The University of Hull

Department of Computer Science

Project Topic Analysis

Medical Image Segmentation using Immersive Visualization

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1 Scope and Context

Nowadays virtual reality plays an important role in the medical field, being integrated in simulators in order to train, help surgeons gain a better understanding of the acquired data and prepare for surgical interventions. Such data mostly comes from radiology such as MRI (Magnetic Resonance Imaging) scans. The latter is particularly advantageous as it is a safe technique (as opposed to the harmful ionising radiations of CT scans).

To help specialists understand the contents of the data, an essential process is the segmentation of this data. It consists of determining the boundaries of the different objects in an image (differents regions of the brain, distincts bones in the hand, etc...) so that the user can interact (e.g. plan surgery) more easily with patient data.

A lot of techniques and algorithms have been developed over the past 30 years for segmenting 2D image maps (many not necessarily aimed at the medical field), and the common point of all these techniques is their suitability to only a certain type of problem and well-defined family of images. No unified working theory of image segmentation exists. More recently, some attempts have been made to develop complex segmentation tools allowing real time 3D image segmentation, often making use of immersive environments [Senger 2005; Vidholm et al. 2004; Vidholm and Agmund 2004; Harders and Székely 2002].

There is currently no intermediate solution: the majority of the tools that perform 2D slice-based segmentation uses classic environments (i.e. a computer screen, a keyboard and a mouse).

The hypothesis of this MSc research work is the suitability of the use of an immersive environment to improve (both in terms of accuracy, speed and user experience) classic 2D slice-based image segmentation techniques.

The equipment platform for this research will make use of a *Reachin Display*, formed of a 6 DOF *Phantom* haptic stylus and a stereo vision system with VR glasses and a mirror to colocate haptics and graphics.

In Section 2, a brief overview of the background knowledge required for the project will be followed by a discussion on the relevancy of choosing to work with 2D rather than with 3D segmentation. The aim and different objectives of the project will be exposed in Section 3. Section 4 will describe with more details the proposed research methodology. Eventually, Appendix A will suggest a time plan for the research work in the course of the year.

2 Project Background and Discussion

Image segmentation is a vast and constantly evolving field. Consequently a good background knowledge is required before undertaking this research project. This section will first introduce a very general mathematical definition of image segmentation. It will then attempt to give a consistent classification of the different existing segmentation techniques. The project emphazises on the gap existing between 2D and 3D segmentation techniques and tools, therefore the discussion in Section 2.3 provides the justification and relevancy of the project.

2.1 A mathematical definition of image segmentation

The following is a very general definition of image segmentation [Spirkovska 1993]. It uses an homogeneity predicate $P()$ that helps formalizing the notion of homogeneity in an image: a region R is homogeneous if and only if $P(R) = True$. Therefore, the homogeneity can be defined in an infinity of different ways: on the grey levels, on the textures or even on non-obvious properties of the image...

Definition 1 (segmentation) *Let I be the set of pixels (the input image) and P() the homogeneity predicate defined on groups of connected pixels.*
A segmentation S of I is a partitioning set of image regions $\{R_1, R_2, \ldots, R_n\}$ *such that*

$$\bigcup_{i=1}^{n} R_i = I \text{ and } R_i \cap R_j = \emptyset \ \forall\ i \neq j \tag{1}$$

and such that the homogeneity predicate P() satisfies

$$P(R_i) = True \ \forall\ i \tag{2}$$

$$P(R_i \cup R_j) = False \ \forall\ R_i \text{ adjacent to } R_j \tag{3}$$

$$(R_i \subset R_j) \wedge (R_i \neq \emptyset) \wedge (P(R_j) = True) \Rightarrow (P(R_i) = True) \tag{4}$$

Equation 1 is a mathematical definition of a partition: the union of all the regions form the whole image and all the regions are distinct. Equation 2 means that the homogeneity predicate is valid on every region. Equation 3 means that the union of two adjacent regions cannot satisfy the homogeneity predicate, i.e. two adjacent regions *must* be distinct regarding the homogeneity predicate. Finally, Equation 4 means that the homogeneity predicate is valid on any sub-region of a region where it is verified.

2.2 A classification of different segmentation techniques

There are numerous types of classifications proposed in the specialized literature [Haralick and Shapiro 1985; Spirkovska 1993], each of which is pertinent respectively to the point of view required by the study. However, the most common classification in papers divides the different techniques into three main families of algorithms:

- *pixel based* techniques (also known as *histogram thresholding*);
- *edge based* techniques;
- *region based* techniques.

This classification is not unique but has the advantage of being simple yet complete.

The pixel based family is probably the most simple family of techniques. It basically consists of finding an acceptable threshold in the grey levels of the input image in order to separate the object(s) from the background. It is often referred to as *histogram thresholding* since the grey-levels histogram of an ideal image will clearly show two distinct peaks similar to Gaussians (which can be obtained by applying a filter to the image) representing the distribution of grey levels for one object and its background. This kind of histogram is sometimes referred to as *bimodal*.

The edge based family of techniques tries to detect edges in an image so that the boundaries of the objects can be inferred. The most simple method of this type is known as *detect and link*: the algorithm first tries to detect local discontinuities and then tries to build longer ones by connecting them, hopefully leading to closed boundaries which circumscribe the objects in the image. The main disadvantage of this technique lies in the fact that, depending on the quality of the input image, the algorithm is not guaranteed to produce closed edges, thus not allowing to sharply split the image into regions. Some improvements over this method have been proposed in order to overcome this type of issue [Yanowitz and Bruckstein 1989; Parker 1991].

The region based family of techniques basically aims at iteratively building regions in the image until a certain level of stability is reached. The region growing algorithms start from well chosen seeds (usually defined by the user). They then expand the seed regions by annexing their homogeneous neighbours. The process is iterated until all the pixels in the image have been classified. The region splitting algorithms use the entire image as a seed and splits it into regions until no more heterogeneity can be found. An algorithm that associates the advantages of both methods, called the *Split, Merge and Group* (SMG) algorithm, has been developed [Horowitz and Pavlidis 1976].

2.3 Comparison between 2D and 3D techniques

Until fairly recently, image segmentation was entirely dedicated to 2D images. A lot of pseudo-general techniques as well as very specific techniques have been developed to improve the segmentation of 2D image maps.

3D segmentation is therefore a relatively new field of research. One could naïvely think that, to segment a 3D image map (made up of voxels while a 2D image map is made up of pixels), the only thing you have to do is take a 2D algorithm and basically extend it to 3D space. This is generally not true. 3D techniques are not a simple extension of 2D techniques.

While in 2D segmentation a lot of approaches exist (see Section 2.2), the main approach used in 3D segmentation is the region based segmentation (region growing or region splitting algorithms). Edge based techniques do not have any efficient equivalent in 3D yet.

The main issue when working with a full 3D environment is the graphical representation, first of the raw input data (a voxel map), then of the segmented result (surfaces). *Texture mapping* is usually used to render the 3D data in a meaningful way. It is a powerful yet technically demanding technique, and its implementation can become very complex. Similarly, surface rendering is not a trivial task. Last but not least, the conception and implementation of an ergonomic 3D user interface is, in itself, a huge amount of work since both programmers and users are used to manipulating 3D objects in 2D based environments.

For all of these reasons, it is argued that the development of a fully 3D integrated environment would be time consuming and not necessarily worth it. The main interest of the project, as stated in Section 1, is to focus on the integration of haptics rather than dealing with graphical problems.

Furthermore, there may be vital lessons learnt for 3D segmentation by first having a good understanding of the issues, problems and potential solutions in developing haptic-aided 2D segmentation. Hopefully, most of the understanding in 2D segmentation will also be applicable to 3D segmentation.

3 Aims and Objectives

The aim of the project is to test the suitability of the use of haptics to 2D based segmentation, to investigate whether it can bring visible improvements to what already exists. The project in itself can be split up into a set of objectives, the results of which, together, will help verify, or invalidate, the hypothesis.

1. Select a set of suitable 2D segmentation techniques. These techniques will then be implemented in the tool. They must be carefully selected for their relevance and their potential aptitude to integrate haptics.
2. Identify a set of possible uses of haptics and map them onto the previously selected segmentation techniques.
3. Develop the tool that will integrate both a convenient user interface and the haptically enhanced segmentation algorithms.
4. Evaluate the results by defining an evaluation framework. This framework will have to allow comparisons at different points of view and a real valuation of the improvements and/or drawbacks of the tool and compare with existing segmentation techniques.
5. Propose how haptic-aided 2D segmentation tool might be extended to 3D.

All of these objectives (except for the last one) are obviously tightly linked. Therefore, they must be seen as a whole, and the fulfilment of each of them will contribute to the overall aim of the project.

4 Proposed Research Methodology

This section describes with more details the proposed methodology that will be used during the project to fulfil all of the objectives defined in Section 3.

4.1 Mapping haptic behaviours with specific algorithms

This is probably the most important part of the initial exploratory phase of the project. Once the segmentation algorithms have been chosen (2 or 3 is a realistic number), it is necessary to study the possible ways to integrate haptics into them. Basically and very generally, the haptic device can be used in four different manners. It can:

- help the user *feel* the input and/or output data in a passive way (i.e. the tactile force depends on the values and the gradients in the image);
- guide the segmentation process according to some pre-computed decisions;
- make the haptic interaction control one or more of the input parameters of the algorithms, allowing the user to intuitively modify them;
- allow him to inspect the result, and possibly to manually edit it.

All these possibilities can of course be combined, and the aim of this phase is to determine which combinations are to be made and how they will technically be implemented. The final aim is to dramatically improve the user experience, not to bother him with a complicated and non-ergonomic tool.

4.2 Immersive environment

As stated in Section 4.1, the ergonomy of the user interface of the tool is critical. The interest of the immersive environment mainly depends on the reliability of the user interface.

Ideally, before even thinking of starting to implement the environment, everything should be conceived and defined in detail to make sure everything is going to fit perfectly and all the components of the immersive environment will interact as anticipated. However, this ideal approach is not really realistic since using haptics is hard.

Therefore the process of the design of the immersive environment may take an iterative approach to help make decisions. The production of a complete tool might need to do quite a lot of iterative experimentation and testing.

This implies the choice of a suitable graphical toolkit that will integrate with both the graphics and haptics libraries used.

4.3 Validation and testing

The validation phase aims at evaluating the benefits obtained compared to standard tools and segmenting environments.

In order to carry out this task efficiently, a framework of precise comparison points will be defined as well as an objective way of numerically evaluating these points. The developed tool together with other selected tools (e.g. *Amira*'s segmenter) will be submitted to this series of tests, ideally with a set of different involved users, to make the validation process as meaningful as possible.

The results of the validation process will be used to tune the developed environment in order to make it as efficient as possible, and, insofar as it is possible, the defects will be eliminated.

4.4 Expanding work to 3D

Eventually, and if all the previous results are encouraging, the feasibility of expanding the developed tool to a full 3D environment will be studied. The point is not to develop a new tool from scratch but really to use as much as possible what will have been done previously and to adapt it, hopefully revealing interesting novel approaches to 3D segmentation.

This phase fully depends on the previous work and is not assured to produce any usable results. It will be undertaken only if time allows it, and the expected result would be a detailed proposal for the conception of such a tool rather than the tool in itself.

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A Time Plan

Here is a list of all the tasks of the project and a Gantt chart showing the progress of the work in the course of the year:

1. Documentation research
2. Preliminary research
3. Project Topic Analysis
4. Library Skills Module
5. Familiarization with tools and APIs
6. Specification of how to integrate haptics into segmentation
7. Development of immersive environment to provide haptic-aided segmentation
8. Mid-year report
9. Validation framework
10. Proposal for expanding tool to 3D
11. Poster
12. Draft thesis
13. Thesis
14. Presentation and demonstration