Project Acronym:

MRBREASTBIO (CONCEPT/0521/0040)

MRI breast robotic system for biopsy

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Title: Navigation software

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Executive Summary

This deliverable describes the development of a software platform for controlling the biopsy system. The software has been developed to control the motion of the 2 degrees of freedom robotic device developed under the framework of the "MRBREASTBIO" project, as well as communicating with peripheral devices such as MRI for controlling robot navigation. The software was written in C# (Microsoft Corporation, Washington, USA) and has been developed with a User-friendly environment for communicating with the motors of the electronic driving system through an Arduino microcontroller (Arduino, New York, USA), resulting in accurate motion. The various features of the software such as automatic connection with the microcontroller for motion control, as well as control of the navigation parameters are described. Additionally, integration of real-time transfer of MRI images in the software during scanning and the positioning of the robotic device based on an MRI image are described. Navigation plans for manoeuvring the biopsy needle can be designed on MRI images and can be executed offering real-time positioning of the needle relative to the target area. Additionally, a software database was developed and described, offering storage and retrieval of subject and navigation planning data.

1 Software Structure

1.1 Software features

The software was developed with essential functions offering precise localization, and navigation of the biopsy needle for accurate tissue targeting. The software was developed using the Windows Presentation Foundation (WPF) platform (Microsoft Corporation) to result in a modern graphical environment offering quick execution of commands and flexibility for any future software expansions. Table 1 shows the features of the software.

Table 1: Software features.

Biopsy Software Features
User-Friendly environment – Several functionalities in a single platform
Standard software workflows – minimize probability of User errors
Auto-Connect of USB devices (Motion control board)
Overlay of navigation planning on real-time MRI images
Precise robot positioning procedure
Navigation report export

1.2 Robot selection menu

The software offers the ability for selection, addition, and modification of robotic devices. To achieve this, several robot classes, methods and properties were developed in the software as shown in Figure 1. A graphical user interface (GUI) was developed for robot selection (Robot selection panel), featuring a visual representation and description box for each of the available robotic devices. During each initial operation of the software, the robot selection panel appears as shown in Figure 2, so that the User first selects the desired robot, before proceeding with any further actions. Table 2 describes the functionalities of the several buttons of the robot selection panel as shown in Figure 2.

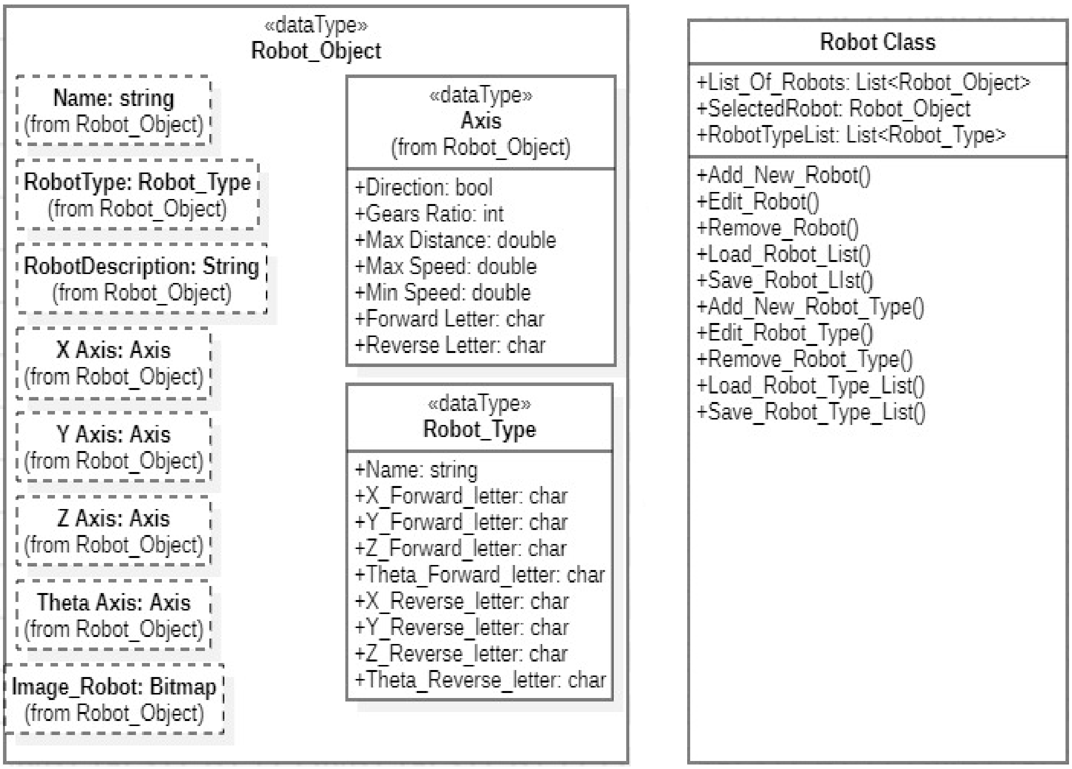


Figure 1: Robot class, object, properties and methods.

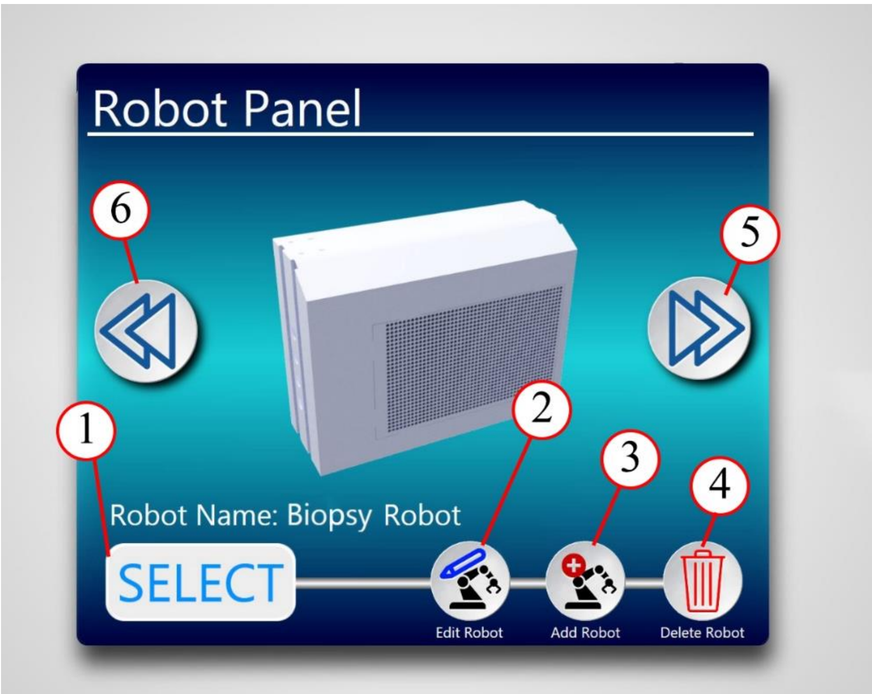


Figure 2: Screenshot of the robot selection panel

Table 2: Robot selection panel buttons.

Buttons	Functionality
Button ①	Selects the current robotic device and continues to the main navigation window of the software
Button ②	Edits currently selected robotic device
Button ③	Adds a new robotic device
Button ④	Removes the currently selected robotic device
Button ⑤	Shows the next robotic device from the list of robots
Button ⑥	Shows the previous robotic device from the list of robots

Addition of new robot:

For adding a new robotic device, the User sequentially performs the following steps:

1. The User clicks on  (button ③ in Figure 2), and a new window appears (Add New Robot Form) as shown in Figure 3, with the User filling all form fields shown in Table 3:

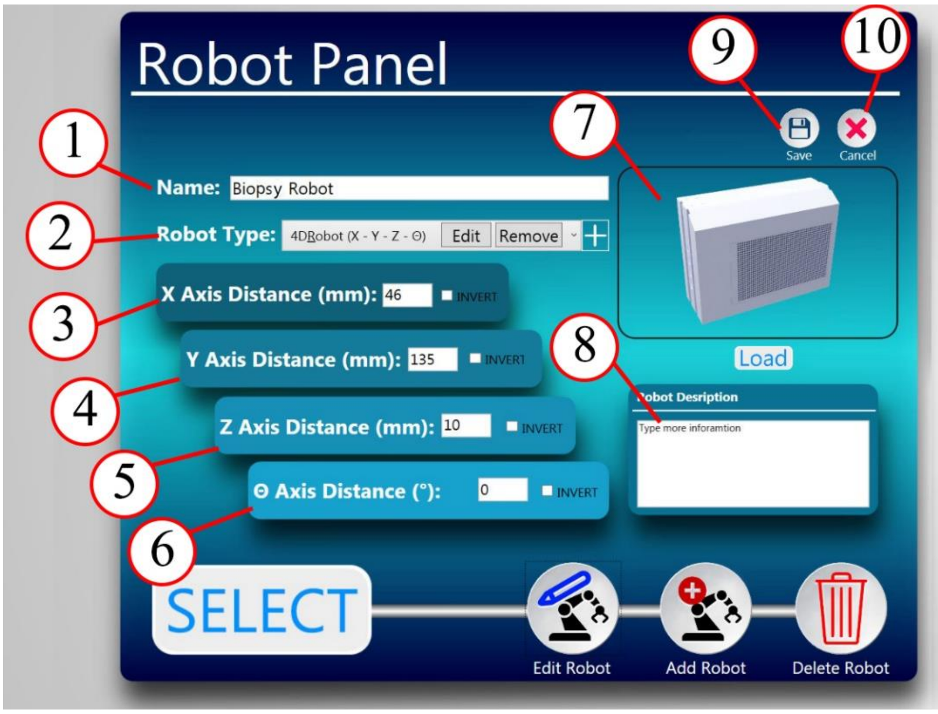


Figure 3: Screenshot of *the "Add New Robot Form".*

Table 3: Required fields of the "Add New Robot Form".

Field	**Description**
Field ①	Robot name
Field ②	Robot type based on the motor setup
Field ③	The maximum distance of the X-axis
Field ④	The maximum distance of the Y-axis
Field ⑤	The maximum distance of the Z-axis
Field ⑥	The maximum distance of the Θ-axis
Image Box ⑦	Robot image (User must select an image of the robot in .png format)
Field ⑧	Extra robot description
Button ⑨	Confirms the "Add new Robot Form" process
Button ⑩	Cancels the "Add new Robot Form" process

2. After the required form fields are filled, the User can confirm the addition of the robotic device by clicking on  (button ⑨ in Figure *3*).
3. If the User wants to cancel the procedure, he/she can return to the initial state of the robot selection menu by clicking on  (button ⑩ in Figure *3*).

The procedure of adding a new robotic device is implemented by the decision flowchart as shown in Figure 4, by calling the method ("Add_New_Robot" from "Robot Class") as mentioned in Figure 1.

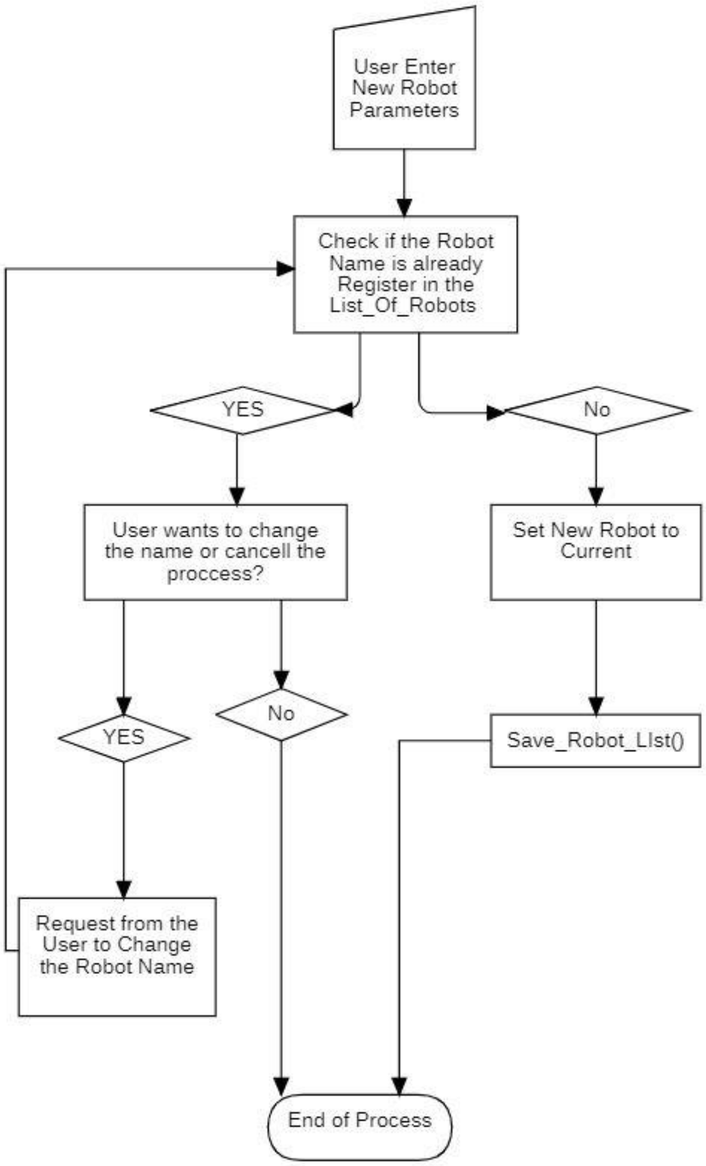


Figure 4: Process flowchart for adding a new robotic device.

Editing of robot:

For editing a robotic device, the User sequentially performs the following steps:

1. By clicking on  (button ② in Figure 2), a new window appears as shown in Figure 3, which reloads all parameter fields of the currently selected robotic device.
2. After the parameter fields are modified, the User can confirm and save the requested changes by clicking on  (button ⑨ in Figure *3*).

3. If the User wants to cancel the procedure, he/she can return to the initial state of the robot selection menu by clicking on  (button ⑩ in Figure *3*).

Removal of robot:

For removing a robotic device from the software, the User follows the steps below:

1. By clicking on  (button ④ in Figure 2) the selected robotic device is removed from the list of robots.

Selecting a robot:

The User selects a specific robot by performing the following procedure:

1. By clicking on SELECT as shown in Figure 2 (button ①), the current robotic device is selected from the existing list of robots. After selection of the robotic device is performed, the "Main Navigation Planning Window" appears as a new window, as shown in Figure 5.

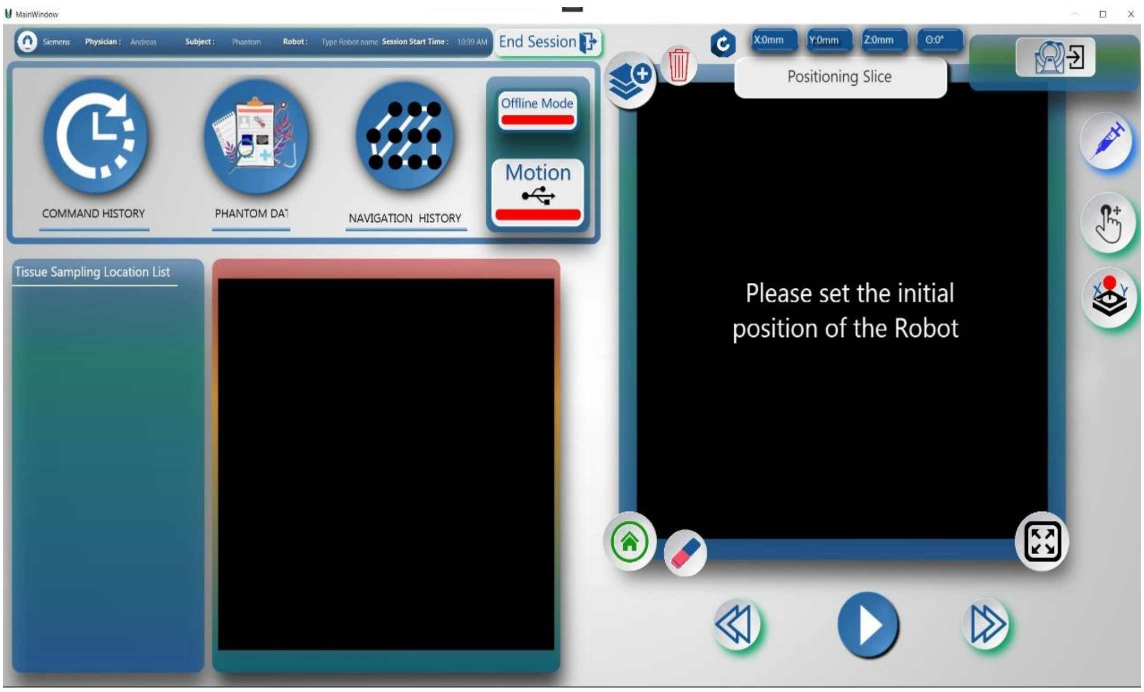


Figure 5: Screenshot of the "Main Navigation Planning Window".

1.3 Motion controller

The functions of the Motion controller are described. The software was developed offering automatic connection to the motion driving system without the need for selecting the name of each COM port for connection. Additionally, a feature of a “Homing” procedure and a functionality for “Point to Point” motion based on the User-selected coordinates were developed. Specifically, with the “Point to Point” motion a simplified manual control system was achieved. For implementation of the motion controller functions, various motion controller classes were developed in the software as shown in Table 4.

Table 4: Motion controller class.

Motion Controller Class
+Connect_Status: bool +Motion_Status: bool +Current_Robot: Robot_Object +Current_X_mm: double +Current_Y_mm: double +Current_Z_mm: double +Current_Theta_mm: double +Maximum_X_mm: double +Maximum_Y_mm: double +Maximum_Z_mm: double +Maximum_Theta_mm: double
+Connect() +Disconect() +SetRobot(Robot_Object Selected_Robot) +Move_X_Axis(double distance_mm) +Move_Y_Axis(double distance_mm) +Move_Z_Axis(double distance_mm) +Move_Theta_Axis(double distance_mm) +MoveToPoint(Point CurrentPoint, Point GoalPoint) +ResetCordinates()

Auto-Connect of motion controller:

Software connection with the motion control board is achieved with a Serial Port Communication through a Universal Serial Bus (USB) port. This connection is executed automatically based on the identification of the device through two unique IDs. These two IDs are Vendor ID (VID) and Product ID (PID). USB VID and PID are 16-bit numbers used for identifying a computer or other host USB devices. In this case, the motion board (Arduino microcontroller) has VID = 00X1A86 and PID = 00X7523. Using these two IDs, the software can find the corresponding port number of the motion control device and initiate connection. During initial launch, the software tries to auto-connect to the motion control device. If the motion control device is connected to the computer, the software automatically connects to the device and the motion board connect button (Figure 6), located in the "Main Navigation Planning Window", turns green, as shown in Figure 7.

Figure 6: Screenshot of the motion board connect buttons.

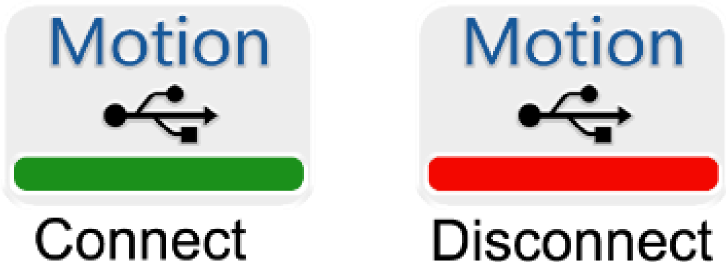


Figure 7: Motion board connection status.

Otherwise, if the motion control device is not connected during initial launch of the software, the User can execute a manual connection with the motion board by clicking on .

Manual motion controller:

A simplified control tool was developed for manual motion control of the robotic device. The manual motion control tool can regulate motion in up to 4 degrees of freedom. The User can initiate manual motion control by performing the following steps:

1. By clicking on  located on the "Main Navigation Planning Window" as shown in Figure 5, a manual motion control element appears over the main navigation planning window, as shown in Figure 8.

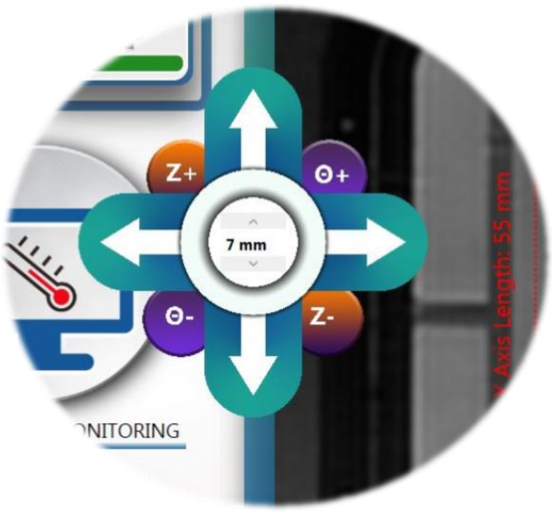


Figure 8: Screenshot of the manual motion control element.

2. By clicking on the up/down arrows in the center of the control tool (Figure 8), the User can specify the value (in mm) for the desired motion.
3. The robotic device moves to the corresponding axis by clicking on the up/down, left/right, Z+/Z- or Θ+/Θ- buttons. Simultaneously, each time the robotic device changes position, the current robot position labels as shown in Figure 9 are updated. Table 5 shows the description of the current robot position labels shown in Figure 9.

Figure 9: Screenshot of the current robot position labels.

Table 5: Current robot position labels.

Buttons	Description
Label ①	Shows the current position of the robot on the X-axis
Label ②	Shows the current position of the robot on the Y-axis
Label ③	Shows the current position of the robot on the Z-axis
Label ④	Shows the current position of the robot on the Θ-axis
Button ⑤	Sets all current robot positions to zero

Reset to zero coordinates:

If in any case the robotic device is mispositioned, or the User wishes to reset the current position of the robot device, one can click on (button ⑤) as shown in Figure 9.

Digital Imaging and Communications in Medicine (DICOM) viewer panel:

A DICOM viewer panel was inserted in the software allowing transfer and loading of the MRI images. Each time the panel is called to show the DICOM images, it retrieves all available DICOM images from the Local Directory path (the directory in which all MRI images synchronize using the Directory watcher application). For this procedure, a Python (Python Software Foundation, Delaware, USA) script was developed for extracting information from the DICOM images using the DICOM Tags as shown in Table 6. All DICOM Tags information is retrieved from the Python script through the “list_of_DICOM_object.json” file located inside the main directory of the software. Figure 10, shows the flowchart of the operations for this procedure. In Appendix 4.1, the Python script for this operation is provided.

Table 6: DICOM tags information extraction.

Data Information	DICOM Tag	Sample
DICOMFileName	"FileName"	FileName.dcm
PixelRowSpacing	0 × 0028, 0 × 0030	256p
PixelColumnSpacing	0 × 0028, 0 × 0030	256p
SliceThickness	0 × 0018, 0 × 0050	10
SlicePosition	0 × 0020, 0 × 0032	147.416\-4.9206\141.04
Sequence	0 × 0008, 0 × 103E	2D FSPGR
Type	0 × 0018, 0 × 0020	GR
Coil_Name	0 × 0018, 0 × 1250	HD BodyUpper
Acquisition_Type	0 × 0018, 0 × 0023	2D
TR_Info	0 × 0018, 0 × 0080	35,4
TE_Info	0 × 0018, 0 × 0081	22
Flip_Angle_Info	0 × 0018, 0 × 1314	35
Echo_Train_Length	0 × 0018, 0 × 0091	1
Pixel_Bandwidth	0 × 0018, 0 × 009	15.625
Acquisition_Matrix	0 × 0018, 0 × 1310	64 × 64
No_of_Averages	0 × 0018,0 × 0083	2
Triggering_Time	0 × 0018, 0 × 1060	13976

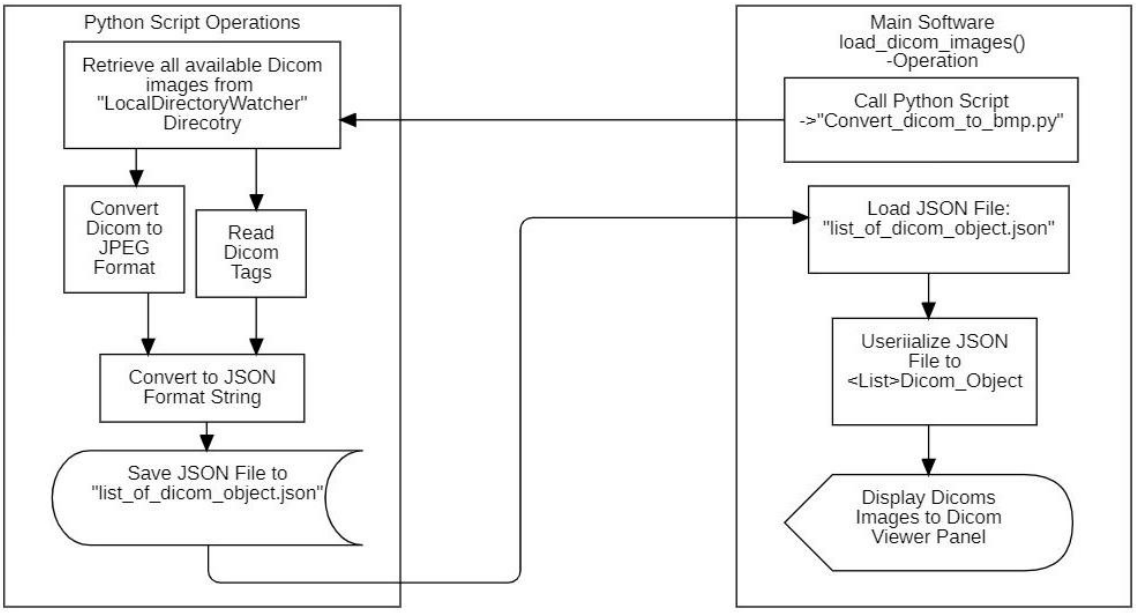


Figure 10: Flowchart of loading DICOM images to the main software.

For each DICOM image loaded to the DICOM viewer panel, the file name and a snapshot of the image are shown. The User selects the desired image by clicking on it. After selecting the image, the outline of the selected image turns yellow, as shown in Figure 11. Table 7 shows the DICOM viewer panel elements as shown in Figure 11.

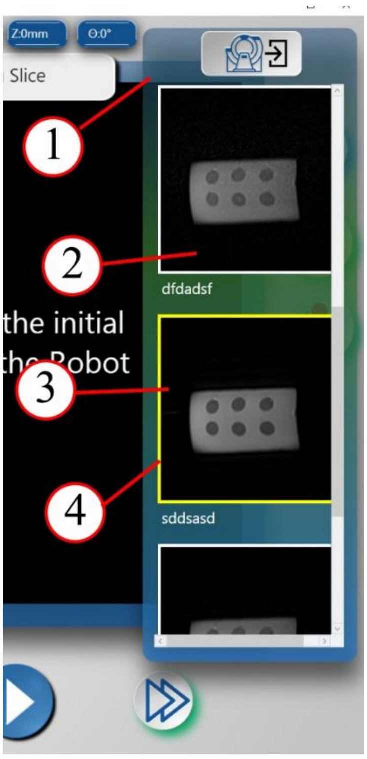


Figure 11: Screenshot of the DICOM viewer panel.

Table 7: DICOM viewer panel elements.

Buttons	**Description**
Panel ①	DICOM viewer panel
Picture Box ②	DICOM image
Label ③	DICOM file name
Border ④	Selected DICOM - Yellow border

Robot positioning process:

The User selects and loads the DICOM image on which the biopsy robot positioning will be performed. A circle equal to the diameter of the biopsy needle appears as shown in Figure 12**Error! Reference source not found.** (number ①). This way, the User is able to accurately position the robotic device by overlapping the circumference of the circle with the circular rim (point) of the needle as visualized on the DICOM image.

The software automatically determines the diameter of the circle based on the diameter of the needle (3 mm) so that the two rings overlap precisely. Once the two rings overlap, a marker  (marker ⑤) appears on the DICOM image, at the center of the biopsy needle, thus accurately showing the current location of the biopsy needle on the DICOM image as shown in Figure 12. Characteristically, with each robot movement, the position of the marker label is updated accordingly on the medical image, thus accurately showing the position of the needle relative to the target tissue. Table 8 **Error! Reference source not found.**shows the main elements of the robot positioning procedure as shown in Figure 12**Error! Reference source not found.**.

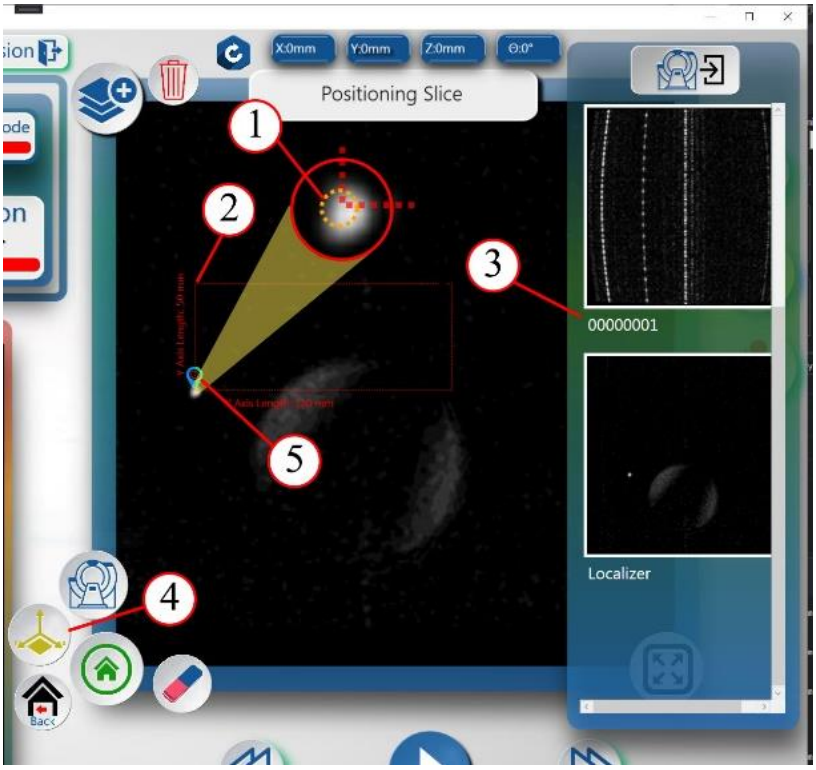


Figure 12: Screenshot of the initial robot positioning tools.

Table 8: Description of the robot positioning buttons.

Buttons	Description
Shape ①	Circular doted helplines
Shape ②	Active workspace area
Panel ③	DICOM viewer thumbnail panel
Button ④	Initial position tool
Marker ⑤	Current robot position marker

The User can set the initial position of the robotic device (i.e the origin point for the needle) by following these steps:

1. The User clicks on , and the “Homing” tool menu appears as shown in Figure 13**Error! Reference source not found.**.

Figure 13: Screenshot of the “Homing” tool menu.

2. The User then selects the localizer DICOM image using the right side DICOM viewer thumbnail panel as shown in Figure 12**Error! Reference source not found.** (number ③).

3. After selecting the DICOM image, the User clicks on  (button ④ in Figure 12), and a yellow dotted circle appears on the image.
4. Finally, the initial position of the robot is set by moving and overlapping the digitally generated yellow circle on the needle, and clicking on the needle center.

If the User wishes to update the initial position of the robot, the procedure is repeated.

“Homing” procedure:

A “Homing” functionality was added to the software. “Homing” works by moving the robot axes (X, Y) to a pre-defined position where a sensor or a switch in that location acts as the reference point for the motion control board, thus accurately knowing the position of the axes. The bottom left corner of the World Frame Map (WFM) of the robotic device was defined as the reference point (on the X-Y plane) for the biopsy needle point that is maneuvered by the robotic device, as shown in Figure 14. A pre-requisite for executing the “Homing” procedure is to complete the initial robot positioning process.

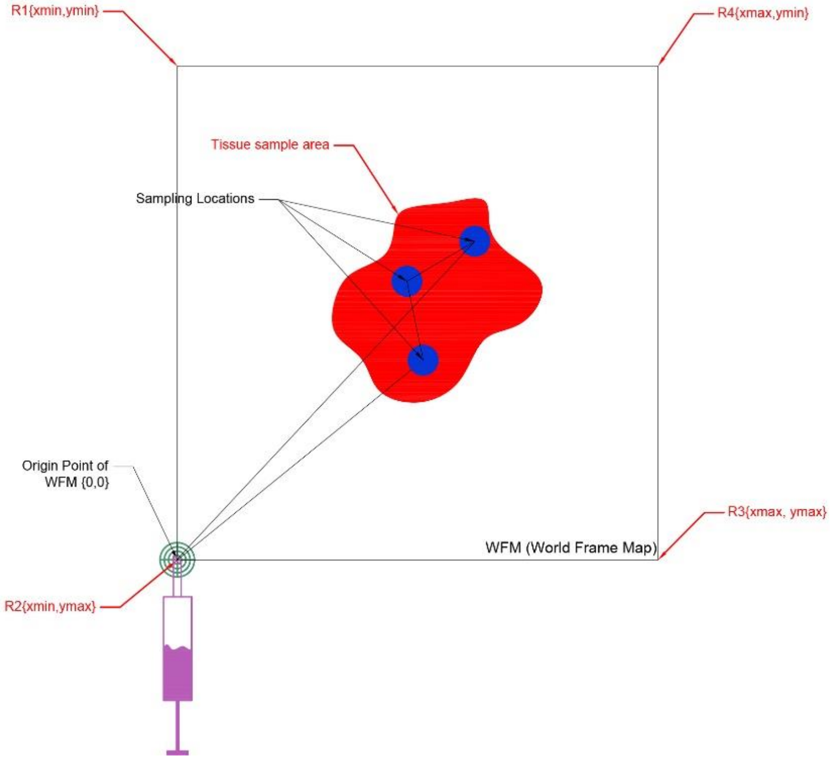


Figure 14: Reference point diagram.

The “Homing” procedure is automatically executed during the initial startup of the software, or after execution of the navigation planning, allowing return of the robotic axes and ultimately the needle, to the initial position of the robotic device. Alternatively, the User can manually execute the “Homing” procedure by following these steps:

1. The User clicks on , and the “Homing” tool menu appears as shown in Figure 13.

2. Then, by clicking on  (Figure 13), the “Homing” procedure starts until the needle navigation point reaches the reference point position (X:0, Y:0).

“Move to Goal” procedure:

The “Move to Goal” procedure is a function developed for moving the needle either from “Point A to Point B” or from the “current position to the goal position” on the X and Y planes. To implement this function, two primary operations were used; the *‘Move_X_Axis (in double distance_mm)’* and ‘*Move_Y_Axis (in double distance_mm)*’ of the motion controller class, as shown in Table 4.

For example, the current position of the needle is set at Point A with coordinates (X: 13 mm, Y: 16 mm), and the User wishes to move the needle to the goal Point B with coordinates (X: 24 mm, Y: 37 mm). In this regard, the length between the two points on each corresponding axis is calculated using Equations 1-2 below:

$$Length\ X = GoalPoint\ X - CurrentPoint\ X \tag{1}$$

$$Length\ X = 24 - 13 = 11\ \text{mm}$$

$$Length\ Y = GoalPoint\ Y - CurrentPoint\ Y \tag{2}$$

$$Length\ Y = 37 - 16 = 21\ \text{mm}$$

Additionally, for safety reasons, before sending the commands '*Move_X_Axis (11 mm)*' and '*Move_Y_Axis (21 mm)*' for motion execution, the coordinates of the goal point are examined whether they are located inside the active workspace (motion range) of the robotic system. The "Move to Goal" function is used as part of the Navigation planning procedure described below (Section 1.4).

1.4 Navigation planning procedure

The navigation planning procedure acts as the main control unit, integrating all functionalities of the motion controller (connection with motion control board, "homing" procedure, "move to goal" procedure, etc.). The navigation planning process allows the User to design and execute the biopsy navigation plans using various drawing tools that were developed. Additionally, DICOM image navigation tools (zoom/pan/drag) were introduced, facilitating with the navigation planning. Navigation planning is based on layers and therefore initially, the User must create a new empty layer. The main advantage of layers is that they can easily be edited on an individual basis (editing on separate layers) with each active layer modified, deleted or erased. For example, different layers can be used for the design of different navigation plans. Correspondingly, by creating multiple layers, Users can individually design and compare various navigation plans (i.e. for different target tissue areas). The navigation planning procedure can be initiated after performing the robot positioning and the layer creation procedures as shown in the workflow in Figure 15.

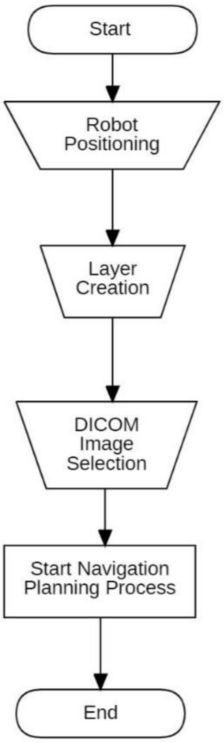


Figure 15: Flowchart of the navigation planning procedure.

Navigation planning tools:

Navigation planning tools are divided into two subcategories: tools for managing layers and tools for the objects within the layers. Figure 16 shows the various navigation planning tools, while Table 9 shows a short description of the tools.

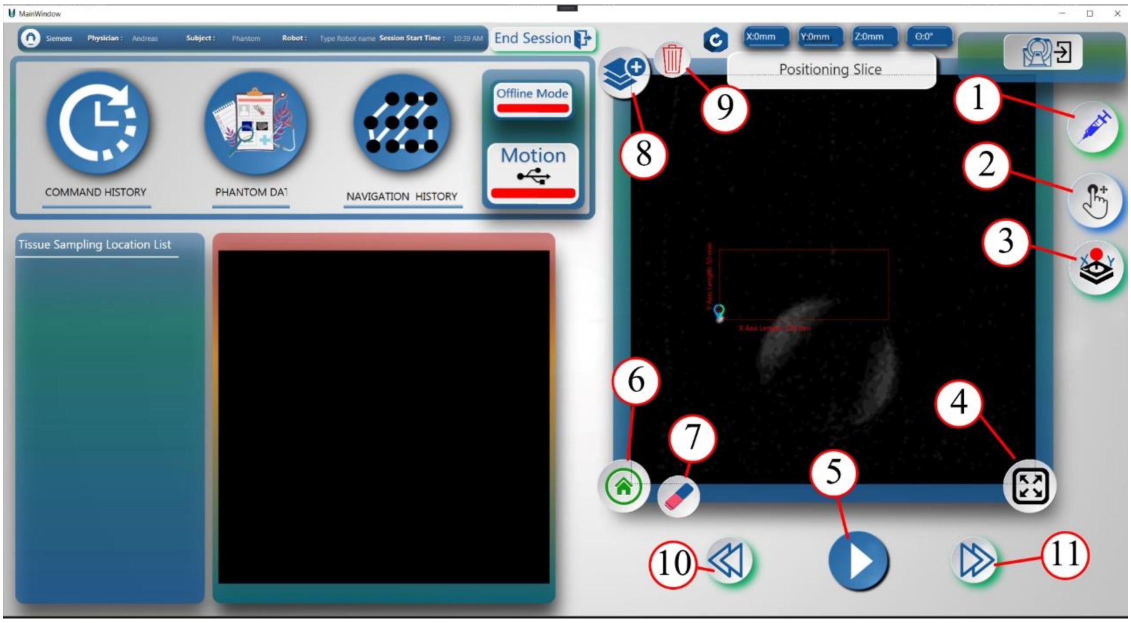


Figure 16: Screenshot of the navigation planning tools.

Table 9: Description of the navigation planning tools.

Buttons	**Description**
Button ①	Draws navigation points
Button ②	Image Zoom and Pan Tool
Button ③	Manual motion control
Button ④	Extends image to the frame
Button ⑤	Starts navigation planning process
Button ⑥	"Homing" menu
Button ⑦	Erases all layer navigation points
Button ⑧	Creates a new layer
Button ⑨	Deletes current layer
Button ⑩	Goes to the previous layer in sequence
Button ⑪	Goes to the next layer in sequence

For designing the navigation planning, the User initially has to create a new active layer by following these steps:

1. By clicking on  (button ⑧ in Figure 16), the DICOM image viewer panel (number ②) and the Z position panel (number ①) appear as shown in Figure 17.

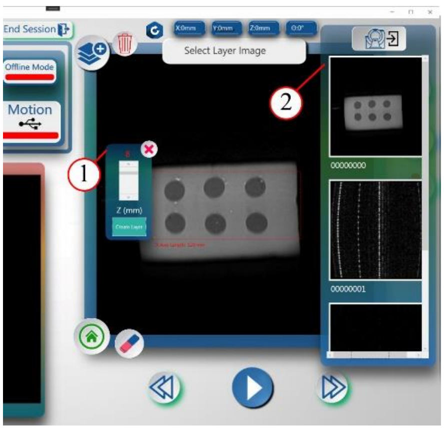
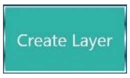


Figure 17: Screenshot of the Create a new layer process.

2. The User must then select the DICOM image, from the DICOM viewer panel (number ② as shown in Figure 17), on which the navigation planning will be performed.

3. After image selection, the User clicks on the 

button (located on the Z position panel as shown with number ① in Figure 17, and the layer is created.

Nevertheless, to ensure a smooth planning process error messages appear in cases an active layer cannot be created. Table 10 shows a list of events preventing the User from creating a layer. In cases any of the events occur, the corresponding error message is shown to the User as shown in Table 10.

Table 10: Events preventing layer creation and error messages.

Case Description	**User Error Message**
User does not select an image	"No image selection"
User does not select an image that matches the localizer image in response to pixel size	"Home Image Step Size doesn't match with Image Step Size"

By creating the first layer, the User can then proceed with the navigation planning procedure. The User has access to the navigation planning drawing tools by clicking on the  button (button ① in Figure 16), and selecting one of the additional design tools from the pop-up menu as shown in Figure 18.

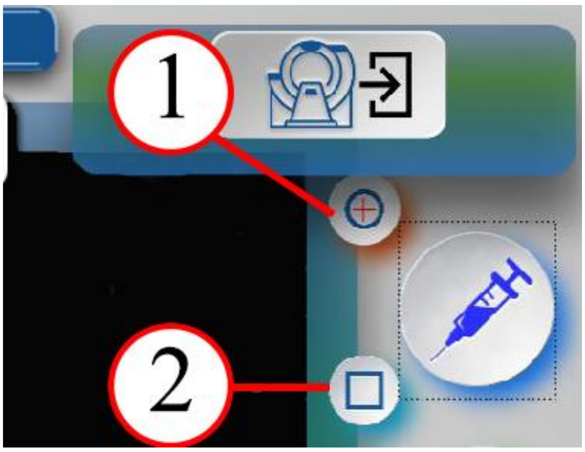


Figure 18: Screenshot of the navigation planning drawing pop-up menu.

By clicking on one of the optional design tools as shown in Figure 18 and described in Table 11, the User can initialize the navigation planning on the current Layer which had already been created prior to this step.

Table 11: Description of drawing tools of the pop-up menu.

Buttons	**Description**
Button ①	Draws single navigation points
Button ②	Draws rectangular navigation areas

The following steps describe how each the drawing tools can be used for navigation planning:

<u>Single navigation point drawing tool</u> 

A single navigation point is created as a yellow circle on the desired location (target tissue area), by simply clicking on the navigation planning image. After repeating the same procedure, the User can set multiple points as shown in Figure 19.

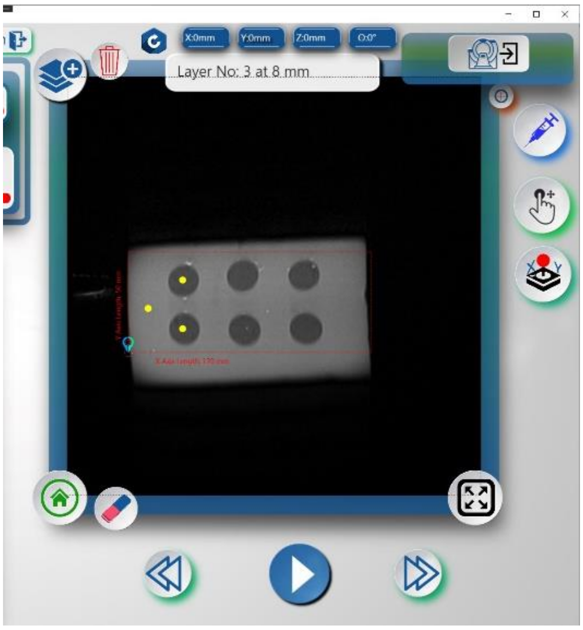


Figure 19: Screenshot of the single navigation point drawing tool.

<u>Rectangular navigation area drawing tool</u> 

The User can create a rectangular navigation area by positioning the cursor on the desired point on the image and clicking and dragging on the selection until the area reaches the desired size in mm, as shown in Figure 20. The navigation area is confirmed by the User after filling the desired step sizes for motion in the X and Y axes between navigation points and finalizing the procedure by pressing the “Set” button (Figure 20).

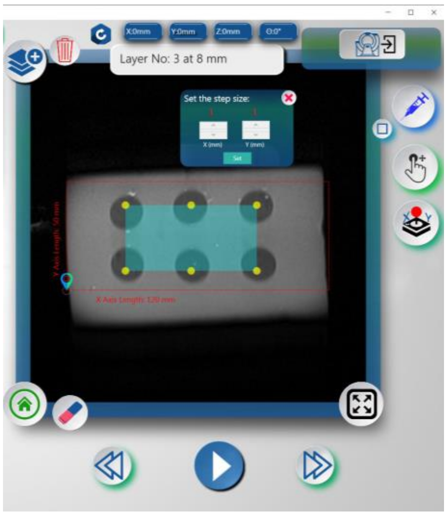


Figure 20: Screenshot of the rectangular drawing tool.

The User can start the navigation planning process by clicking on the  button (Figure 20). Navigation safety features were inserted, ensuring movement only upon the User’s wish. A message prompting the User for motion to the next point appears as shown in Figure 21. In this regard, navigation to each point is only performed subsequently to the User pressing the “OK ” button as shown in Figure 21.

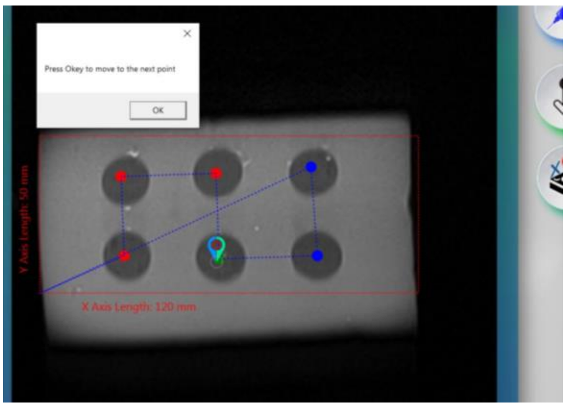


Figure 21: Message prompting the User to continue to the next point.

2 Software Database

A local database was also implemented, so that the software stores and retrieves data from the local disk. Specifically, SQLite was used as the database management system. The database is divided into 2 main categories; the first is for the storage of all data related to the Users (physicians and subjects) while the second is for the storage of all software commands. Specifically, various database tables as mentioned in Table 12 were implemented to support all required functionalities of the database and a range of data storage. The database tables are interlinked and connected as shown in the database structure provided in Figure 22.

Table 12: Description of database tables.

Database Tables	Description
Sessions	Stores all session data
Physicians	Stores all physician data
Subjects	Stores the primary ID and the subject type
Human	Stores all patient data
Animal	Stores all animal data
Phantom	Stores all phantom data
Robots	Stores all robot data
Navigation Planning	Stores all planned navigation locations (i.e. the target tissue areas)
Results	Stores all results of the corresponding navigation planning
Command History	Stores all software commands
Photos	Stores all images with a unique ID
Documents	Stores all documents with a unique ID

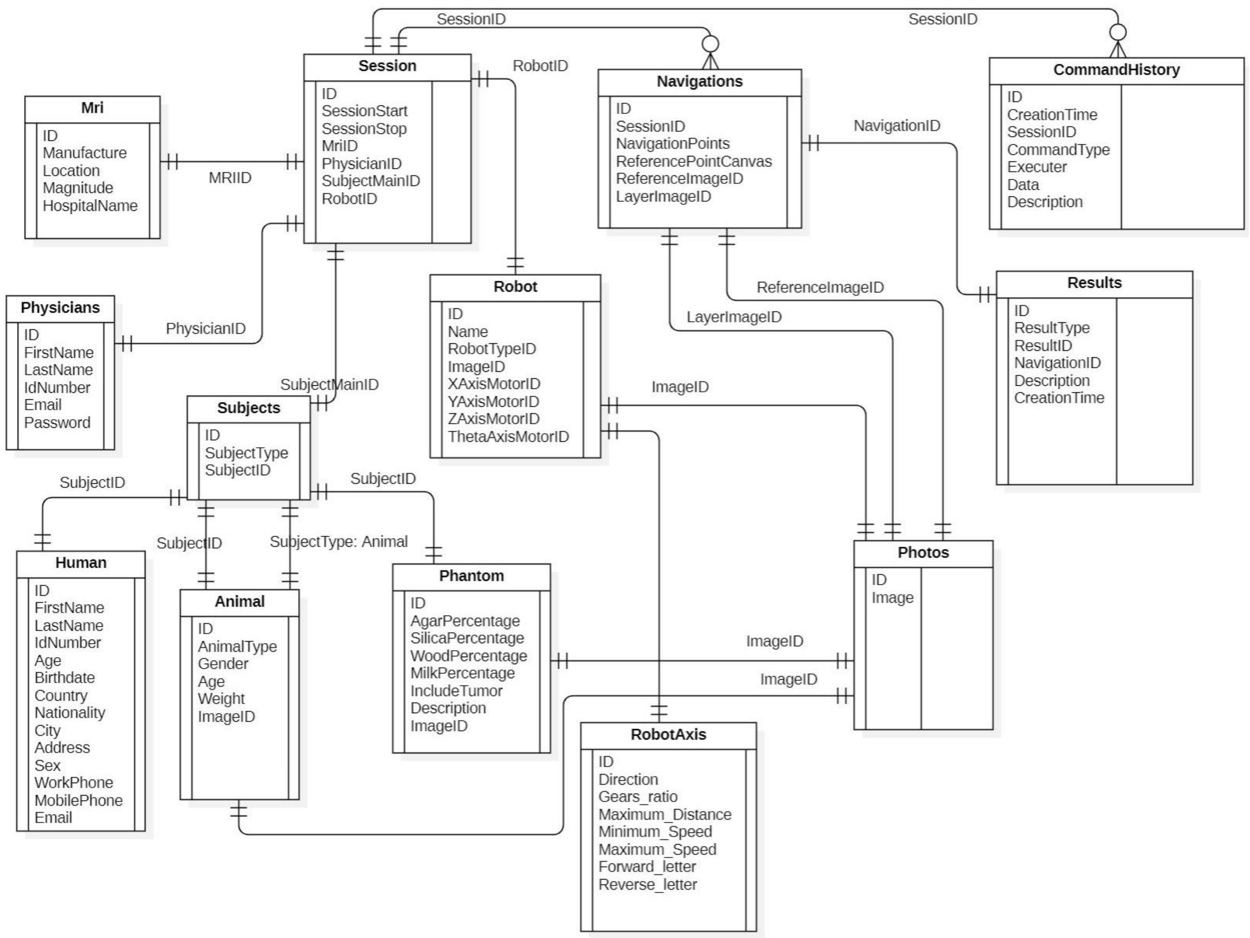


Figure 22: Database structure.

2.1 Session Panel

All software operations and functionalities such as navigation or motion control, are linked through sessions that have unique IDs. A session uses different parameters as shown in Table 13, to provide essential information regarding the robotic device, MRI scanner, physician, subject, navigation planning and session timeframes (initialization and termination).

Table 13: Description of session parameters.

Parameter Name	Description
ID	Unique ID number of the session
SessionStart	Date and time the session started
SessionStop	Date and time the session ended
MriID	Unique ID number of the MRI
PhysicianID	Unique ID number of the physician
RobotID	Unique ID number of the robot
SubjectMainID	Unique ID number of the subject

Each session acts as the primary identification key for the Navigations, Results and Command History tables as shown in Figure 22. Search functionalities of the software database are basically relying on the session ID. Figure 23 shows the workflow for starting a new session. Each time the User (physician) logs in the software, a new session entry is created, with the time and date of creation saved as the "SessionStart" parameter of the Session database table. Notably, all software functionalities executed by the User during the session share the same session ID. The session is completed with the "end session" event, commanded by the User, with the date and time of termination stored as the "SessionStop" parameter.

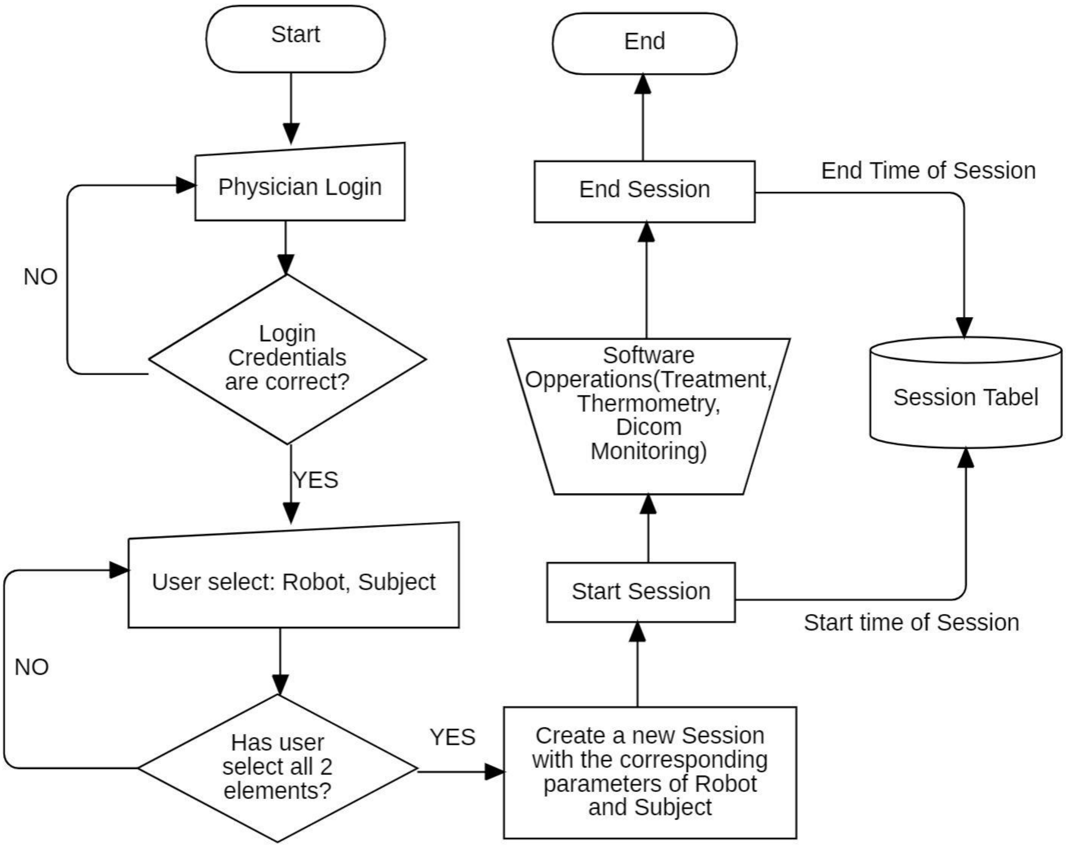


Figure 23: Workflow of initialization and termination of a new session.

Upon software launch, the physician login panel appears as shown in Figure 24. For starting and terminating a new session, the User (physician) undertakes the following steps:

1. Initially, the User (physician) enters his/her credentials, through the physician login panel, in order to log into the system. Each physician has a unique ID number and a private key (password) as shown in Figure 24.

Figure 24: Screenshot of physician login panel.

2. By clicking on the Login button (Figure 24), the software checks whether the User credentials are correct. If the credentials are validated, the User is redirected to the session panel as shown in Figure 25**Error! Reference source not found.**, otherwise, the software requires once more the correct User credentials. The session panel consists of 2 main categories (robot panel, and subject selection panel) as shown in Figure 25. The various GUI elements of the session panel as shown in Figure 25 are described in Table 14**Error! Reference source not found.**.

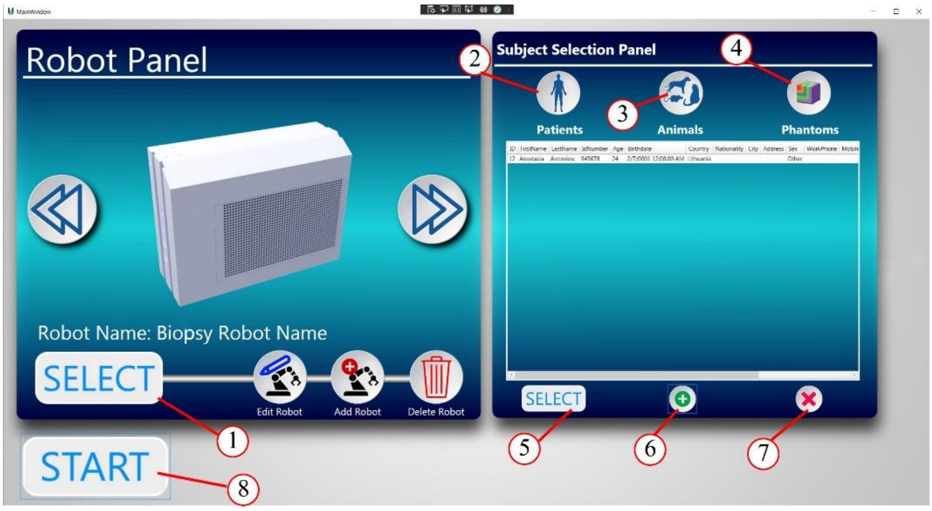


Figure 25: Screenshot of the session panel.

Table 14: Description of the session panel GUI elements.

Buttons	**Description**
Button ①	Robot confirmation
Button ②	Shows patient category
Button ③	Shows animal category
Button ④	Shows phantom category
Button ⑤	Subject confirmation
Button ⑥	Adds a new subject
Button ⑦	Removes a subject

Button ⑧	Starts session

3. From the session panel, the User must define the robot and subject elements in order to proceed to the main panel (Navigation Planning Window). The subject selection panel is divided into 3 subcategories; humans, animals, and phantoms (buttons ②, ③ & ④ in Figure 25). These categories (humans, animals, and phantoms) were chosen to meet the needs of preclinical trials. The User clicks on the button of each category (buttons ②, ③ & ④ in Figure 25) and the software retrieves all available entries of the corresponding category from the database and loads these to the DataGrid.
4. In case the User wants to create a new entry in one of the categories (human, animal, or phantom), he/she must first select the category and then click on the "add button" (button ⑥ in Figure 25). In the same manner, if the User wants to remove a specific subject entry from the database, he/she can clicking on the "remove button" (button ⑦ in Figure 25).
5. The process is completed with the User, selecting the desired subject from the list (Datagrid), and clicking on the SELECT button (button ⑤ in Figure 25).
6. After the User selects all two required elements (robot and subject), he/she can finalize the procedure by clicking on the START button (button ⑧ in Figure 25).
7. A pop-up panel appears as shown in Figure 26 prompting the User to save the session commands. If the User selects the "yes" option, all commands will be stored into the command history database, otherwise these will not be available for future retrieval. This option was added to the system, since large amounts of data are stored in the command history and in some cases of software experimentation saving command history data is useless.

Figure 26: Screenshot of the command history save option panel.

8. Upon initialization of a new session, all information (physician, MRI scanner, subject, robot, session date and time) is available on the session information panel as shown in Figure 27. When the User finishes with the current session he/she can simply click on the "End session" button as shown in Figure 27 which redirects the User back to the session panel.

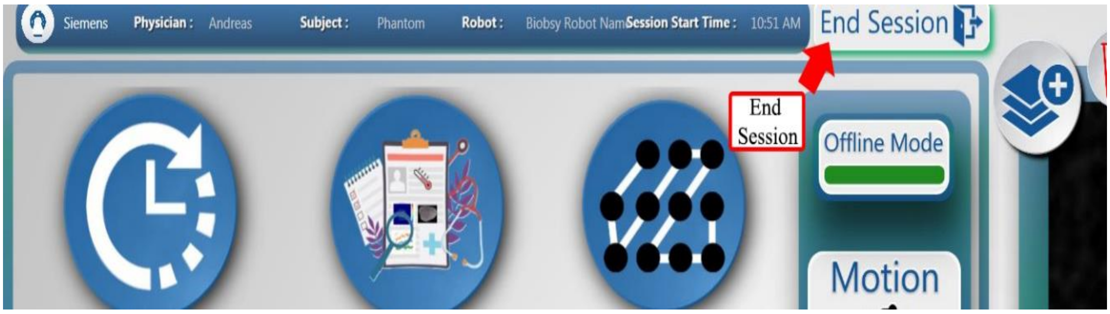


Figure 27: Screenshot of the session information panel.

2.2 <u>Subject Data</u>

For the manipulation and modification of subject data, the subject panel has been developed. After starting a session, the User can easily access the subject data panel by clicking on the  button, which is located on the main screen of the software (Figure 5). Depending on the subject category (patient, animal or phantom) selected in the current session, the corresponding information panel appears. Figure 28 shows the information panel when the patient is selected as the subject category. The panel includes several fields showing the patient's personal data (left side on Figure 28) as well as any results from any previous navigation plannings that are retrieved from the database and presented as a report documentation on the right side of the panel (button ④ in Figure 28).

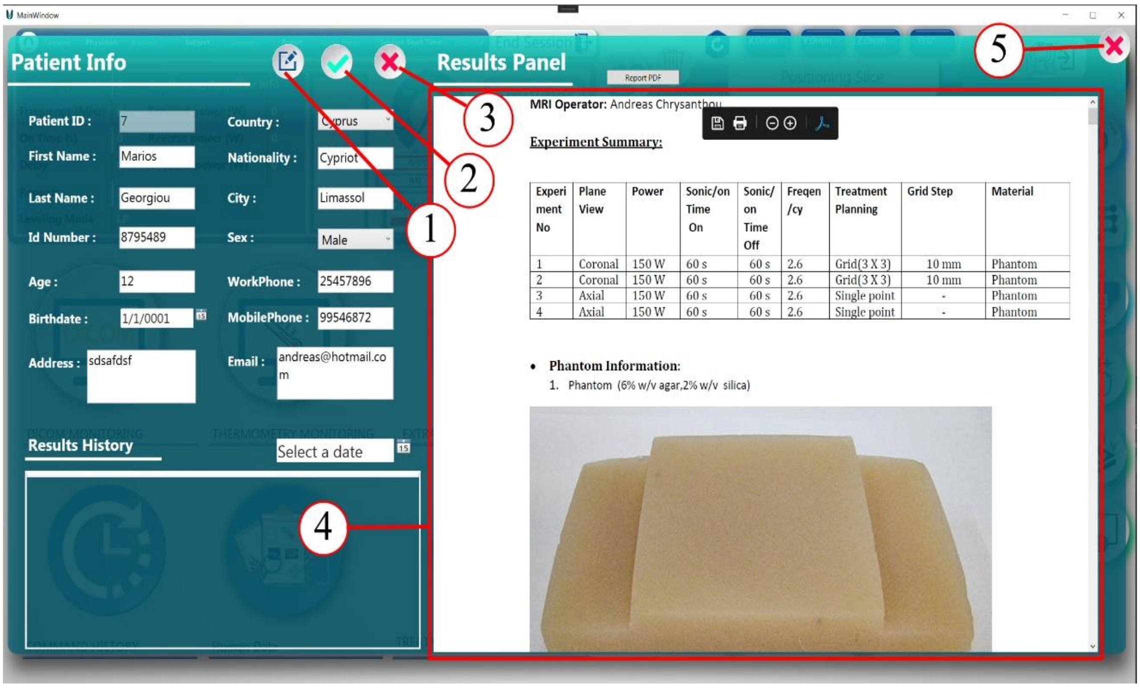


Figure 28: Screenshot of the patient info panel.

The User can modify any of the subject's information by clicking on (button ① in Figure 28) and editing the field data accordingly. Data modification can be confirmed by clicking on (button ② in Figure 28). Otherwise, if the User changes his/her opinion all data changes can be restored by clicking on the button (button ③ in Figure 28), while the information panel can be closed by clicking on the (button ⑤ in Figure 28). Subject data panels for animals and phantoms are presented in a similar way, as shown in Figure 29 and Figure 30 respectively.

Figure 29: Screenshot of the animal info panel.

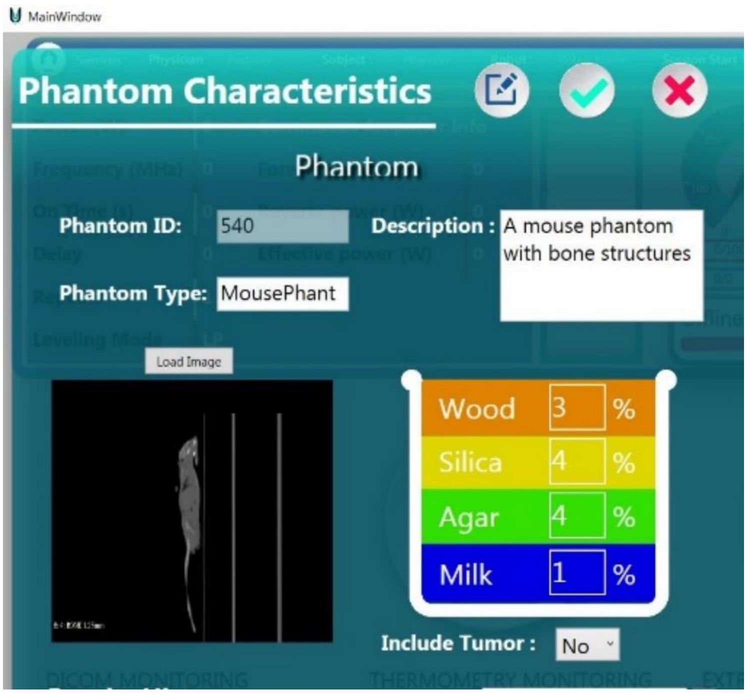


Figure 30: Screenshot of the phantom info panel.

2.3 Command History

A command history feature was also incorporated into the software. Command history accounts for all actions executed either manually by the User or automatically by the software during a session. These actions fall into 4 categories, namely, motion, general, positioning and navigation related commands. Command history stores and retrieves all commands to and from the database, thus providing the User with the ability to search for actions and parameters used in previous sessions. In this regard, previous parameters or navigation plans can be loaded to the current session workspace. The command history panel can be accessed by clicking on the Command History button that is available on the main Navigation Planning Window (Figure 5). The Command history panel consists of a DataGrid viewer for listing commands, and several search fields for filtering options as shown in Figure 31.

The User can perform a filtered search in order to find the requested commands as shown in Figure 31**Error! Reference source not found.**. The User must first p erform a filtered search by creation date (button ① in Figure 31) and then execute further search by command category type (number ② in Figure 31). Additionally, the User can export all filtered commands in an Excel table format by clicking the EXPORT button (button ④ in Figure 31. Table 15 describes all available elements of the command history panel.

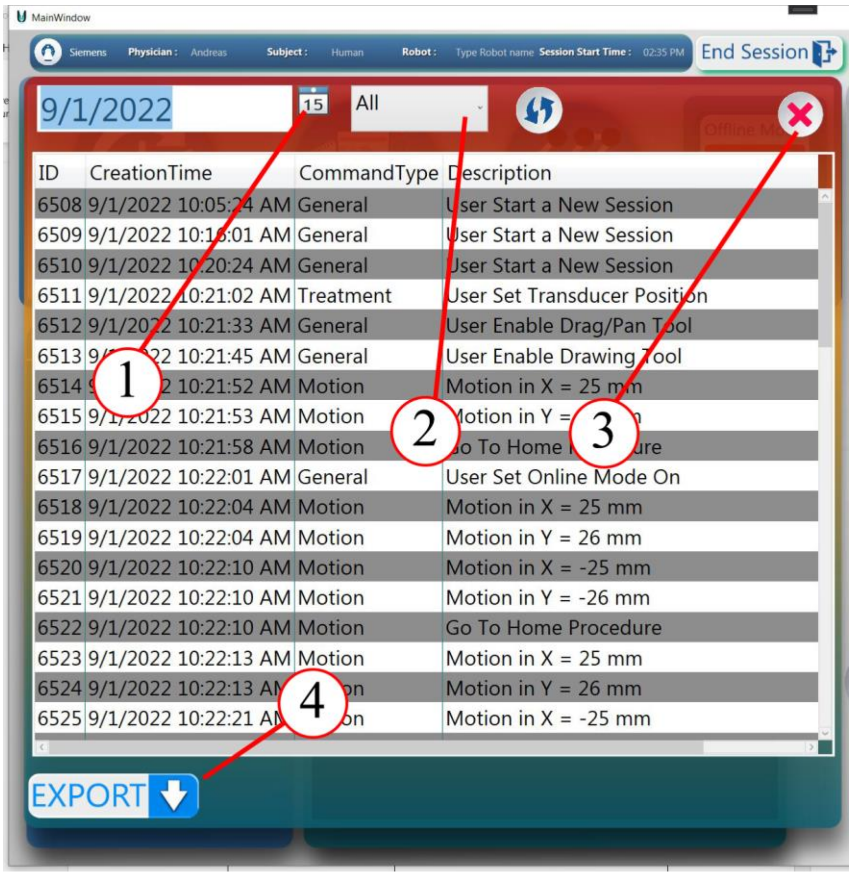


Figure 31: Screenshot of the command history panel.

Table 15: Description of the elements of the command history panel.

Buttons	**Description**
Button ①	Calendar for creation date selection
List ②	List of command type
Button ③	Closes command history panel
Button ④	Exports commands in Excel table format

2.4 <u>Navigation Panel</u>

Additionally, a navigation panel feature was introduced in the software. To ensure a smooth workflow, Users must initially create at least one working layer to have access to the navigation panel. The navigation panel provides Users with the ability of performing a chronological search for previous navigation plannings of a subject, based on that subject's unique characteristics (name, ID number). For instance, the User can search and find all navigations plannings of a patient whose name is "John" or his/her IDNumber equals to "2321454". Therefore, the User can easily load previous navigation points or layer images on the active layer of the current session. The navigation panel as shown in Figure 32, acts as a navigation planning history, showing all previous navigation plans. Table 16 describes all available elements of the navigation panel.

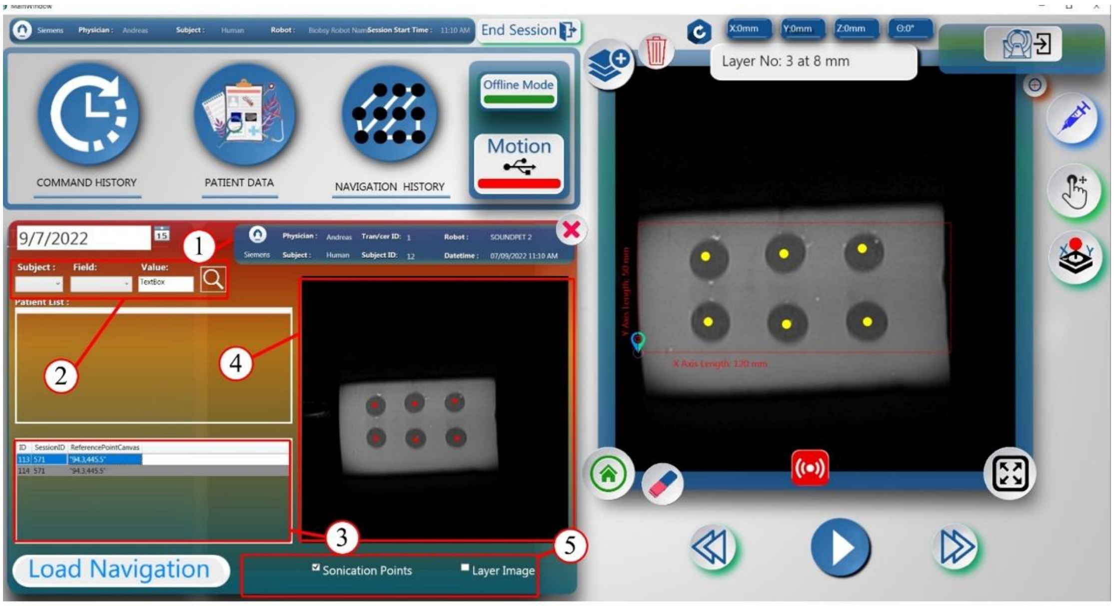


Figure 32: Screenshot of the navigation panel.

Table 16: Description of the navigation panel elements.

Buttons	**Description**
Panel ①	Currently selected session information
Panel ②	Search by subject parameters
DataGrid③	List of navigation plans
Image Viewer ④	Layer image with navigation points
Checkboxes ⑤	Loads required parameters

The User, by clicking on the calendar and choosing a specific date, can find all corresponding navigation plannings executed on the selected date. All navigations are linked with a unique session ID. All information related to the active navigation session can be found on panel ①, as shown in Figure 32. The User can easily search for previous navigation plans by using the search filtering panel (number ②, in Figure 32). The User selects the subject type (human, animal or phantom) and search field (name, ID number), and inserts the corresponding search field value so that he/she can find the related navigation plans. Table 17 shows the available search fields and an example of the search field value for each subject category (human, animal and phantom). Each time the User applies new search rules, he/she has to click on the  button (number ② in Figure 32), in order to update the navigation list (number ③ in Figure 32).

Table 17: Description of search fields and an example of their corresponding value that can be used for filtered search.

Subject	Field	Value
Human	ID	Unique ID of patient, e.g., XX, XX
	FirstName	First Name, e.g., “John”
	LastName	Last Name, e.g., “Doe”
	IdNumber	Civil ID, e.g., XXX..X
	MobilePhone	Mobile Number, e.g., XXXX…X
	Email	john.doe@domain.com
Animal	ID	Unique ID of animal, e.g., XX, XX
	AnimalType	Animal Species, e.g., ”Cat”, “Dog”, “Mouse”
	Gender	“Male”, “Female”
	Age	Age of Animal, e.g., 10yr
	Weight	Weight of animal, e.g., 10Kg
Phantom	ID	Unique ID of patient, e.g., XX, XX
	PhantomType	Description of phantom type, e.g., “Breast”
	AgarPercentage	Percentage of Agar, e.g., XX%
	SilicaPercentage	Percentage of Silica, e.g., XX%
	WoodPercentage	Percentage of Wood, e.g., XX%
	MilkPercentage	Percentage of Milk, e.g., XX%
	IncludeTumor	Tumor existence, e.g., True or False
	Description	Description of phantom

Navigation points used in previous navigation plans are visible as red circles overlayed on the navigation planning image that is loaded on the Image Viewer (number ④) of the navigation panel as shown in Figure 32. The User has the choice to load on the active navigation planning layer these previously used navigation points and layer image, by checking the relevant boxes on the bottom right corner of the navigation panel (number ⑤ in Figure 32). The process is completed by clicking on the Load Navigation button on the bottom left corner of the navigation panel (Figure 32).

If the navigation points checkbox is checked, the system asks the User whether he/she would like to erase any existing (already drawn) navigation points from the active layer as shown in Figure 33. By clicking ‘Yes’, any existing navigation points on the active navigation planning layer are completely erased, and the navigation points of the selected (previous) navigation are loaded on the layer as shown in Figure 33. Otherwise, if the ‘No’ option is selected, the navigation points of the selected navigation are added to the existing navigation points on the active navigation planning layer as shown in Figure 33.

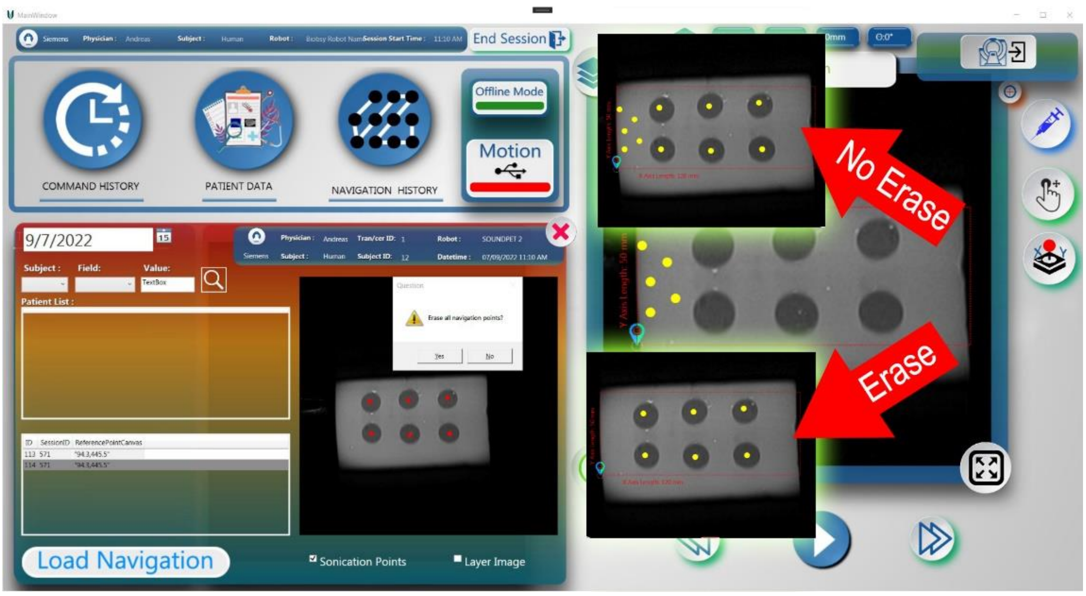


Figure 33: Screenshot of loading navigation points from previous navigations on the active navigation planning layer.