. Individual contributions

A. Amanda Rautio

Main responsible for the GUI. Have worked on the layout and GUI features during the execution phase. This includes the manual control steering in different coordinate systems, rotation of robot hand according to object and position in the 3D-space, interactive point selection where the user clicks on the object's surface in the plot to select scanning points, collision detection between robot hand and object so that a user can never drive into the object, scanning area selection and other smaller features improving the usability of the system. These previously mentioned work packages are considered completed. Is currently working on microwave scanning point generation for the whole object and smaller marked areas, which is taking longer than expected, but is on track and before schedule as the previous parts were completed before planned end dates.

B. Aref Bahtiti

In the beginning, it was primarily about finding, reading, and summarizing relevant literature. The initial project report follows.Finding limitations and requirements of this project was a part of the work in the beginning. An inventory list of the available varieties and alternatives has been started in order to discover the precise laser distance sensor that meets the project criteria. In order to select the best distance laser sensor, a table of sensors has been made with their benefits and drawbacks. Baumer OM30-L0550 was the best sensor for this project, but the stakeholder had another option that had been used in a prior iteration of the project, so it was preferable to use it (OPTO NCDT 1302-200).SOLIDWORKS software was used to design the 3D model of the breast.
There are actually two variations, the first of which is symmetric and the second of which is asymmetric. The end-effector design took the longest time because it had to be rebuilt, 3D printed and mounted four times to find the optimal option. Choosing the best step-down converter, power supply, and MCU. To replace the real Sender and receiver on the system, create plastic 3D versions that are similar to the originals. Although the sender robotics arm should be built later in this project, the receiver should be put on the YuMi robot's arm. To hold the sender, a little stand has been created. All of these parts are held together by a box that has been developed specifically for the MCUs and power supply. Analog mode tests have been performed to determine the sensor's condition. Lastly the System Installation Bench (SIB) has been design on SOLIDWORKS.

C. Emanual Bjurhager

Setup openProject server, lot of management related things such as Gant charts, work package planning etc. Fixing 3D printer, creating CAD model for sender robot + sender end effector, beginning of distance sensor communication, soldering PCB for power delivery, looking for appropriate components, ordering components, communication between computer and Arduino using Ethernet. Helping Amanda and Ingrid with network issues related to MATLAB to YuMi Ethernet communication.

D. Ingrid Bjonge

Contributed with all the parts written in "Robot Control" and "Creating breast surface point" under "software". Setting up connection between the robot and Matlab.

E. Jonathan Holm

Creating sample point before the laser sensor was implemented through different means. Implementation of power crust and making so that it meets the need for the project.

F. Victor Aziz

Software planning, researching, and implementing Scanning protocol. For more information about software members, and contributions check [1].

References

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