Segmentation solutions for clinical imaging applications

Impact case, Smedby group

1. Summary of the impact

In clinical medicine, there is a great need for image-based measurement tools to assess the degree of disease. Often these require delineation of an anatomical structure (segmentation). Our group has developed and patented an automated segmentation method that is both accurate and fast enough for clinical use. It has been tested with image data from vessels, tumours and brain structures and shown good agreement with manual segmentation by experts. It has great potential for clinical use in early diagnosis, e.g. in cardiovascular or neurodegenerative disease, and for evaluation of therapy, e.g. in cancer.

2. Underpinning research

In a situation with a growing number of available treatments, but limited resources for health care, the diagnostic process is more important than ever. In order to select the optimal treatment for each patient and to evaluate the effect of treatment given, there is a great need for quantitative measures of the degree of disease. Developing such quantitative measures from medical imaging (often called imaging biomarkers) is the main theme in the research carried out in Örjan Smedby’s research group, which recently moved from LiU to KTH.

In most cases, the image data are 3D representations of the human anatomy (voxel data) from sources like Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). Typically, the measures (volumes, areas etc.) require some anatomical structure to be delineated in the image (segmentation). Today’s commercial clinical workstations use a variety of algorithms for segmenting anatomical structures, but the performance in terms of accuracy and speed is usually far from satisfactory. One of the most accurate segmentation algorithms currently available is the level sets method, which offers sub-voxel precision, but for voxel data it has until now been far too time-consuming, even on top-of-the-line computers, to be practically useful in clinical routine.

After first working on improving more traditional segmentation methods [B56], our group invented in 2011 a novel way of performing level sets segmentation (coherent propagation), which avoids counterproductive repetitions and speeds up the process by 10–100 times [A82, B73]. This enables interactive use of the method with voxel data. It can even be used completely interactively, so that a complete 3D segmentation is obtained interactively while the operator draws a line in the image with results in close agreement with time-consuming manual segmentation slice by slice [A96].

To evaluate the algorithm, we have taken part in a series of “Grand Challenges in Biomedical Image Analysis”, i.e. competitions where different research groups’ algorithms are run in parallel on the same, previously unseen, image data using manual segmentation by experts as the reference standard. The results indicate that our method compares favourably with alternative algorithms. Currently (Febr. 2016), our multi-organ segmentation method is ranked 1st for kidney and urinary bladder segmentation in contrast-enhanced images in the VISCERAL challenge, and among the best for several other organs. In the coronary artery analysis challenge, our skeleton-based vessel segmentation is ranked 2nd for stenosis quantification. Our automated brain segmentation is ranked 11th among 31 teams in the brain MRI segmentation challenge.
3. References to the research

Publications


Related grants

<table>
<thead>
<tr>
<th>VR-NT</th>
<th>Vascular segmentation at interactive speed</th>
<th>1000 kSEK/year</th>
<th>2012–14</th>
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<tbody>
<tr>
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<td>Fast vascular segmentation: skeleton-guided level sets combined with machine learning</td>
<td>800 kSEK/year</td>
<td>2015–17</td>
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<tr>
<td>Hjärtlungfonden</td>
<td>Improved CT diagnosis of coronary artery disease</td>
<td>400 kSEK/year</td>
<td>2009–11</td>
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<td></td>
<td></td>
<td>500 kSEK/year</td>
<td>2012–16</td>
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4. Details of the impact

Active contours can be seen as a rubber band in 2D or an elastic balloon in 3D, and the image segmentation using active contours is similar to stretch the rubber band towards the object border with some external force related to the image information (e.g. intensity), while the internal elastic force try to keep the contour smooth. The object’s contour can be represented explicitly as 2D curves or 3D meshes, but in the level-set method, it is represented by a dynamic implicit function (level set function), which is usually a signed distance function. By iteratively evolving this function according to external and internal forces, the 0-level set can be deformed to the shape of the object of interest. This evolution can be expressed by a partial differential equation (PDE) designed to minimise an energy function driven by external and internal forces. The external forces attract the contour towards the boundary, while the internal forces keep the contour smooth.
Due to noise and numerical errors, the propagation front will almost inevitably assume a zigzag shape. The faster points in the neighbourhood (point 2 and 4 in Fig. 1A) will be “pulled back” by the curvature force in the next iteration, even if the trend of the local segment is to move forward when the neighbour points catch up. This temporary backwards propagation slows down the propagation significantly.

![Figure 1. A: Example of temporary backwards propagation. B: Coherent propagation. The arrow indicates the global propagation trend, the gray line is the current contour, and the dashed line is the contour after one iteration.](image)

With coherent propagation, on the other hand, the speed of these points is set to zero and they are “put to sleep” [B73]. This clearly results in a small overshoot error for most parts of the contour. A periodic forward and backward propagation is then needed to compensate for these errors, and a criterion formulated for terminating these periods. The new method has been tested in a number of CT and MRI images from various anatomical regions, and the execution time was reduced by a factor between 10 and 100 compared to earlier implementations of the level sets algorithm [A82, B73].

In applied studies, we have tested the usefulness of our segmentation methods in a clinical situation [A72] and proposed new ways of integrating the novel techniques into the IT systems handling image data in a clinical environment (the Picture Archiving and Communication System, PACS) [A64, A59]. Collaborations have been initiated with three groups of clinical partners, i.e. prospective end users.

To ensure possibilities of disseminating the outcome of the research via commercial channels, patent applications were submitted before publishing the new segmentation methods (see below). Patents have now been granted in Sweden, the European Union and the US, and indications from the Chinese patent authority have so far been encouraging. A company has been formed: Novamia AB, which currently owns all patents.

The lead users of the technique are expected to be established vendors of medical image processing equipment. Since Novamia AB does not have the resources to undertake the certification process for medical products, its main business idea is to license, on a non-exclusive basis, the algorithms to companies interested in including it in their clinical image processing workstations. So far, deals have been concluded with two customers, one Swedish and one international.

As end users we envisage clinical radiologists, cardiologists, oncologists, geriatricians and internal medicine specialists who are in need of measurement tools for their daily work with patients. This is relevant both for selecting the optimal treatment for each individual patient (personalised medicine) and for evaluating the effect of treatment, either in the individual patient or for larger patient cohorts in clinical trials. For thoracic and vascular surgeons as well as tumour surgeons, the tools may also become useful for surgical planning.
5. Sources to corroborate the impact

*Publications*


*Patents*


*Clinical partners*

Geriatrics Dept. at Karolinska university hospital Huddinge: Lars-Olof Wahlund, Senior Consultant and Professor of Geriatrics at Karolinska Institute.

Oncology Dept. at Karolinska university hospital Solna: Rolf Lewensohn, Senior Consultant and Professor of Oncology at Karolinska Institute.

Neuroradiology Dept. at Karolinska university hospital Solna: Patrik Ring, Senior Consultant in Neuroradiology.

*Other sources*

Novamia webpage: [http://www.novamia.com](http://www.novamia.com)

Interview with [Hjärtlungfonden](http://www.novamia.com).