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Software for the Use of Multi-Modality images in External Radiotherapy



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1 SUMMER-MITK Prototype

The SUMMER project stands for Software for the Use of Multi-Modality images in External Radiotherapy ("About SUMMER," 2012). Within the SUMMER project, a common research prototype platform called Medical Imaging Interaction Toolkit (MITK) was selected (AQUILAB, 2013). It is a free open-source software system for the development of interactive medical image processing software ("The Medical Imaging Interaction Toolkit (MITK)," 2015).

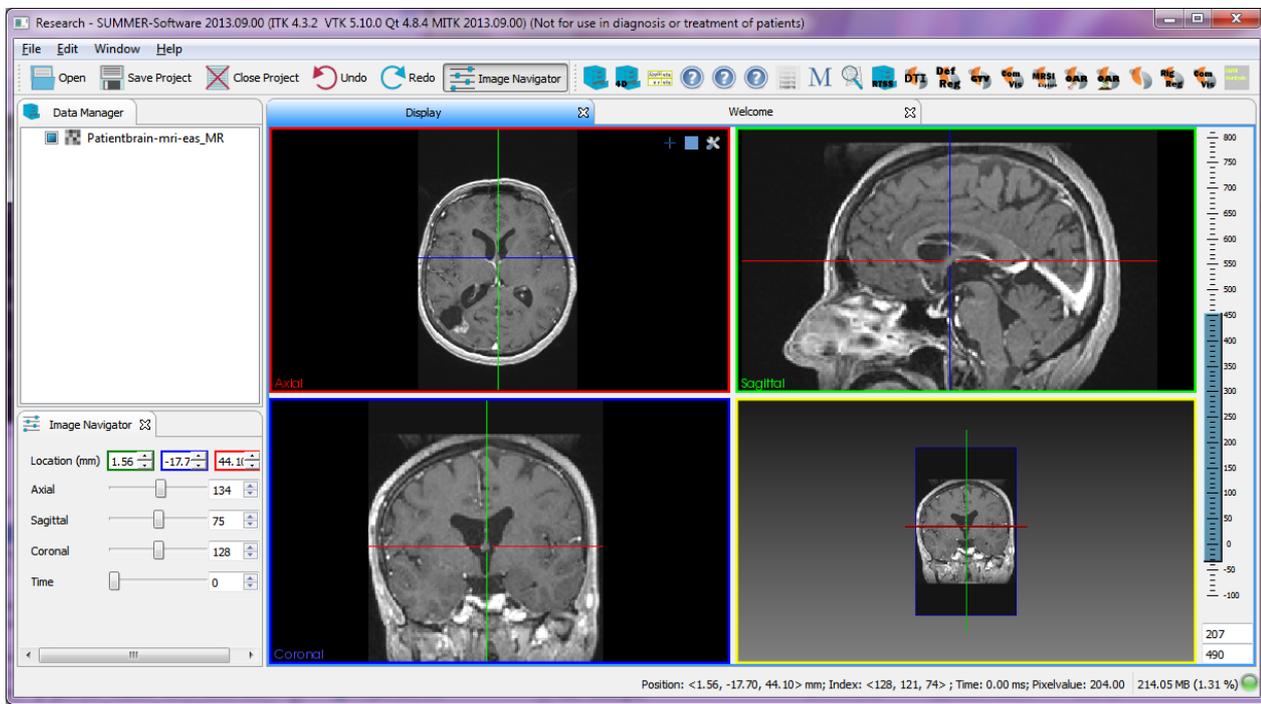


Figure 1: Screenshot of the SUMMER-MITK prototype

Within the SUMMER project, involved partners have been developing different plugins depending on their research topic (see <http://summer-project.eu/>). The plugins are as follows:

- *RT-Struct* - A plugin that allows importing/exporting structures from/to a RT-STRUCT file
- *Dicom4DLoader* - A plugin that allows importing a 4D dataset as a single datanode with timepoints
- *Rigid Registration* - A plugin that allows rigid registration between two selected datasets
- *Deformable Registration* - A plugin that allows deformable registration between two (CT/CBCT) datasets
- *OARs Segmentation (by contour)* - A plugin that allows watershed and graph-cut based semi-automatic segmentation of various organs at risk based on few drawn contours
- *OARs Segmentation (by seed)* - A plugin that allows watershed and graph-cut based semi-automatic segmentation of various organs at risk based on background and foreground drawn seeds
- *GTV Segmentation PET* - A plugin that allows seed based (4D) PET image segmentation and provides metric of the segmented volume
- *MRSI Exploration* - A plugin for MR spectroscopy data processing
- *External software ComVis* - an external research software for visual analytics
- *MRSI ComVis Analysis* - A plugin for connecting to external software ComVis for advanced MRSI data exploration and volume creation
- *fMRI ComVis Analysis* - A plugin for connecting to external software ComVis for advanced fMRI data exploration and volume creation
- *Renderer* - A plugin for advance image visualization, primarily for MR Spectroscopy dataset visualization
- *DTI Tractography* - A plugin for extracting tracks from the raw DWI dataset
- *fMRI-DTI Visualization* - A plugin for fMRI and DTI data visualization and tracks based segmentation

Additionally, there are some other pre-existing MITK plugins to be included in the SUMMER-MITK prototype:

- *Data Manager* – the plugins that allows managing all the included datasets, structures, and other binary images.
- *Image Navigator* – a plugin that allows changing the slices on all three planes and select the time point in case of the 4D dataset.
- *Segmentation* – a plugin with 2D and 3D tools for creating segmentations
- *Measurement* - measuring may be need at some point during the use workflow (e.g. measure distance between OAR and Tumor) and thus should be enabled.

One challenge in distributed research projects between partners with different research focuses is combining the results into one platform. Within SUMMER project there was a dedicated work-package “Technical research integration and quality assurance” to tackle this challenges. As such the integrator put significant effort into increasing consistency between and within the SUMMER plugins. In this report, heuristic evaluation (Nielsen, 1994) based approach was taken, and final suggestions to the prototype are given. The evaluation was conducted on the prototype version of May 2015.

2 General guidelines

There are multiple usability guidelines available online. The most well know list of heuristics, rules of thumbs, is the Nielsen’s “10 Usability Heuristics from User Interface Design” (Nielsen, 1995):

1. Visibility of system status
2. Match between system and the real world
3. User control and freedom
4. Consistency and standards
5. Error prevention
6. Recognition rather than recall
7. Flexibility and efficiency of use
8. Aesthetic and minimalist design
9. Help users recognize, diagnose, and recover from errors
10. Help and documentation

Another set of guidelines to support users’ cognition was developed by Gerhardt - Powals (1996):

1. Automate Unwanted Workload
2. Reduce uncertainty
3. Fuse data
4. Present new information with meaningful aids to interpretation
5. Use names that are conceptually related to function
6. Group data in consistently meaningful ways
7. Limit data-driven tasks
8. Display only that information needed at a given time
9. Provide multiple coding of data
10. Practice judicious redundancy

A more extensive list of heuristics was proposed by Weinschenk and Barker (2000) based on their research into multiple heuristic’s sources

1. User Control
2. Human Limitations
3. Modal Integrity
4. Accommodation
5. Linguistic Clarity
6. Aesthetic Integrity
7. Simplicity
8. Predictability
9. Interpretation
10. Accuracy
11. Technical Clarity

12. Flexibility
13. Fulfillment
14. Cultural Propriety
15. Suitable Tempo
16. Consistency
17. User Support
18. Precision
19. Forgiveness
20. Responsiveness

The above-mentioned lists of heuristics are not the only ones available. However, which guidelines to follow depend on the situation and possibilities. With the SUMMER-MITK prototype we based our evaluation on these three sets of heuristics.

In the following section we are highlighting the most relevant guidelines for the SUMMER-MITK prototype that allow detecting potential usability errors and we give suggestions how to avoid them.

2.1 Reduce excess interactions

Reducing the number of clicks and keystrokes is one of the quickest ways to increase usability. The main recommendations to achieve this are following.

- Avoid or reduce switching between plugins.
- Whenever possible, preset the values for the user.
- Critically analyze every input field to determine whether:
 - They are really needed;
 - They could be combined.
- Remove excess information
 - Less is more – the more is presented to the user the more likely it is that the user will click or select a “wrong” thing. Therefore the minimum required should be displayed.

2.2 Error prevention

Preventing user errors reduces the overall interaction time, usability and overall user satisfaction.

- For inputting data:
 - Indicating clearly what values are expected
 - Do not allow entering incorrect values
- Make it clear what is the purpose of each UI element (e.g. buttons with clear labels)
- Do not rely only on “user will learn it”. There is a learning curve for any new software. However, the curve should be as flat as possible.

2.3 Consistency

Another way to rapidly increase usability is by ensuring consistency and by following conventions. This applies to the word usage, interactions as well as to the graphics. The main recommendations to achieve this are following.

- Things that look the same (buttons, icons etc.) should behave the same and vice versa.
- Terminology should follow end-user’s terminology (and not be based on the technical terminology)
- Terminology should be consistent within a plugin as well as between plugins.
- Consistent style (spacing, font, size, color, etc.)

2.4 Data selection

In addition to the possibility of selecting datasets from the *Data Manager* plugin, add a dropdown within the plugin. This reduces the need to move attention from one area of the screen to the other and thus reduces cognitive load.

2.5 Structuring content of the plugin

- The input fields should be presented in the expected order of interaction from top to down.
- Avoid displaying disabled fields – instead hide them and display them only when they are editable. This is to reduce visual clutter.

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- When there are numerous input/information fields, group them into logical visually distinct clusters (e.g. use background colors for clusters).
 - In case there are items that are less frequently needed within a cluster, consider using *Advanced* option (e.g. **Advanced settings**) where these options are displayed only once the advance option display is enabled.
 - In case of having multiple visually long clusters representing different steps in a workflow, consider using collapsible panels. At the same time caution is needed for the use of collapsible panels when the content could fit without. Typically such elements also include visual indication of its openness state (e.g. + or – sign, triangle or arrow). Suggestion is to include a visual indication also within all SUMMER plugins. The primary panel should be open by default.

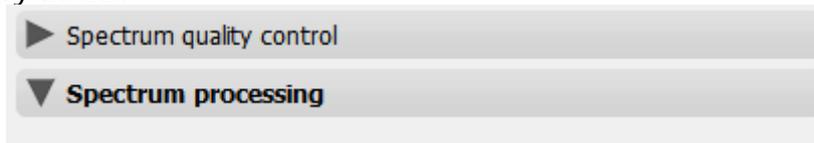


Figure 2: Example use of collapsible panels to organize workflow

- In case of having multiple independent workflows, consider using tabs.

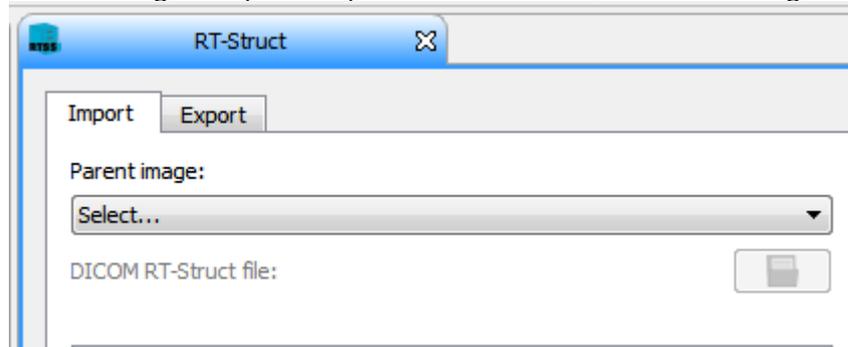


Figure 3: Example use of tabs for independent workflows

3 Usability feedback on the prototype

In this section we present the usability evaluation results

3.1 General

In this section we present usability feedback that does not directly relate to the SUMMER plugins, but are more related to the MITK itself.

3.1.1 Data manager

In the Data Manger the name presented after loading the datasets should be improved to increase readability and reduce cognitive load (heuristic “Recognition rather than recall”). Information needed for each dataset: patient name/ID, dataset modality name (type), date. While being limited to single level of items, the suggestions are as follows.

- Scenario 1: all datasets are of the same patient:
 - Add a label in the upper region indicating the patient name;
 - Each dataset node named as StudyDate + Modality. Date first to enable quick visual comparison as they have the same length.



- Figure 4: Example of how the Data Manager could look in case of Scenario 1

D2.3 – Usability Feedback

- Scenario 2: datasets of different patients:
 - No label in the upper region;
 - Each dataset node named as PatientName/ID + StudyDate + Modality

Other recommendations:

- The short names of modality types should be as follows: CT, MRI T1, MRI T1 gado, MRI T2, MRI FLAIR, fMRI, DTI.
- Renaming of dataset by the user should still be allowed

3.1.2 Contours

- Contouring tools:
 - active contour (ROI) is by default red, it should remain visible as the color it is given
 - Function like interpolation is required
- ROI color - the icon in front of the ROI name should be a filled square of the color of the contour
- Contour display should have fill/de-fill option. When the segmentation is filled, the overlay covers the whole region and because of which the users are unable to see the organ clearly. It should be possible to contour only the boundary.

3.1.3 Images display

- Indicate slice number as an overlay on the image
 - Do not open the *Image Navigator* plugin by default when opening the prototype

3.1.4 General tools

- Panning with mouse middle button click-and-hold can cause accidental slice changes. Better mouse interactions need to be investigated and tested with users.
- Zooming should be possible also with separate buttons.
- Opposite functions (e.g. draw and delete) need to be combined as one tool. This will reduce the number of mouse clicks.

3.1.5 Plugin icons



Figure 5: Iconbar of consisting of mainly SUMMER-MITK prototype plugins

Most of the plugin icons are very similar in design which enables the user to identify the SUMMER plugins quickly. However, some of them are too similar and it requires extra cognitive effort to recognize the correct one. The change suggestions are following:

- GTV - rename to PET GTV to emphasize that it is for PET based segmentation
- OAR - two visually similar icons. There is some overlap between the GUI elements and functionalities of these two plugins. In case the functionalities of the two plugins cannot be combined into one plugin, the icon design should be improved.
- ComVis - two visually same icons, one for MRSI and other for fMRI. These GUI of the plugins appear very similar. Therefore the recommendation is to merge these two plugins into one. In case that is not possible, separate icons need to be designed.
- Renderer plugin icon – this icon does not have any text on it, which requires the user to remember that this is the renderer plugin. Adding a text or an overlay representing data viewer could improve recognizability.
- The font size is slightly too small in some cases.

3.2 Workflow welcome page

- The proposal is to have a SUMMER project specific welcome/tasks page
- According to the selected task from the workflow, the suitable layout (selection of plugins and their distribution) should be presented

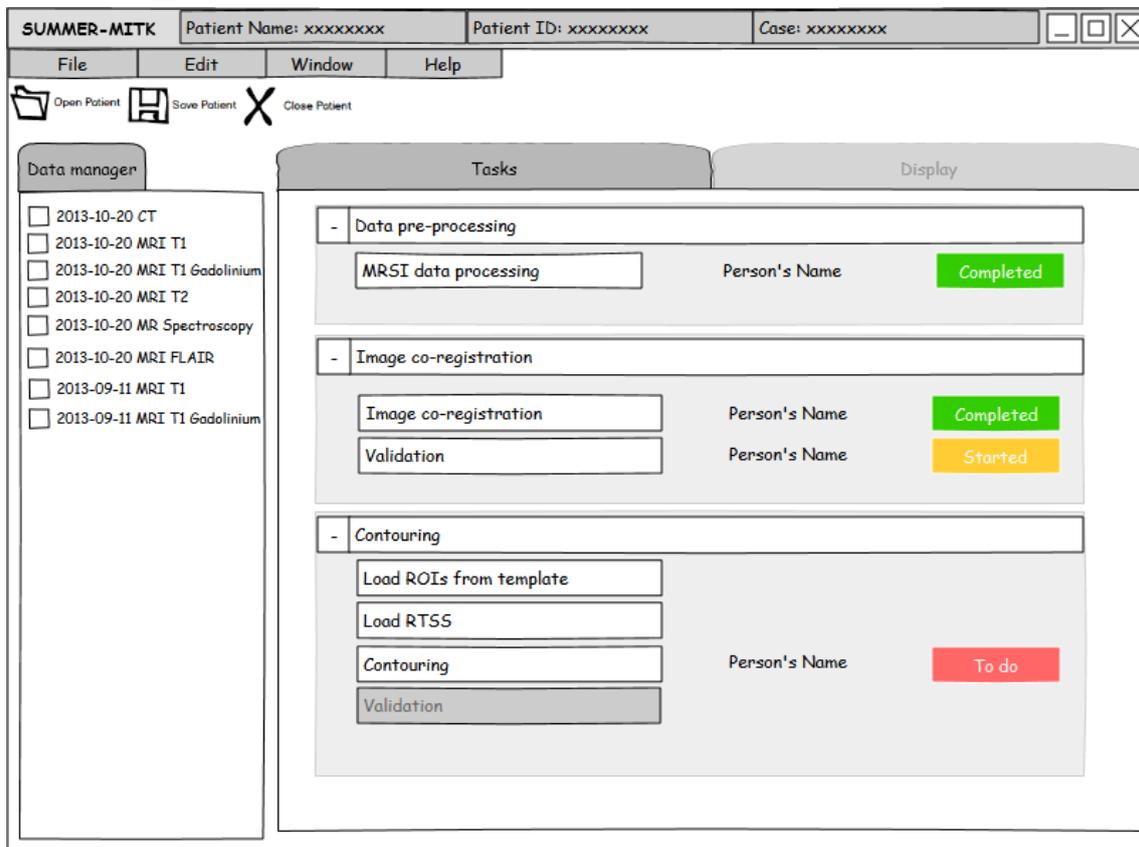


Figure 6: Sketch of the proposed SUMMER welcome/tasks page (Ramkumar, Aselmaa, & Song, 2014)

3.3 RT-Struct

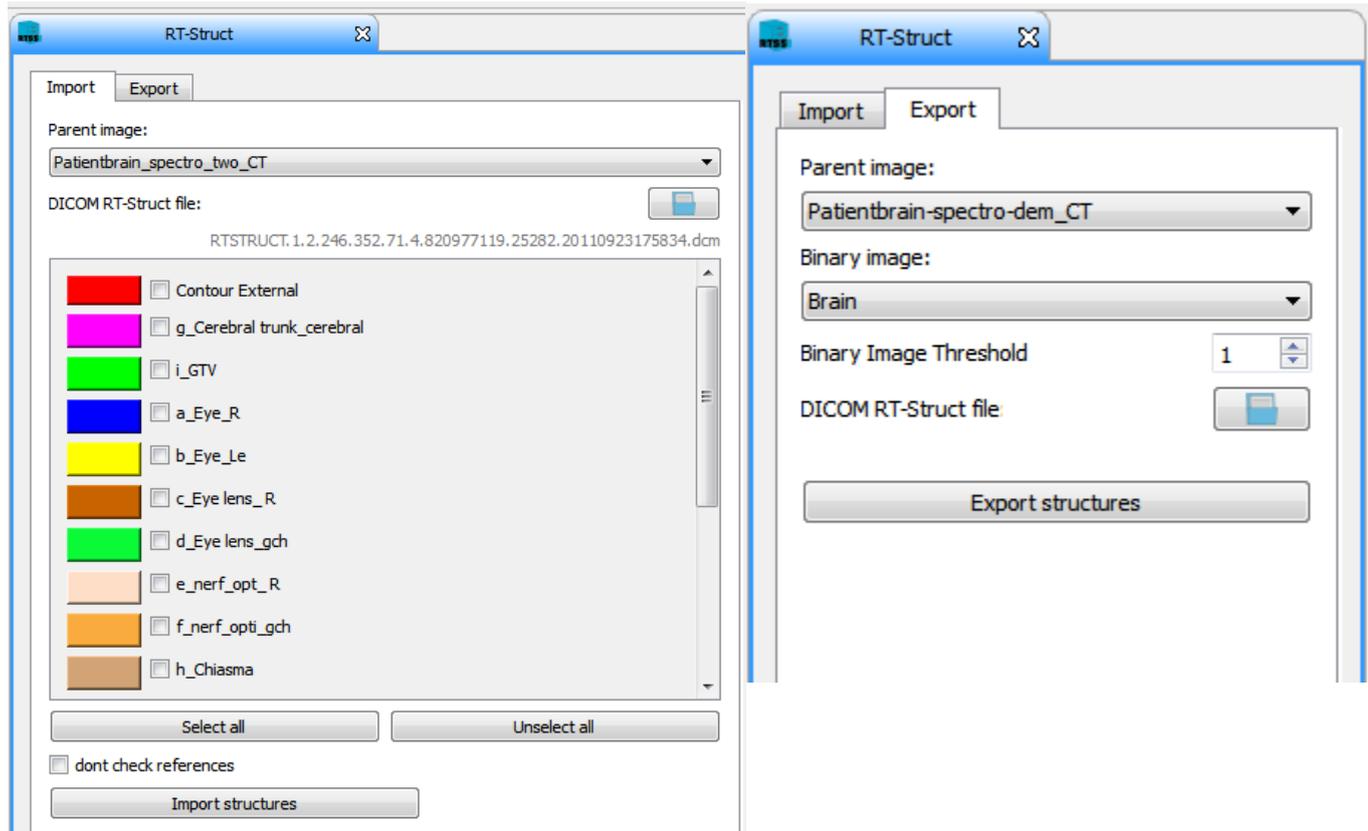


Figure 7: Screenshot of the RT-Struct plugin import tab (left) and export tab (right)

Previously given feedback has been implemented. Further suggestions are:

- Import
 - Reduce the width of the list of organs area to avoid unnecessary horizontal scrollbar when the plugins width is smaller.
 - When the color is clicked a color-picker appears. However if one cancels that dialog without selecting anything "red" color is chosen. Instead the color should remain as was initially.
 - The speed of import is rather slow for larger structures
- Export
 - How to use "Binary image" and "Binary image threshold" threshold is not clear.
 - Most cases the "Binary" image is the name of the contour – perhaps separate the primary use case (exporting list of structures) and secondary use case (exporting a thresholded image) into two different regions.
 - It should be possible to export all structures simply by selecting the parent image (a.k.a. the image the structures are connected to)
 - It should be possible to export a selection of structures

3.4 Dicom4DLoader

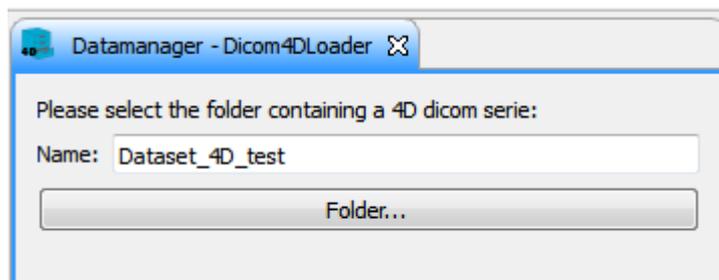


Figure 8: Screenshot of the Dicom4DLoader

The plugin is very simple and straight-forward to use. The suggestions are:

- provide visual feedback (e.g. progress bar) while the datasets are being loaded
- possible bug, the name entered is not being used (the dataset is loaded as “unnamed”). Alternatively automatic naming could be used based on the dicom header, based on the patient name, modality and the date (as described in section 3.1.1)

3.5 Rigid Registration

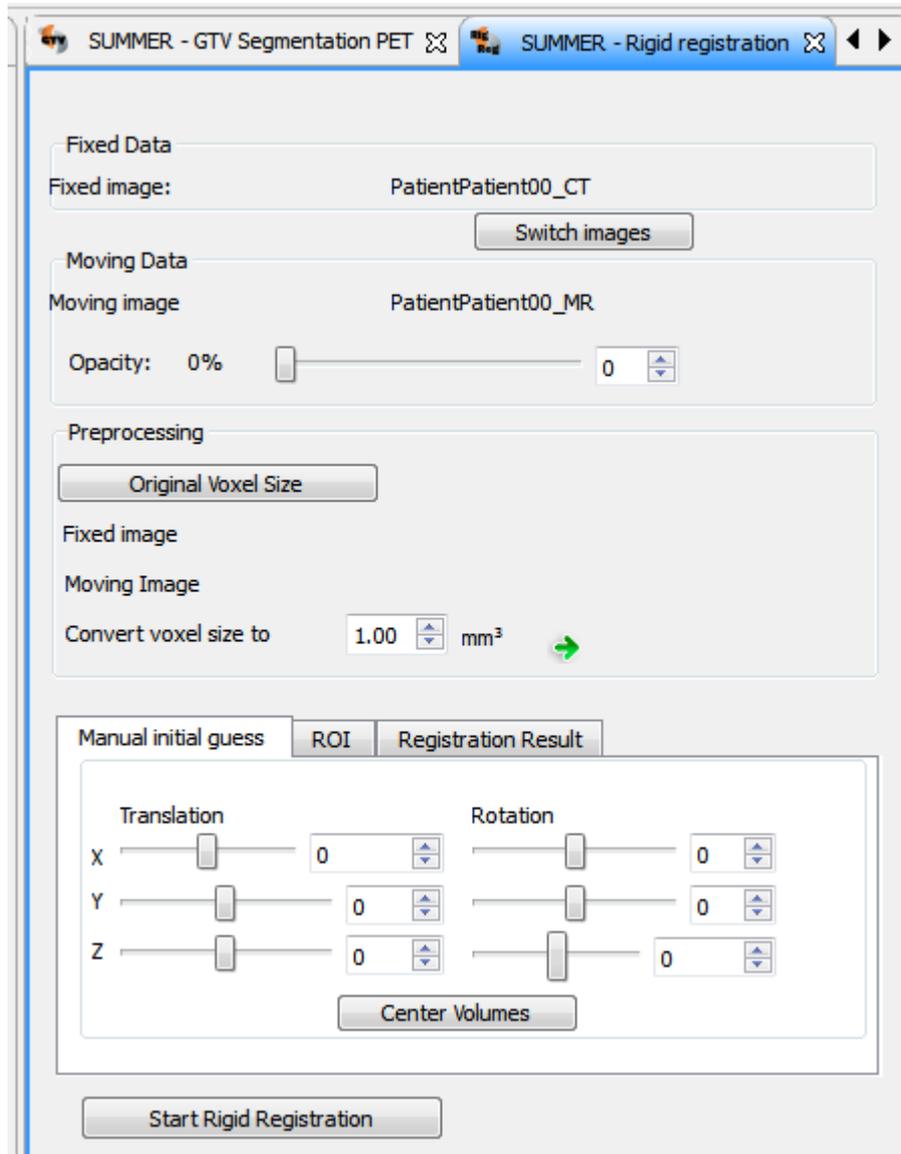


Figure 9: SUMMER Rigid Registration plugin

- Dataset selection
 - It is not obvious how to select datasets on first use. Suggestion, have drop-downs listing loaded datasets after "Fixed image:" and "Moving image"
 - Preselect fixed image to the CT image if it is loaded in the data manager
- Interface elements
 - Consistency "Moving image" -> "Moving image:"
 - Align texts/buttons in "Fixed data" "Moving data" and "Preprocessing" to the same vertical (invisible) line
 - Area "Preprocessing"
 - "Fixed image" and "Moving image" lines should not be empty
 - The arrow is not centered in the button when hovering on it

- Tab ROI
 - "Generate ROI:" -> without ":"
 - The buttons in ROI area do not have labels or icons
 - Not clear how to use it
- Interaction
 - Add possibility to manually position the moving image with drag-and-drop
 - No obvious visual feedback when the registration is running (e.g. the green loading bar in the bottom of the page)

Possible bugs:

- Tab "ROI", after clicking on both "empty" buttons and "Generate ROI:" the software crashes
- Opacity with registration: opacity is set to the "moving image" -> register -> uncheck the new generated structure -> the "moving image" disappeared and only "fixed image" is visible

3.6 Deformable Registration

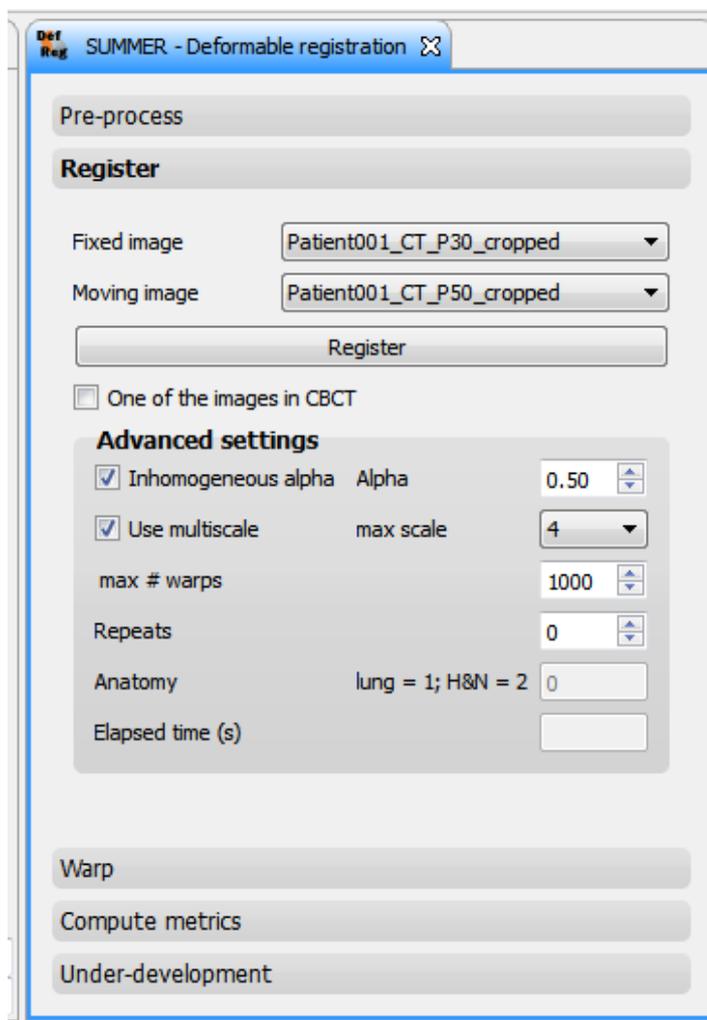


Figure 10: SUMMER deformable registration plugin

- It is very convenient that the plugin automatically opens the main area "Register" for the user on opening. This allows performing the registration with minimum effort. At the same time if needed, additional pre-processing is still possible.
- In the *Advance settings* the anatomy option should be indicated as text

Further evaluation was not possible due to technical errors in running the algorithm.

3.7 OARs Segmentation (by contour)

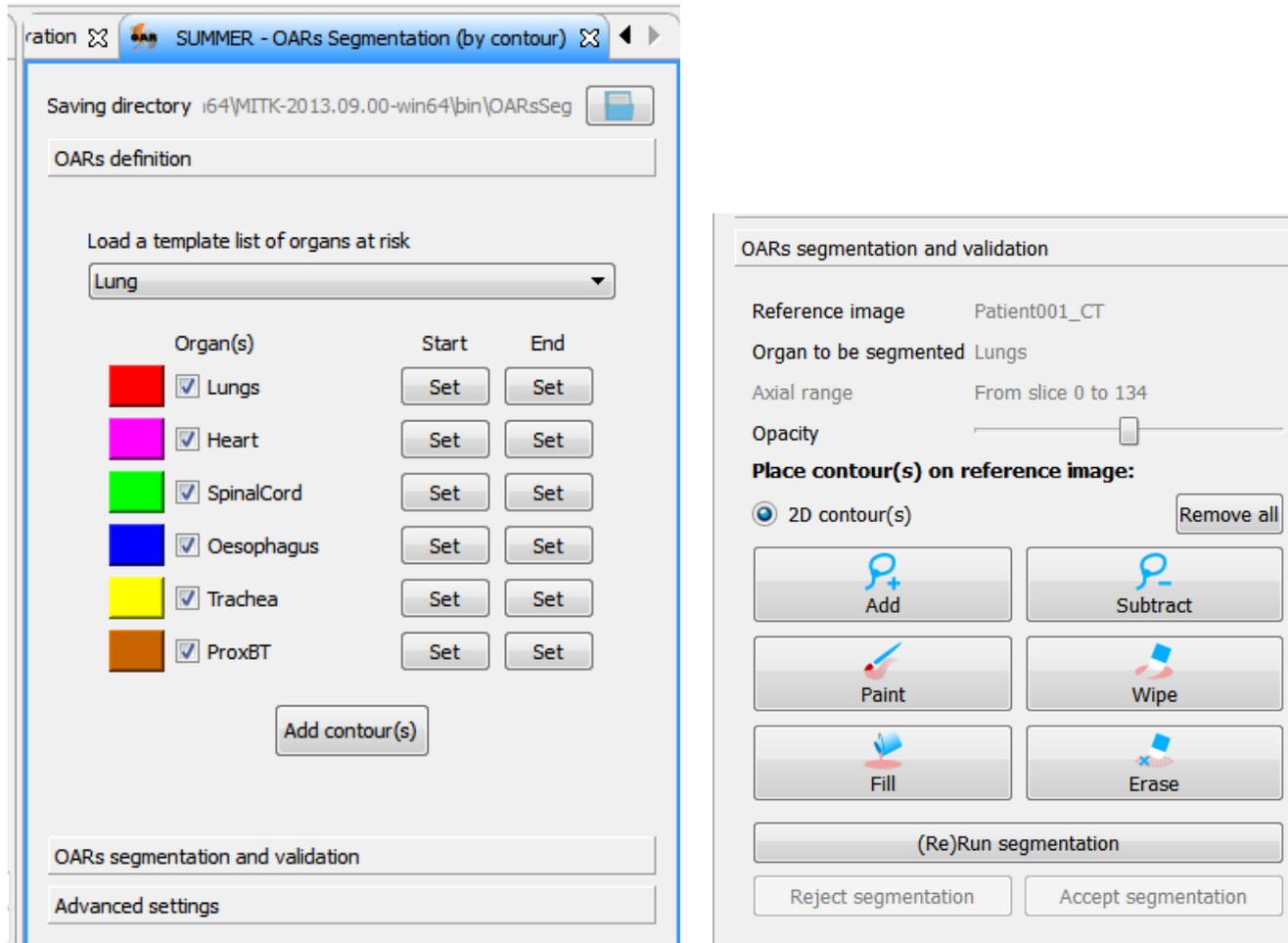


Figure 11a: Screenshot of the current plugin OARs Segmentation (by contour)

The plugins were iteratively improved in terms of usability. The remaining suggestions are as follows.

- The style of collapsible panels is different than elsewhere (lighter color and missing rounded corners). The style should be unified.
- While loading the list of organs at risk, add a possibility to add an additional item in the list before importing them into the *Data Manager*
- The *Add contour(s)* be renamed simply as *Add* as an empty structure is added while pushing the button and not a contour
- The *Add* tool should be renamed as *Freehand*. The interaction of this tool is of a free hand drawing tool and which is a familiar term for the users.
- The difference between *Wipe* and *Erase* is confusing and physicians they are not used to it. It is better to rename as the *Erase* (renamed from *Wipe*) and *Delete* (renamed from *Erase*) to better represent the action behind them. The (new) *Erase* button will be for erasing a small part of contour, while the (new) *Delete* is for deleting the contouring in one slice. Additionally *Remove all* should be renamed as *Delete all*.

3.8 OARs Segmentation (by seed)

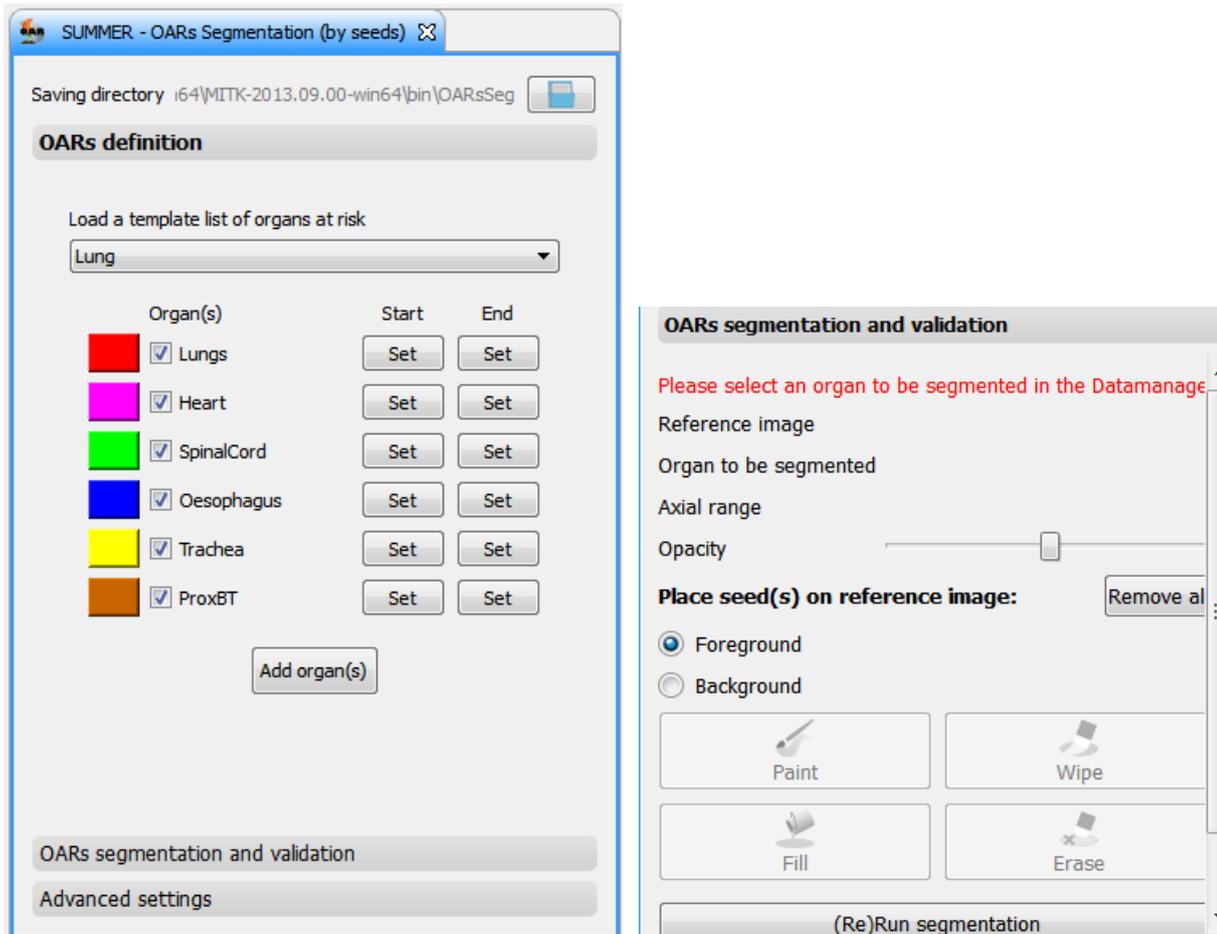


Figure 12b: Screenshot of the current plugin OARs Segmentation (by seed)

- Similar suggestions apply as for the plugin OARs Segmentation (by contour)
- Additional findings from a user study were following (Ramkumar, Dolz, et al., 2014).
 - Many errors were made by physicians in choosing the *Foreground* and *Background* function. This was primarily since the terms were new to them. Suggested naming would be *ROI* and *non-ROI*.
 - Most of the time during the interaction, the *Paint* was activated. However this cause unplanned drawing while the users were interacting with the images (e.g. while panning or zooming). Hence an additional *Arrow* tool is required so that physician can choose that while scrolling/thinking/zooming.
 - Deciding where to place the background seed is sometimes cognitively demanding since the algorithm was sensitive to the input.
 - In the case of segmenting the trachea, the physicians expected to include also the cartilage within the volume. However this was not possible with this algorithm.

3.9 GTV Segmentation PET

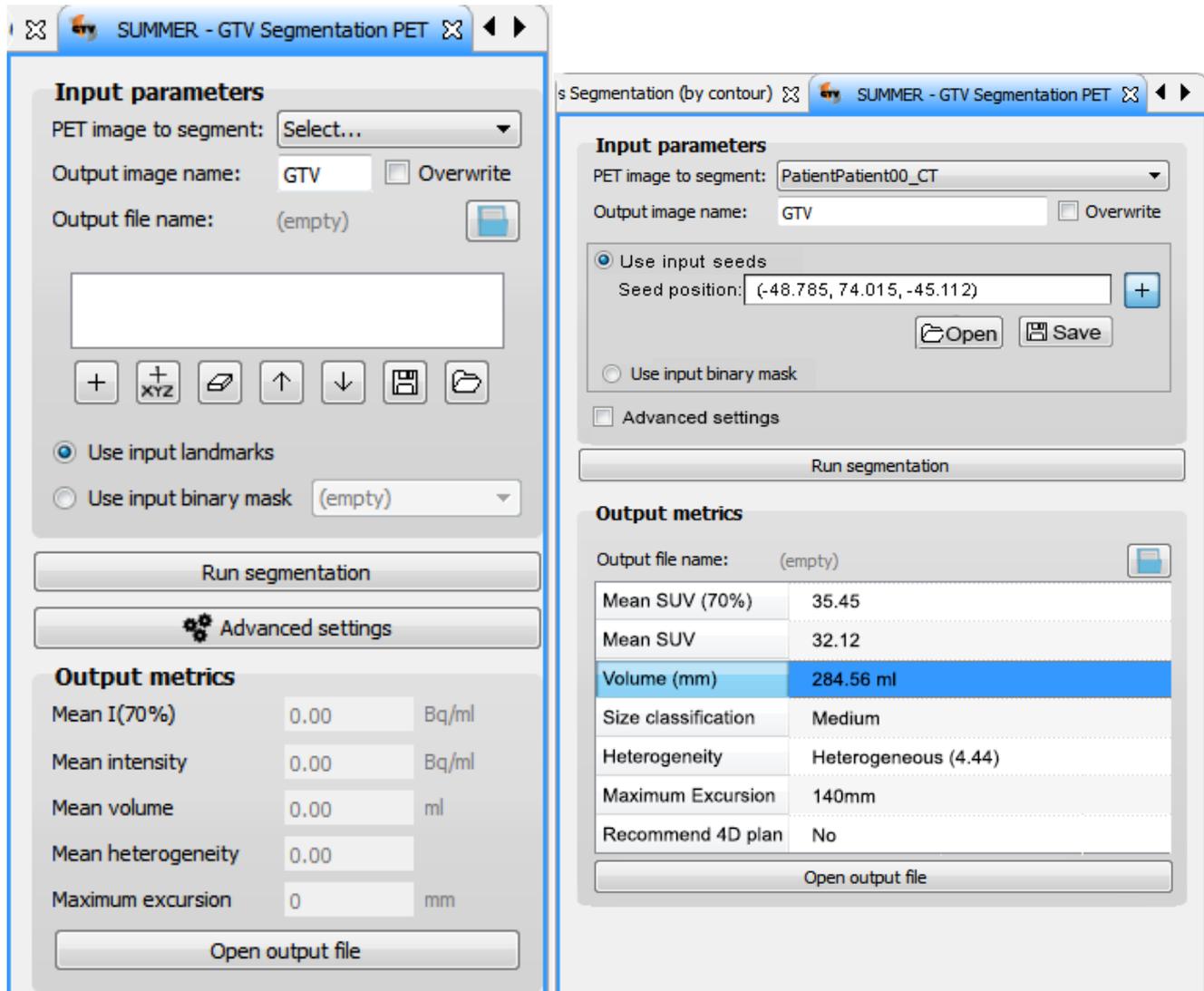


Figure 13: left) Screenshot of the current plugin, and right) proposed changed layout

- Region “Input parameters”
 - Radio option *Use input landmarks*
 - Move the radio button “use input landmarks” before the listing of points
 - Rename “Use input landmark” as “Use input seeds”
 - The algorithm allows only one seed point as entry – use an input field instead of a table element. Allow both selecting the point on the images (with the + button) and well with manual editing (and deleting content).
 - Reduce the number of buttons (many are relevant for a table element, but no longer for the single point entry)
 - Add text *Open* and *Save* for the corresponding buttons
 - Radio option *Use input binary mask*
 - Show the dropdown only once the radio button has been selected. This reduces visual clutter.
 - Merge the *Advanced settings* overlay into the area of *Input parameters*. Show the advanced parameters only when the checkbox is checked
- Output metrics
 - Update to the correct values when the segmented GTV is selected within the *Data Manager*
 - Move the *Output file* selection from *Input parameters* to *Output metrics* section. Rename as “Save results to:”
 - Suggestions for the data shown

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- Present result data in a table
- In addition to showing the Volume value in milliliters, to indicate also the categorization based on the size: “Small”, “Medium”, or “Large”
- In addition to the value of Heterogeneity, to indicate also the categorization: “Homogeneous”, “Heterogeneous”
- In addition to showing the value in mm of Maximum Excursion, to give indicate whether 4D RT-planning is recommended

3.10 MRSI Exploration

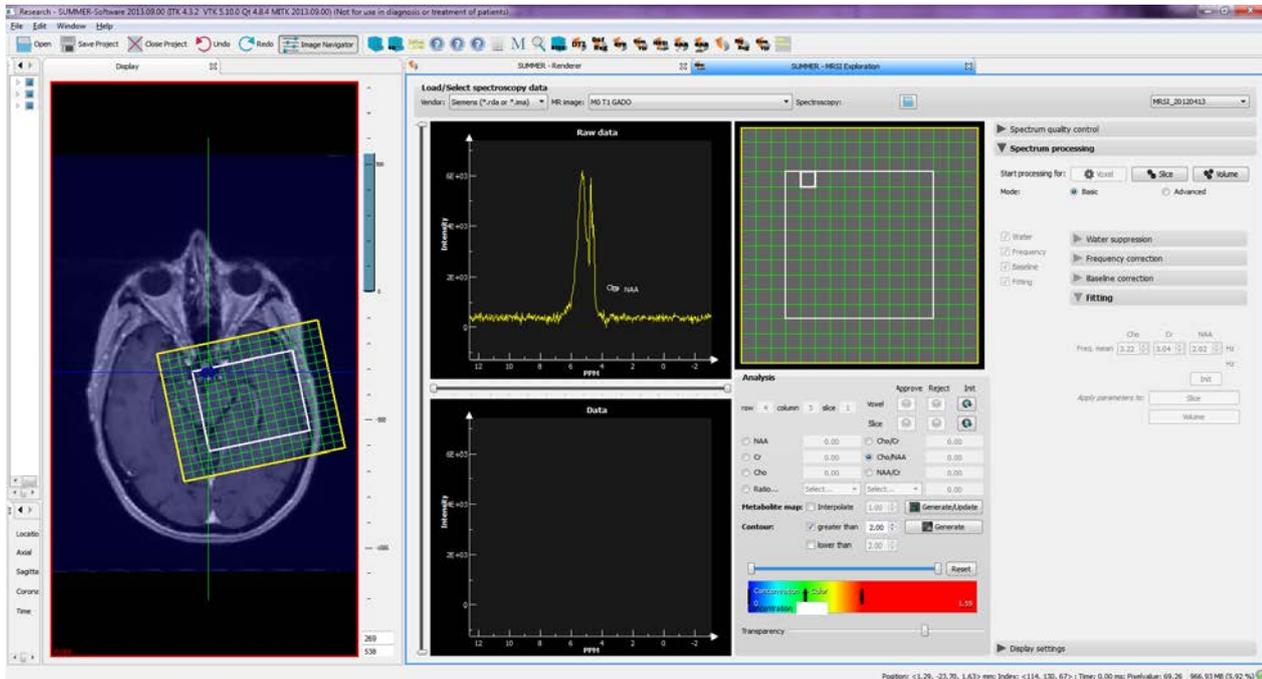


Figure 14: Screen shot of the MRSI exploration plugin

The plugin was iteratively improved through development in terms of usability. The remaining suggestions are as follows.

- The layout would need optimization for different screen resolutions
- The *Data* graphs should be renamed to *Processed Data* to make it clear what is the difference compared to *Raw Data*
- The user should not need to select the vendor – this should be detected based on the file extension.
- There are multiple automated action that increase usability. Further work on increasing the speed of them would increase the user experience further.

The overall usability is high and user testing with physicians is required for further evaluations.

3.11 External software ComVis

ComVis is a research software intended to be used as a prototyping environment for new visualization techniques (Matković, Freiler, Gračanin, & Hauser, 2008). ComVis supports coordinated multiple views for interactive visual analysis. This allows the user to interactively explore their data via various visualizations.

3.12 MRSI ComVis Analysis

The *MRSI ComVis Analysis* plugin enables communication between MITK and ComVis. Proposed name for the plugin is “ComVis connector for MRSI” as the plugin’s function is to connect, send and receive data but not analyzing it.

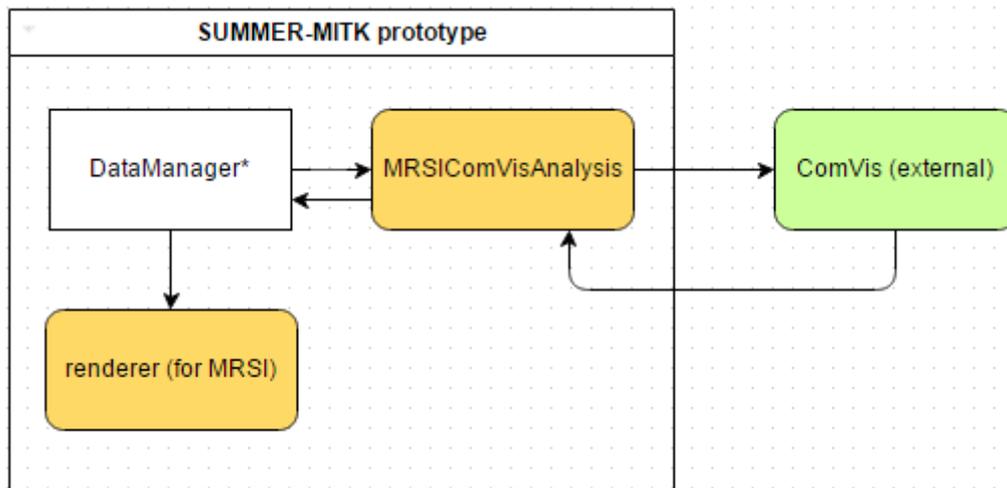


Figure 15: Overview of the relations between *MRSI ComVis Analysis* plugin and the *Renderer*

The plugin uses collapsible panels – see suggestions in Section 2.5.

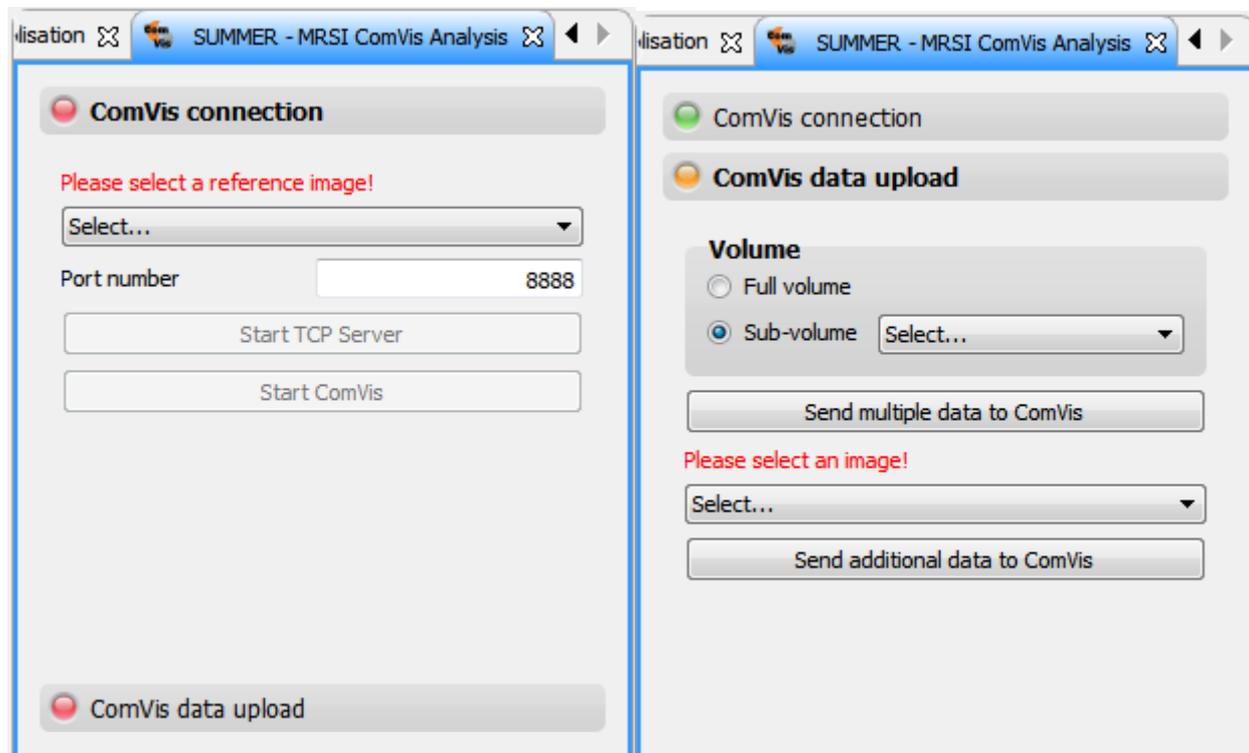


Figure 16: MRSI ComVisAnalysis plugin: left) ComVis connection section, right) Data upload section

- Section “ComVis connection”
 - Instead of using red (implies “error” but the user has not done anything “wrong” yet) it would be more appropriate to have a label “Reference image:” before the dropdown.
 - It is not clear what is expected to be used as a reference image. Use a tooltip which show explanation when hovering over the label or dropdown.
 - After connection is established, the IP address where the connection was done should be shown.
 - It should be possible to stop the TCP Server
 - Problematic situation when a different dataset is loaded – the plugin assumes the TCP Server is not running, but at the same time it is not possible to start it again either.
- Section “ComVis data upload”

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- The data selection for sending to ComVis is not clear. In one hand the user needs to select data from the Data Manager, but also from the dropdown shown in the plugin.
 - The data selection should be limited to one plugin only (either Data Manager of the current plugin). For example, one option would be that the user would select the data to be sent within the plugin only. For example similar checklist could be used as within RTSS plugin. Or a multi-select dropdown could be used. However, this introduced duplication of data within the prototype (both in the Data Manager as well as within the plugin).

3.13 fMRI ComVis Analysis

The fMRI ComVis Analysis plugin is similarly to “MRSI ComVis Analysis”, a plugin for communicating between the ComVis software and the SUMMER-MITK prototype. Possibility to merge these two plugins into one “ComVis connector” should be investigated to eliminate the need to switch between different plugins. The same suggestions apply as for the “MRSI ComVis Analysis”.

3.14 Renderer

Rendered plugin allows advanced visualization of data. It allows visualizing two different volumes. Intended for the use of MRSI based region visualization.

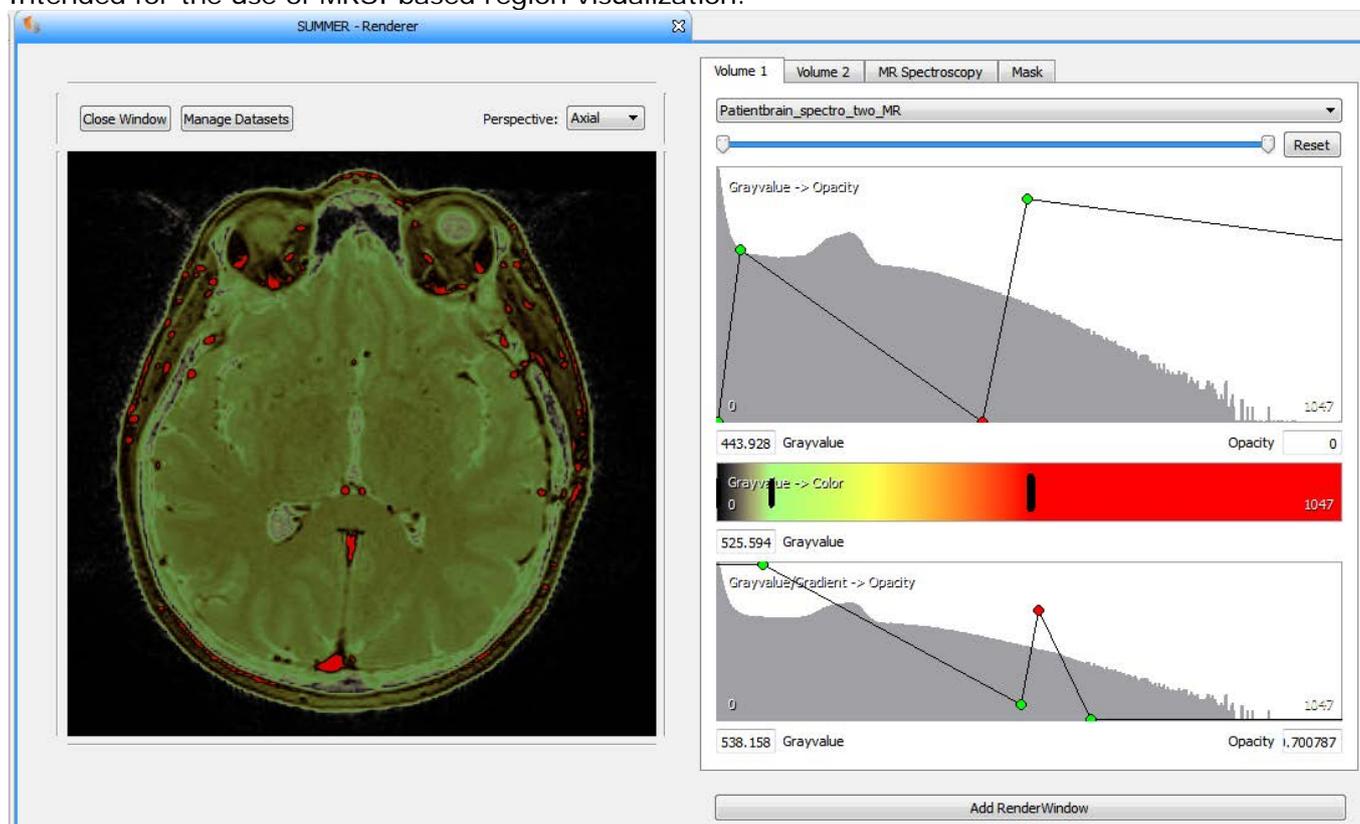


Figure 17: Example screenshot of the renderer plugin

- The value of opacity/greyvalue not always fully visible due to having too many decimal places. Increase the input area size.
- The zooming and panning is with different mouse interactions than MITK. Consistency between different elements would increase usability (e.g. zooming with right-mouse instead of left, panning with middle-mouse instead of right)
- Pre-sets for the (combined) visualization would be useful – e.g. MRI T1 Gado + NAA). Also possibility for the user to save the settings of visualization could be useful.
- “Volume 1” could be named as “Base volume” or “Main image”
- “Volume 2”, “MR spectroscopy” and “Mask” tabs could be merged into one tab “Overlay”. Each of these remaining as one section within the tab.

3.15 DTI Tractography

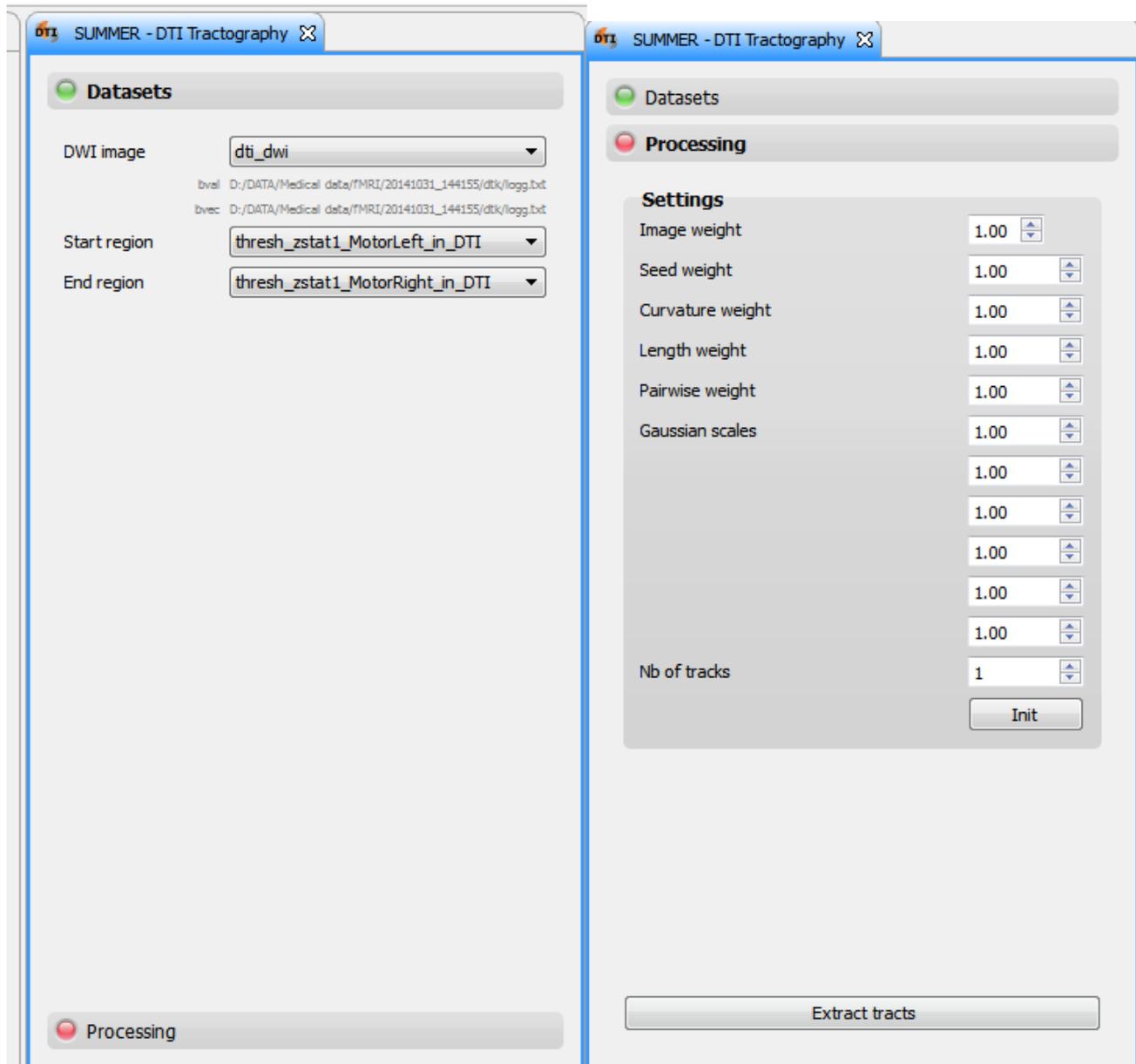


Figure 18: Current plugin for DTI Tractography: Dataset selection (left) and processing settings (right)

- Section “Datasets”
 - The required *bval* and *bvec* files selection should be consistent with similar interactions elsewhere.
 - The file selection should follow the common style with the file icon  with a clearly readable label indicating what file is required.
 - It is good that the user is guided through the selection on files by automatically opening the file selection dialogs.
- Section “Processing”
 - It is not clear why there are numerous *Gaussian scales* inputs. In case they are all needed, there should be a clarifying label for each of them. Otherwise it should be limited to commonly used number and add a possibility to add new elements.
- The collapsible panels are not needed within the plugin – the UI elements could fit without.

D2.3 – Usability Feedback

- Additionally *Advanced* option could be created (e.g. Advanced settings), where the least often needed parameters can be placed. These would then be visible only when the checkbox is checked.
- Information should be provided to the user (e.g. tooltip, help page) on what are the requirements for the dwi data and the bval and bvec files. Further evaluation is needed once correct datasets are available.

Further evaluation was not possible due to lack of test data and documentation.

3.16 fMRI-DTI Visualization

The general suggestion is to critically revise existing tabs – not all are relevant for fMRI/DTI visualization (e.g. “RT Dose”).

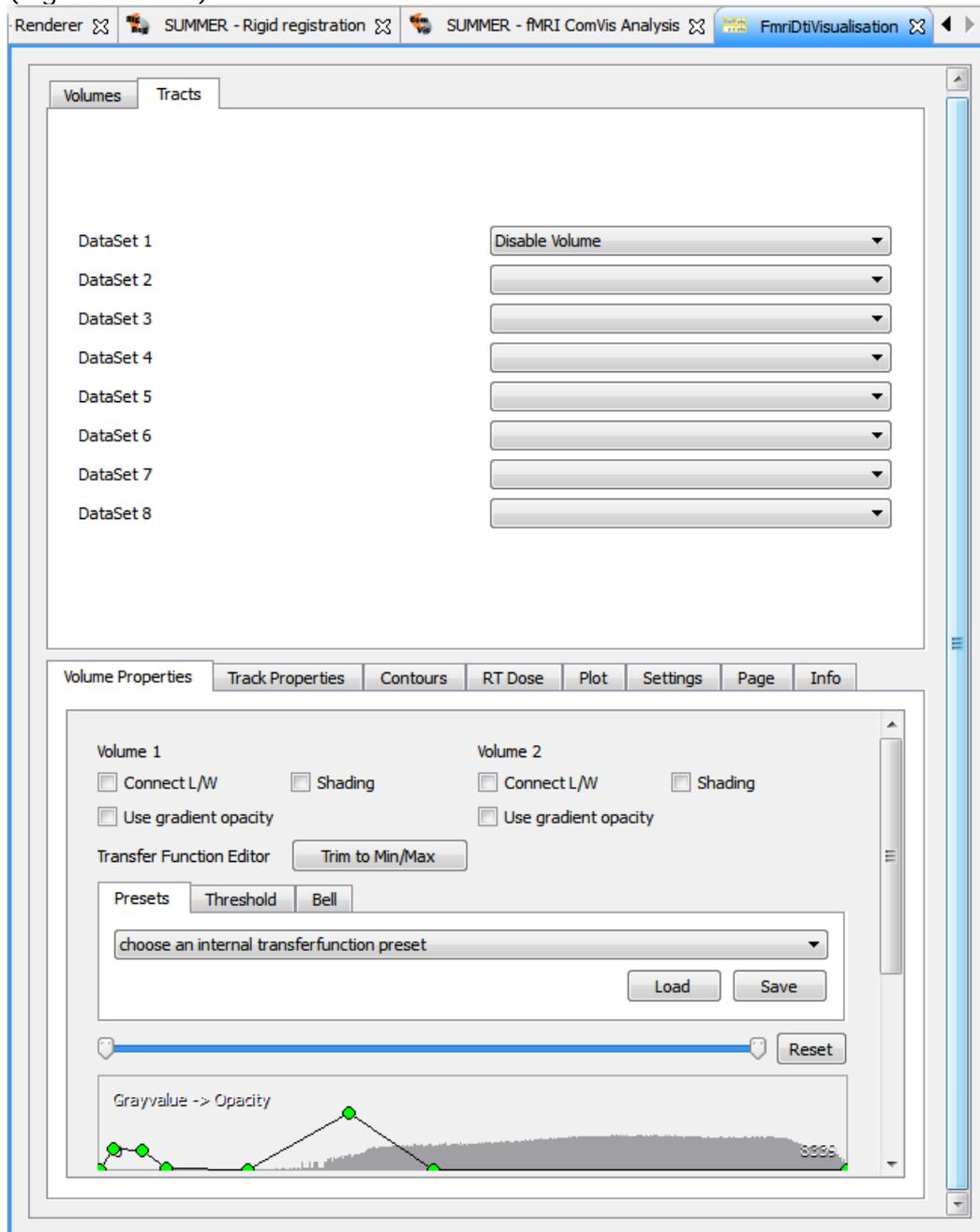


Figure 18: Current plugin of fMRI-DTI Visualization

The intended workflow for DTI track based segmentation is show on Figure 19.

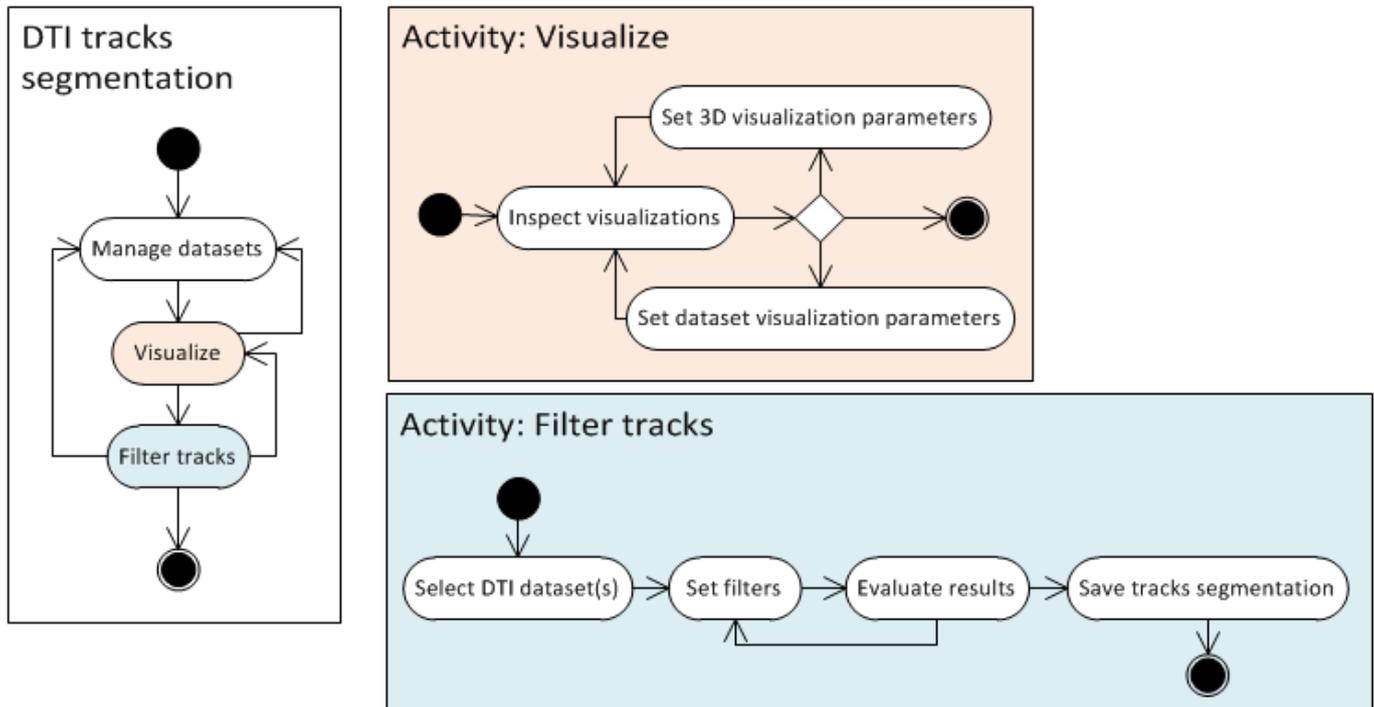


Figure 19: The use flow for DTI tracks segmentation

Additional suggestions of increasing usability:

- “Volume rendering” and “Slice rendering” checkboxes, which replaces the default MITK rendering with new renderers. Suggestion is to rename them as “Replace 3D rendering” and “Replace 2D rendering”.
- Within the tab “Volume Properties” it is not clear to which volume “Volume 1” and “Volume 2” are referring to. Better to indicate the corresponding name of the selected volume, i.e. “Volume: XXXX”.

Due to technical errors it was not possible to conduct further evaluation.

4 Conclusions

The plugins developed within SUMMER-MITK prototype served for specific research purposes. As such, they corresponded to a very narrow task areas within the overall radiotherapy treatment planning workflow (Aselmaa et al., 2013).

During the evaluation of the SUMMER-MITK prototype, it was observed that the maturity level of different plugins varied. Some plugins had been iteratively developed and tested – thus only minor errors occurred. Others were still in development phase and thus at some occasions, we encountered technical problems during evaluation (e.g. software crashing). However, it is expected that a prototype developed during a research project will not reach ready-to-use level of usability. To be able to reach that, much more extensive usability tests would be needed. Furthermore, in addition to heuristic evaluations (Nielsen, 1994), usability testing (Rubin & Chisnell, 2008) with end-users would be necessary.

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