

VIRTUAL GASTROINTESTINAL TRACT VIGOR++

Deliverable: 3.1

Description of the Image Analysis Toolbox 1

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Summary

This document gives a description of the image analysis tools that have been developed for VIGOR++. The tools are part of the image analysis toolbox/library that has been developed to aid in the assessment of Crohn's disease activity. The toolbox is presented here as deliverable 3.1 of the VIGOR++ project.

Introduction

The library contains algorithms encoded in MATLAB that enable quantitative measurement of Crohn's disease features. The algorithms deal with the following MRI analysis problems: (1) identification of the bowel surface; (2) MRI data registration and (3) Colon wall segmentation. The next sections shortly describe each of those algorithms separately.

Description of the algorithms

T1.1 Identification of the bowel surface.

The colonic wall thickness is typically increased with active Crohn's disease. A first step to enable automated measurement of the thickness (see below) is to identify the bowel surface in the MR-images. This is a challenging problem, because the shape varies sharply, the lumen is regularly narrowed in the stenotic parts, and the contrast between wall and lumen is space variant, i.e. it varies along lumen's trajectory due to the varying content (fecal remains) and surrounding tissue (fat, fibrous tissue, etc.).

A semi-automated method was devised that overcomes most of these problems. The post-contrast MRI sequence appeared most suitable for measuring the wall thickness as it combines the best contrast with high resolution. Initially, a centerline is manually drawn by an expert through a part of the bowel suspected of Crohn's activity. Subsequently, a so called level-set representation evolves to match the bowel surface. The level-set is steered by the image information (transitions in intensity) while smoothness constraints restrict its shape. Additionally, it deals with heterogeneities in the lumen by taking measurements along the path. The method proved capable to segment healthy as well as diseased bowel parts, as can be seen in figure 1

The algorithm requires the user to coarsely specify a region of interest that includes a piece of bowel of interest. Furthermore, a set of coordinates need to be given that correspond to points on the bowel's centerline. The outcome of the algorithm is a level set function and a binary image that contains the segmentation of the inner bowel surface. A small MATLAB example script is given below showing the function description and how it could be executed:

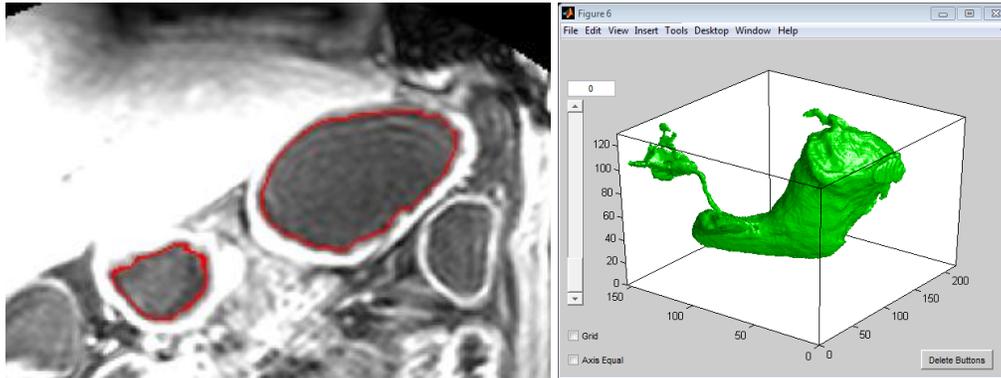


Fig. 1. Example of the bowel surface segmentation: left original data, right 3D surface representation.

```

% [U_lev,T_surface] = BSS1stAnnualReview(I_sub,x_path,n_iter);
%
% Input:
% I_sub: Region of interest in a T1_weighted image of a piece of bowel
% x_path: image coordinates of points on the centreline
% n_iter: number of iterations for the level set algorithm
%
% Output:
% U_lev: Level setfunction
% T_surface: Segmentation of the inner bowel surface
%
% Example Algorithm
% load ExampleROISmallBowel.mat
% [U_lev,T_surface] = BSS1stAnnualReview(I_sub,x_path,50)
% overlay(I_sub,T_surface)

```

T1.2 MRI data registration.

The Time Injection Curves (TICs) obtained from Dynamic Contrast Enhanced MRI (DCE-MRI), are expected to contain important information on the degree of inflammation of the bowel wall. However, respiratory and peristaltic motions complicate an easy analysis of such curves since spatial correspondence over time is lost. Therefore, a gated, 3D non-rigid motion correction method was developed that sustains robust extraction of the time intensity curves from bowel segments.

The algorithm works in several steps: (1) images are selected from the breath-out phase since these contain the least blurring defects; (2) a non-rigid registration (alignment) procedure is adopted to compensate for misalignment, e.g. due to small peristaltic movements; such matching is performed to a position that has a minimum distance to the selected images, so that result is unbiased; (3) the bowel wall is extracted from manually indicated regions of interest.

TICs of ROIs in original, gated and registered data are compared in Fig.2(b)-(d). The red region contains inflammatory bowel wall; the other regions are added for comparison. Notice the particularly smooth TICs of the registered data in Fig.2(d). Clearly, the red curve demonstrates the largest intensity enhancement. A similar phenomenon was found

in regions corresponding to active Crohn's disease in 12 other subjects. This may reflect that the inflammation information could be distinguished by the TICs after our registration procedure.

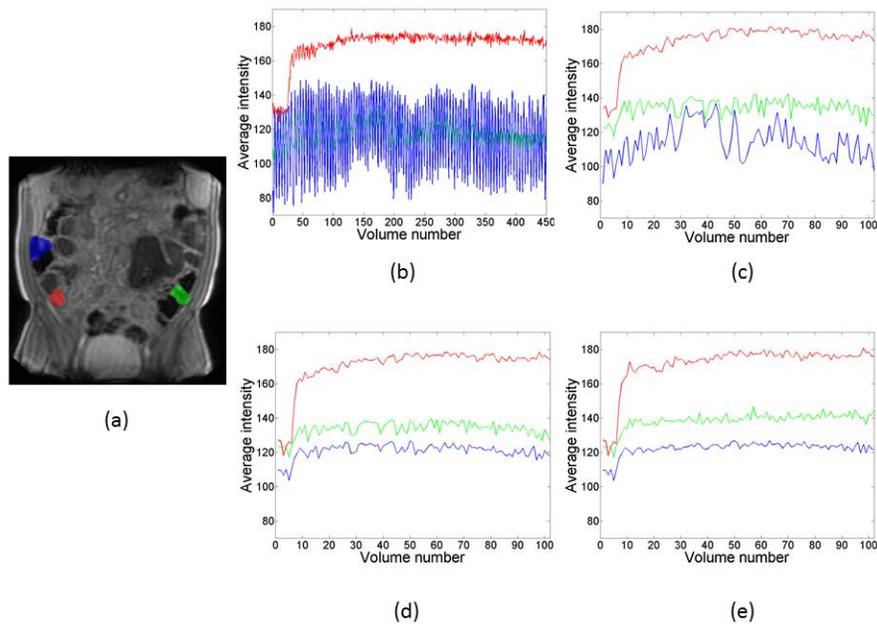


Fig. 2. The TICs of a ROI. (a) is the annotated data, the red region contains a bowel segment affected by Crohn's disease. (b) - (d) show the TICs of original data, gated data and registered data (notice the reduced number of volumes in the gated dataset). (e) is a constructed TIC 'ground truth' image.

The abovementioned algorithms are packaged in one main MATLAB function. The code uses of a publically available image registration toolbox: Elastix [1]. The function description in MATLAB code is:

```
function MMR(inDir,outDir)
% load Dicom image from path
[imnew,x,y,z,info]=Load_Dicom4D(inDir);
Resolution=[x,y,z];
% save the original image
im=make_nii(imnew,Resolution);
imname=strcat(outDir,'Raw.nii');
save_nii(im,imname);
% Build the breath-out atlas
[BreathOut,AverageImg,AllTransX,index]= ...
    BreathOut_Atlas(imnew,Resolution);
% Export nii for Elastix
Export_nii(BreathOut,Resolution,outDir);
% save the atlas
Ave=make_nii(AverageImg,Resolution);
Average=strcat(outDir,'Average.nii');
save_nii(Ave,Average);
system('4D-nonrigid-new.bat')
```

The acronym ‘MMR’ stands for Mono-modality Registration. It has two input variables: ‘inDir’ is the DCE-MRI DICOM file directory; ‘outDir’ is the directory of the registered DCE-MRI images in the breath-out phase. Initially, the data is loaded from ‘inDir’. Subsequently, the breath-out atlas image is calculated and saved. The breath-out phase images are selected and saved as well. Then, both atlas image and breath-out images are sent to the ‘elastix’ registration toolbox for an unbiased registration procedure. Finally, the registered results are saved in ‘outDir’.

The post-contrast images facilitate measurement of colonic wall thickness, which is typically increased with active Crohn’s disease. As such, these images contain complementary information to DCE MRI. A non-rigid registration procedure was devised to match the DCE data to the post-contrast MR images to achieve correspondence. This algorithm proceeds from coarse to fine registration and matches based on the so-called mutual information. This metric sustains a comparison of different contrasts. Typical results are shown in Fig.3.

The algorithm of this procedure is also packaged in one Matlab function:

```
function MULMR(DCE_inDir, THRIVE_inDir, Annotation_inDir)
% Load data
imDCE = Load_Result(DCE_inDir);
[imTHRIVE, xv, yv, zv] = Load_Dicom3D(THRIVE_inDir);
% Load annotation
LoadAnnotation(imDCE, imTHRIVE, Annotation);
% Doing registration
system('3D-nonrigid');
```

The acronym ‘MULMR’ stands for Multi-modality Registration. It has three input variables; ‘DCE_inDir’ is the directory of the registered DCE-MR images in the breath-out phase, ‘THRIVE_inDir’ is the directory of post-contrast (THRIVE) images and ‘Annotation_inDir’ is a region of interest(ROI) annotated by an expert. The registration is done in a window centered around the ROI. The non-rigid registration is also performed by the ‘elastix’ toolbox.

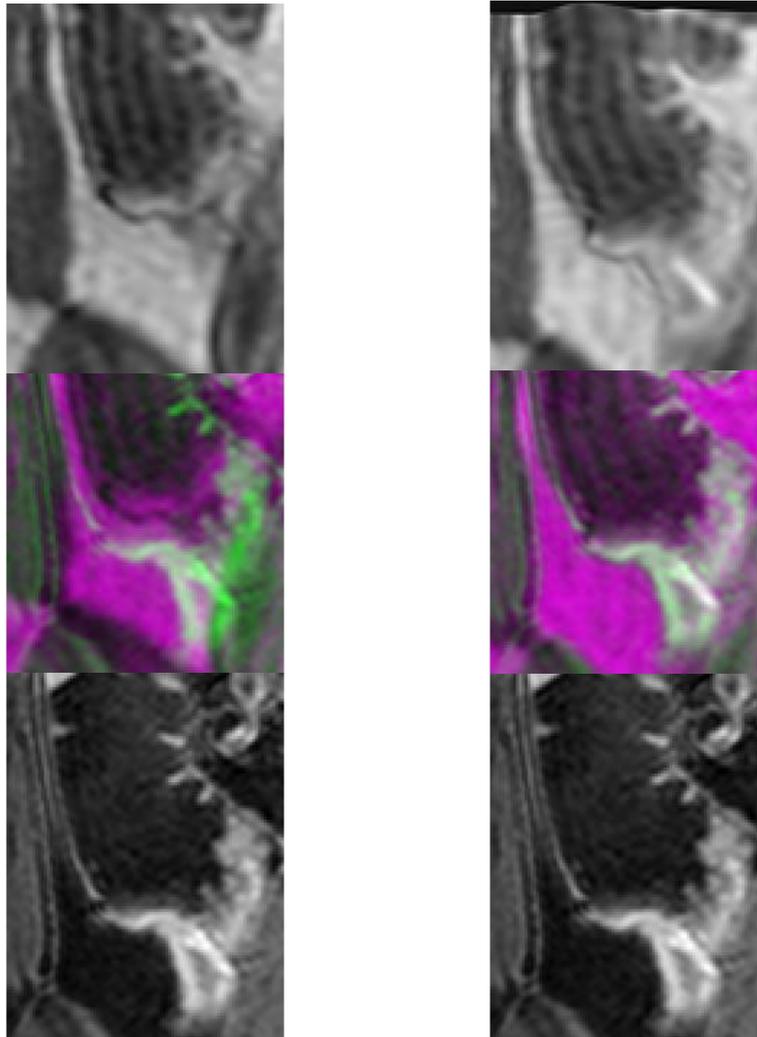


Fig. 3. Example of the DCE to post-contrast image registration. The DCE image (top) is encoded in the red and blue channels (middle); the post-contrast image (bottom) in the green channel (middle). Left is prior to, right after registration.

T1.3 Colon wall segmentation [TUD, ETHZ, B3D].

A method was developed for colon wall segmentation that assumes an accurately segmented colon surface (see T1.1). Subsequently, 1D profiles of image intensities are recovered in sampled surface points by stepping in either direction perpendicular to the surface. These intensities are modeled as a sum of step functions that reflect transitions in signal from lumen to colon wall and colon wall to surrounding tissue. Additionally, it is asserted that the step functions are convolved by Gaussians representing the MRI scanner's Point Spread Function. The wall thickness is simply retrieved from the parameters of the fitted model, i.e. the distance between the step functions.

A representative result is shown in the next figure:

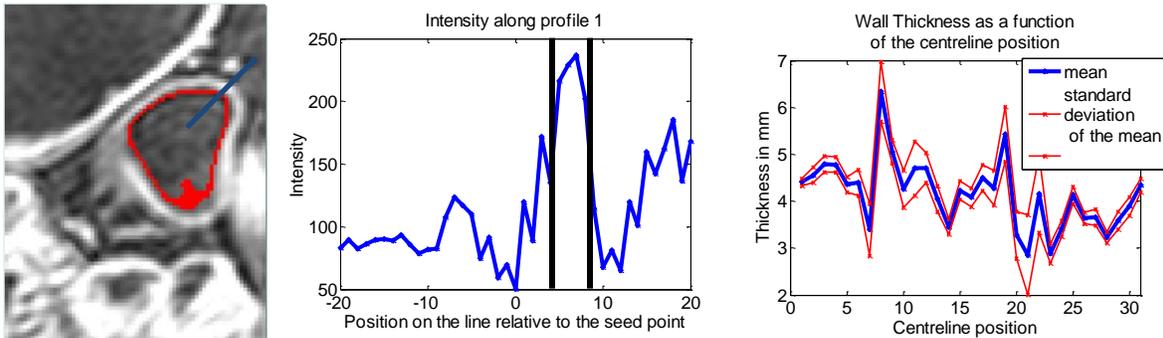


Fig. 4. Part of the colon surface (left) and profile along which intensities are sampled (middle) to retrieve the local wall thickness. The right image shows the wall thickness as a function of position along the centerline.

The algorithm requires the following input variables: A region of interest of a T1 weighted MRI image, a binary image that contains a surface segmentation, the level set function and an image that links the bowel surface points to a point on the centerline. The outcome consists of a vector of thickness estimates, an image that depicts the points on the inner surface and the outer surface, an image that gives the thickness at the position of the input surface segmentation and a vector that gives the average thickness as a function of the centerline location. The MATLAB function description and a small, example script is given below:

```
% [t,T_thick,T_wall,t_reg] = ...
%     WallThick1stAnnualReview(I_sub,U_lev,T_surface,L_nd)
% input:
%   I_sub: Region of interest of a T1_weighted image of a piece
%         of bowel
%   U_lev: Level function
%   T_surface: Segmentation of the inner bowel surface
%   L_nd: An image that labels the bowel surface points to a point
%        on the centerline
% output:
%   t: A vector that contains the thickness at all coordinates given
%     by the input surface image
%   T_thick: The thickness at the coordinates given by the input image,
%           the difference is that this is an image
%   T_wall: An image that contains the inner (value = 1) and outer
%          (value = 2) surface points
%   t_reg: A vector that gives the average thickness as a function
%         of the centerline position
% Example algorithm
% load ExampleWallThicknessInputData
% [t,T_thick,T_wall,t_reg] = ...
%     WallThick1stAnnualReview(I_sub,U_lev,T_surface,L_nd)
```

Conclusion

This document described the MRI analysis algorithms, that are part of the image analysis toolbox of VIGOR++. The semi-automatic bowel surface segmentation algorithm produces reliable segmentation results both on healthy and pathological bowel parts. The colon wall segmentation utilizes the bowel surface segmentation as initialization to find points on the outer surface. The registration procedure compensates for the motion in free-breathing DCE-MRI data. The procedure proved to deal efficiently with peristalsis and breathing motion. Another efficient registration procedure was also developed to match the DCE scans to the post-contrast MRI data.

We would like to reserve some time in the next year to fine tune and evaluate the colon wall segmentation algorithm as well as the registration technique.

Reference

- [1] Klein, S., Staring, M., Murphy, K., Viergever, M., Pluim, J.: elastix: a toolbox for intensity based medical image registration. *IEEE Trans. Med. Imaging* 29, 196–205(2010)