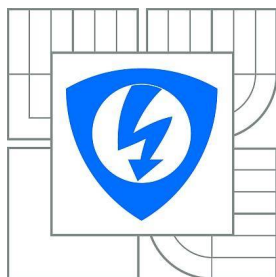


VYSOKÉ UČENÍ TECHNICKÉ BRNĚ  
BRNO UNIVERSITY OF TECHNOLOGY



FAKULTA ELEKTROTECHNIKY A  
KOMUNIKAČNÍCH TECHNOLOGIÍ  
ÚSTAV TELEKOMUNIKACÍ

FACULTY OF ELECTRICAL ENGINEERING AND  
COMMUNICATION DEPARTMENT OF TELECOMMUNICATIONS

## Automatická segmentace medicínských dat s pomocí algoritmu Level Set

BAKALÁŘSKÁ PRÁCE

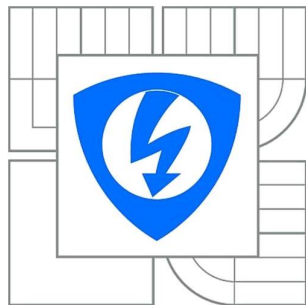
AUTOR PRÁCE  
AUTHOR

SERIK YERPEISSOV

VEDOUCÍ PRÁCE  
SUPERVISOR

Ing. VÁCLAV UHER

BRNO 2014



VYSOKÉ UČENÍ  
TECHNICKÉ V BRNĚ

Fakulta elektrotechniky  
A komunikačních technologií

Ústav telekomunikací

# Bakalářská práce

bakalářský studijní obor  
**Teleinformatika**

*Student:* Serik Yerpeissov *ID:* 133055  
*Ročník:* 3 *Akademický rok:* 2014/2015

**NÁZEV TÉMATU:**

**Automatická segmentace medicínských dat s pomocí algoritmu Level Set**

## POKYNY PRO VYPRACOVÁNÍ:

Nastudujte si algoritmus Level Set pro segmentaci obrazu. Následně využijte poloautomatický algoritmus Level Set z knihovny Fiji a doplňte ho o automatickou volbu nastavení a počátečního bodu. Výsledek otestujte na demostračním snímku.

## DOPORUČENÁ LITERATURA:

[1] BROX, Thomas; WEICKERT, Joachim. Level set based image segmentation with multiple regions. In: Pattern Recognition. Springer Berlin Heidelberg, 2004. p. 415-423. [2] ENRIGHT, Douglas, et al. A hybrid particle level set method for improved interface capturing. Journal of Computational Physics, 2002, 183.1: 83-116. [3] [http://fiji.sc/Level\\_Sets](http://fiji.sc/Level_Sets)

*Termín zadání:* 23.9.2014 *Termín odevzdání:* 16.12.2014

*Vedoucí práce:* Ing. Václav Uher

*Konzultanti bakalářské práce:*

**doc. Ing. Jiří Mišurec, CSc.**  
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V Brně .....

.....

(podpis autora)

# Poděkování

Děkuji vedoucímu práce panu ing. Václavu Uheru za velmi užitečnou metodickou pomoc a cenné rady při zpracování bakalářské práce, za odborné vedení, konzultace, trpělivost a podnětné návrhy k práci.

V Brně dne .....

.....podpis autora

## **ABSTRAKT**

Práce se skládá ze dvou hlavních částí, části teoretické a realizační. V teoretické části jsou popsány jednotlivé segmentační metody. Zejména jde o metodu Level Set. V realizační části bylo za úkol vytvořit java modul pro segmentaci medicinských dat pomocí metody Level set. Práce řeší jednoduchého Gui pro ukázkou dosažených výsledků. Výsledek musí být otestován na poskytnutých datech a ověřena jeho přesnost v porovnání s člověkem. Při nedostatečné přesnosti implementuje další post-processing.

## **KLÍČOVÁ SLOVA**

Level set, Java, ImageJ, Segmentace, Eclipse

## **ABSTRACT**

This thesis contains two main parts, theoretical and implementation. In the theoretical part, there are described the different segmentation methods. Mainly it is about description method Level Set. The aim of practical part is creation of java module for segmentation of medical data by using Level Set Methods. The work solves example of GUI for the display of results. The results should be tested

## **KEYWORDS**

Level set, Java, ImageJ, Segmentation, Eclipse

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# Introduction

An achievement of modern medicine demonstrates how to use technological progress in practice. Using medical imaging systems, for example Computer Tomography (CT) or Magnetic Resonance (MR), doctors can investigate the problem from the inside, without a single cut with a scalpel. These devices generate image data describing the structure and properties in the investigated part of the human body.

Image segmentation is the task of splitting a digital image into one or more regions of interest. It is a fundamental problem in computer vision and many different methods, each with their own advantages and disadvantages, exist for the task. Image segmentation is a particularly difficult task for several reasons. Firstly, the ambiguous nature of splitting up images into objects of interest requires a trade off between making algorithms more generalized or having many user specified parameters. Secondly, image artifacts such as noise, inhomogeneity, acquisition artifacts and poor contrast, are very difficult to account for in segmentation algorithms without a high level of interactivity from the user.

In this thesis, segmentation by Level set Method is discussed in a medical imaging context however the proposed algorithm could equally be used in general purpose segmentations. Segmented images are typically used as the input for applications such as classification, shape analysis and measurement. In medical image processing, segmented images are used for studying anatomical structures, diagnosis and assisting in surgical planning. Before computational algorithms existed, segmentation of medical images was a tedious process, performed by hand by clinical experts. This was a fairly accurate, yet slow process. These expert segmentations form the gold standard with which to validate algorithmic segmentations.

# 1 IMAGE SEGMENTATION

Objects need to be separated from the rest of the image, this is the first step in image analysis which is the task of “image segmentation”. Image segmentation is a long standing problem in computer vision. Segmentation means organizing image content into semantically related groups which are connected. In other words, to each pixel of the picture is assigned an index of the segment which expresses a particular object in the image.

Some of the practical applications of image segmentation are:

- Medical imaging
- Object detection
- Recognition Tasks
- Machine vision
- Content-based image retrieval
- Traffic control systems

Allocation of boundaries of different algorithms should lead to the same result, but since segmentation affects by large number of different factors, none of the algorithms does not provide sufficiently accurate information about the boundaries and areas. Segmentation is usually not used alone, but as part of a system (for example, machine vision systems), so the quality of the algorithm is evaluated on the basis of the work of the whole system, the same segmentation algorithm may be good for one task and bad for others.

Image segmentation  $f(x, y)$  is divided into sub images  $R_1, R_2, R_3, \dots, R_n$  that perform the following functions:

$$\bigcup_{i=1}^n R_i = f(x, y) \quad (1.a)$$

$$R_i \cap R_j = \varphi, i \neq j \quad (1.b)$$

## 1. Segmentation methods

- Thresholding and region growing:
  - ❖ Thresholding
  - ❖ Region growing

- variational methods:
  - ❖ Active contours or Snakes: The first work in this direction was the Snake in Kass et al. [1988] which used an explicit type of curve representation.
  - ❖ *Level set methods*: the first issue regarding curve parameterization, approaches using the implicit level set method by Osher and Sethian in 1988.
  - ❖ Geodesic active contours
  - ❖ Active contours without edges
  - ❖ Active shape models
  - ❖ Direction of descent
- Combinatorial methods
  - ❖ Optimality of solutions
  - ❖ Dynamic programming and optimal paths
  - ❖ Graph cuts

## 2 ACTIVE CONTOUR MODEL OR SNAKES

### 2. Základní definice

Active contour model or snakes are widely used in the problems of allocation of contours, boundaries and image segmentation. For the detection of contours in the image are used curves with a minimum energy. The first active contour algorithm introduced in 1988 by Kaas in [1]. Active contour model is a variable circuit, which consist of  $n$  points in two-dimensional space:

$$V = \{v_1, \dots, v_n\}, v_i = (x_i, y_i), i = \{1, \dots, n\} \quad (2)$$

The principle: the circuit is initialized as a simple line and then it is deformed to create a region of the object. The points in the contour seek to the boundary of the object by minimizing the energy of the contour. For every point  $v_i$  exists the energy, which is:

$$E_i = \alpha E_{\text{int}}(v_i) + \beta E_{\text{ext}}(v_i) \quad (3)$$

$\alpha$  and  $\beta$  - constants which provide energy correction.

$E_{\text{int}}$  - energy function that depends on the shape of the contour

$E_{\text{ext}}(v_i)$  - energy function, which depends on the type and properties of the image gradient in the neighborhood of the point  $v_i$ .

The values  $E_i$ ,  $E_{\text{int}}(v_i)$  and  $E_{\text{ext}}(v_i)$  are square matrices. The energy value at the center of each matrix corresponds to energy in point  $v_i$ . The remaining value of the energy in the matrix corresponds to each energy point in the vicinity of the point  $v_i$ . Each point  $v_i$  can potentially go to any point  $v_i'$ , which corresponds to the minimum value of the energy  $E$ . If the energy function is configured correctly, then the contour vertices  $V$  iteratively move and stop near the boundaries of the object. This process is depicted in Figure 2.

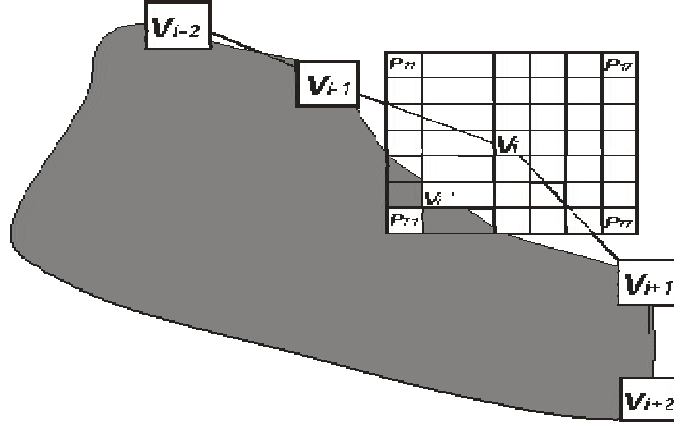


Fig. 14. Visualization of the effect of selection the optimum point for the current iteration of the set of points E[8]

The internal energy  $E_{int}$  calculates as follows:

$$a E_{int}(v_i) = c E_{con}(v_i) + d E_{bal}(v_i) \quad (4)$$

Wherein:  $a, c, d$  - are the weight coefficients.

The internal energy  $E_{int}(v_i)$  consists of two components: the energy of the contour  $E_{con}(v_i)$  (smoothing component) and component  $E_{bal}(v_i)$  that is bursting energy of the contour.

Smoothing energy of closed contour  $E_{int}(v_i)$  can be calculated in this way:

$$e_{jk}(v_i) = \frac{1}{1(V)} \left\| \rho_{jk}(v_i) - \gamma(v_{i-1} + v_{i+1}) \right\|^2 \quad (5.a)$$

$$\gamma = \frac{1}{2 \cos\left(\frac{2\pi}{n}\right)} \quad (5.b)$$

$$1(V) = \frac{1}{n} \sum_{i=1}^n \|v_{i+1} - v_i\|^2 \quad (5.c)$$

Wherein:  $e_{jk}$  - elements of the energy matrix,

$n$  - the number of points in the contour,

$\rho_{jk}(v_i)$  - points (x, y), which correspond to points on the image in the energy matrix.

This component  $E_{con}(v_i)$  pulls the contour and does not allow individual peaks to separate from other peaks. If the object selection is rounded, the weight at this energy should be increased in the relative importance of other factors. The minimum value in

the matrix of smoothing the energy  $E_{con}(v_i)$  will correspond to the value  $p_{jk}(v_i)$ , which is as close to a perfect circle, passing through the two neighbor peaks of the contour  $v_{i-1}$  and  $v_{i+1}$ . (fig.3)

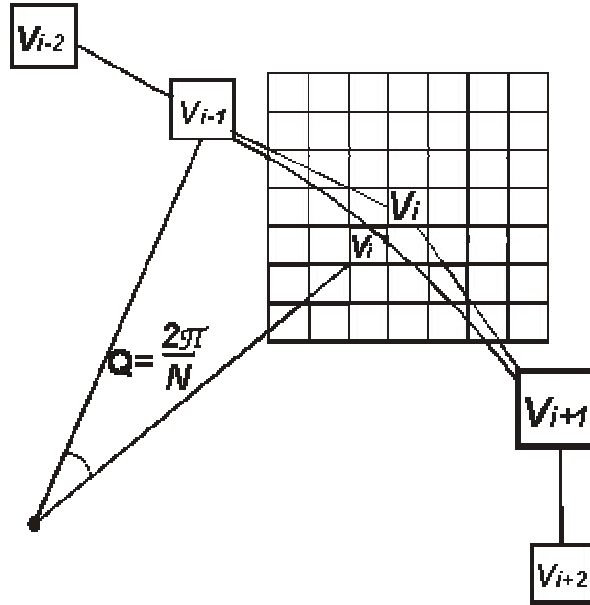


Figure 15. Smoothing component[8]

Bursting energy  $E_{bal}(v_i)$  makes the contour to deform in the same direction. Figure 4 shows the influence of the energy  $E_{bal}(v_i)$ .

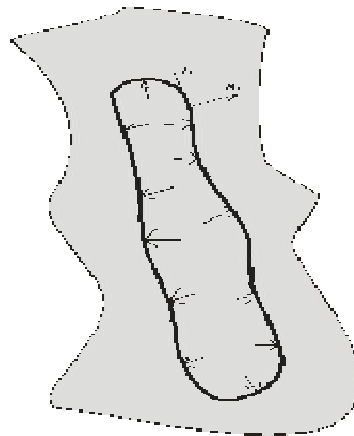


Figure 16. The energy that deforms the contour in the same direction.[8]

The matrix elements of a given energy are calculated using the form:

$$e_{jk}(v_i) = n_i * (v_i - p_{jk}(v_i)) \quad (6)$$

Wherein:  $n_i$  - the unit vector of normal to the contour  $V$ ,

$p_{jk}(v_i)$  - points ( x, y), which correspond to points on the image in the energy matrix.

$e_{jk}$  - elements of the energy matrix/

$n_i$  vector can be found by turning the vector  $t_i$  to 90 degrees:

$$t_i = \frac{v_i - v_{i-1}}{\|v_i - v_{i-1}\|} + \frac{v_{i+1} - v_i}{\|v_{i+1} - v_i\|} \quad (7)$$

The external energy is calculated as follows:

$$b * E_{ext}(v_i) = m * E_{mag}(v_i) + g * E_{grad}(v_i) \quad (8)$$

Wherein: b, m and g are the weight coefficients,

$E_{mag}(v_i)$  image energy and  $E_{grad}(v_i)$  gradient energy are components of  $E_{ext}(v_i)$ .

The matrix of image energy consists of luminance values of image:

$$e_{jk} = I(p_{jk}(v_i)) \quad (9)$$

Wherein  $I(p_{jk}(v_i))$  is a luminance function at  $p_{jk}(v_i)$ .

The matrix of gradient energy calculated as follows:

$$e_{jk}(v_i) = |\bar{V}I(p_{jk}(v_i))| \quad (10)$$

Wherein  $\bar{V}I(p_{jk}(v_i))$  - the gradient function of the image (first derivative of luminance)

Using the proposed algorithm to solve the problem of image segmentation can show a number of restrictions imposed on the analyzed image. For example, if the object has no clear boundaries, or the area is not homogeneous and contains smooth gradients, the algorithm will not solve the problem of segmentation properly, leading to the impossibility of further automated analysis. In addition, the discrete structure of the source data (picture) distorts the value of the bursting energy ( $E_{bal}(v_i)$ ) in the case of significant changes. The normal vector of the tangent at the point can greatly vary in the direction that could lead the merger of points. From this contour can get rough, and very different from the boundaries of selected object[8].

# 3 INTRODUCTION TO LEVEL SET METHOD

This part will introduce the Level Set Method. The role of Level Set Method in segmentation is will be discussed and will be defined mathematical construction

## 3.1. Description of Level Set Method

Level-sets are numerical computation method, which is very useful in many fields of science. For example, nowadays, this method is very useful in computer science as the segmentation of objects on video and images, medicine, aerodynamics, applied mechanics and many other industries. The level set method was introduced by Osher and Sethian in 1988.[2] The main distinguishing feature of the method is that the method level set without problems segments objects that have a different shape, location on image and the divided boundaries, also level set segments multiple objects at one time.(fig.5)

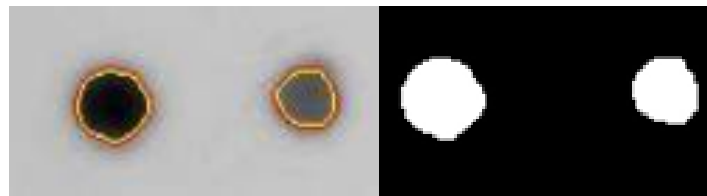


Figure 17. Level set segmentation of multiple objects.[10]

The level set method works with a contour on two dimensions or surface in three dimensions by manipulating a higher dimensional function, which called the *level set function*  $\varphi(x,t)$ , which represents the interface:

$$\begin{aligned} \varphi(x, t) &= 0 \text{ if } x \in \Gamma \\ \varphi(x, t) &< 0 \text{ if } x \in \Gamma_{in} \\ \varphi(x, t) &> 0 \text{ if } x \in \Gamma_{out} \end{aligned} \tag{11}$$

Where  $\Gamma_{in}$  shows the area inside the interface and  $\Gamma_{out}$  shows the area outside (fig.6).



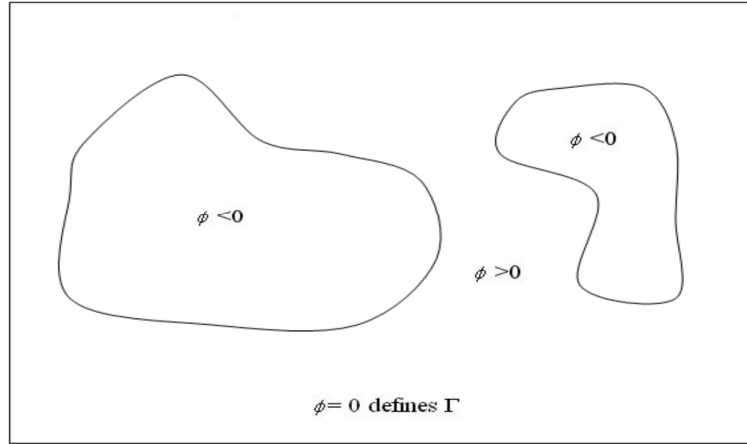


Figure 18. The construction of level set function [6]

The evolving contour or surface has to be obtained from *zero level set*  $\Gamma(x, t) = \{\varphi(x, t) = 0\}$ .

The hallmark of the method level set the model of active contours is that the contours can divide or connect the contours during evolution. The evolution of the contours is controlled by level set equation. The general form of the level set equation defined by [3]:

$$\frac{\partial \varphi}{\partial t} = -|\nabla \varphi| * F \quad (12)$$

F velocity is term which describes the evolution of level set function. Manipulating F may influence level set to different areas or shapes of the particular level set initialization. The solution of partial differential equation (PDE), which calculates iteratively updates  $\varphi$  in each time interval.

$$\frac{\partial f}{\partial t} = \vec{S} * \nabla \varphi + V_n |\nabla \varphi| = bk |\nabla \varphi| \quad (13)$$

This kind of solution allows contours to discontinue or merge during the evolution.

The evolution can be described by convecting the  $\varphi$  with the velocity filed  $\vec{S}$  on the interface [4][9]:

$$\frac{\partial \varphi}{\partial t} + \vec{S} * \nabla \varphi = 0 \quad (14)$$

The velocity in the normal direction to the curve:

$$\frac{\partial \varphi}{\partial t} + V_n |\nabla \varphi| = 0, \text{ when } V_n = 1 \quad (15)$$

The velocity based on twisting curve:

$$\frac{\partial \varphi}{\partial t} = bk |\nabla \varphi| \quad (16)$$

The advantage of using this method is that topological changes such as merging and splitting of the contour or surface are catered for implicitly, as can be seen below in Figure 7.

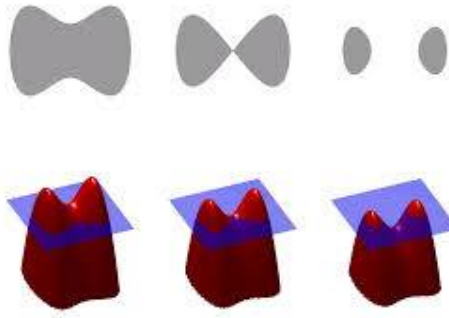


Figure 19. The relationship between the level set function (up) and contour (down) can be seen.[3]

As mentioned before the Level Set method is a part of Partial differential equation based methods

### 3.2. Segmentation using the Level Set Method

For applications in image segmentation level set equation  $F$  is dependent on the pixel intensity or curvature values of the level set. The importance of having a curvature term can be explained in this way: there cannot be force to smoothen high curvatures. This is when the level set surface evolves through a boundary into another object that was not intended to be segmented. This also makes segmentation difficult for objects which have very high curvature as the curvature weighting term often needs to be set very low in order to allow for these high curvatures, yet doing so may result in such leaking. Also  $F$  can be dependent on an edge indicator function, which is defined as having a value zero on an edge and non-zero, this causes  $F$  to slow the level set evolution when on an edge.

F can be dependent on data and curvature functions only for the purposes of image segmentation [4]. Therefore, will be adopt the same methodology which makes the level set equation to:

$$\partial f / \partial t = -|\nabla \phi| [\alpha D(I) + (1 - \alpha) \nabla * \nabla \phi / |\nabla \phi| ] \quad (17)$$

Wherein  $D(I)$  is the data function aims the solutions targeted features and average curvature of expression  $\nabla$ . The expression  $(\nabla \phi / |\nabla \phi|)$  keeps the level set function smooth and the weighting between these two is  $\alpha \in [0, 1]$ , which is previously set free parameter to control the contour to be smooth.

The function  $D(I)$  is the principal force, that drives the segmentation. When  $D$  is positive in desired regions or negative in undesired region, the model will be tending to the sought segmentation. A simple speed function that fulfills this purpose by[4]:

$$D(I) = \epsilon - |I - T| \quad (18)$$

Wherein  $T$  is a central intensity value of the region to be segmented,  $\epsilon$  is intensity deviation around  $T \pm \epsilon$ [5].

### 3.3. Signed distance function

The distance function allocated the value for each pixel, within a binary image that contains the value of one or multiple objects, which represents the minimum distance from the pixel to the nearest pixel on the boundary of the object. Mathematical definition of the function as  $D: R^3 \rightarrow R$  for  $S$  is [2]:

$$D(r, S) = \min |r - S| \text{ for all } r \in R^3 \quad (19)$$

Assigned distance function assigns the sign of distance values as positive for those pixels outside the object and a negative for those inside the object. This is the sign rule, which will be followed in the implementation, but can also be used as a rule of opposite sign. It should be noted that the distance values depends on the selected metric for the distance: some common metric distances are Euclidean distance, chessboard distance, and the block distance. Many algorithms that compute the Euclidean distance transform frequently compared for accuracy and efficiency characteristics that varying levels of complexity.



## 4 IMPLEMENTATION

There are a large number of ways to implement the details of these techniques. A substantial amount of time has been spent on the implementation of the methods presented prior. This chapter shall give an overview of the features and structure of the code. The selling points of the code is that it has written in Java in Eclipse, is for 2D images, using Level Set Algorithmtm.

### 4.1. Level Set Algorithmtm

Active contours evolve an initial contour in time according to multiple intrinsic geometric measures of the image. In the plugin implementation the measures are an edge based constraint, a grey value penalty and a curvature constraint which prevents them from leaking the object boundary at areas of poor edges. During curve evolution the active contours in this implementation can split and merge and thus be used to detect even multiple objects. The algorithm in the plugin is based on a state-of-the-art very memory efficient and fast sparse-field computation which can be easily extended to other variations of the active contour/level set algorithms.[10]

$$\Phi(i) = \Delta T g(i) (W_a F_a |\nabla \Phi| + W_c F_c |\nabla \Phi|) \quad (20)$$

$\Phi(i)$  iso surface at current iteration i

$W_a$  advection weight

$F_a$  advection force

$W_c$  Curvature wight

$F_c$  Curvature force

#### 4.1.1 The algorithm of automatic selection starting point and settings parameters.

Automatically selecting a starting point to begin the function setseed which is in LevelSetImpl.java. when the process starts the algorithm measures the image that was download previously. By the function RGB, the algorithm finds the light part of the

picture, because the aim of this thesis is segmentation of medical data. After the investigating the light part of the picture, for this algorithm was

## 4.2. Graphic GUI of the practical part

In this part of the work will be described in graphic part of the program, which was written in Eclipse. When you run a program, the user has the option to upload a picture function, which will be further segmented by Level Set. It also made a GUI file that has special keys as

- File Selection
- Uploading files
- image processing
- Change processing settings

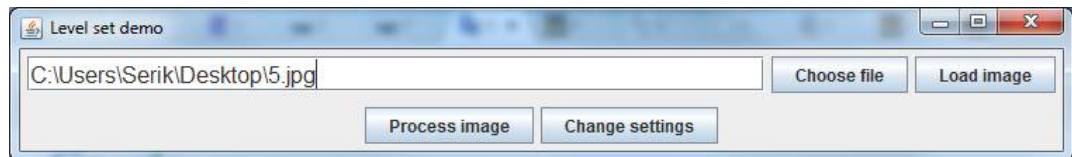


Figure 20. main menu

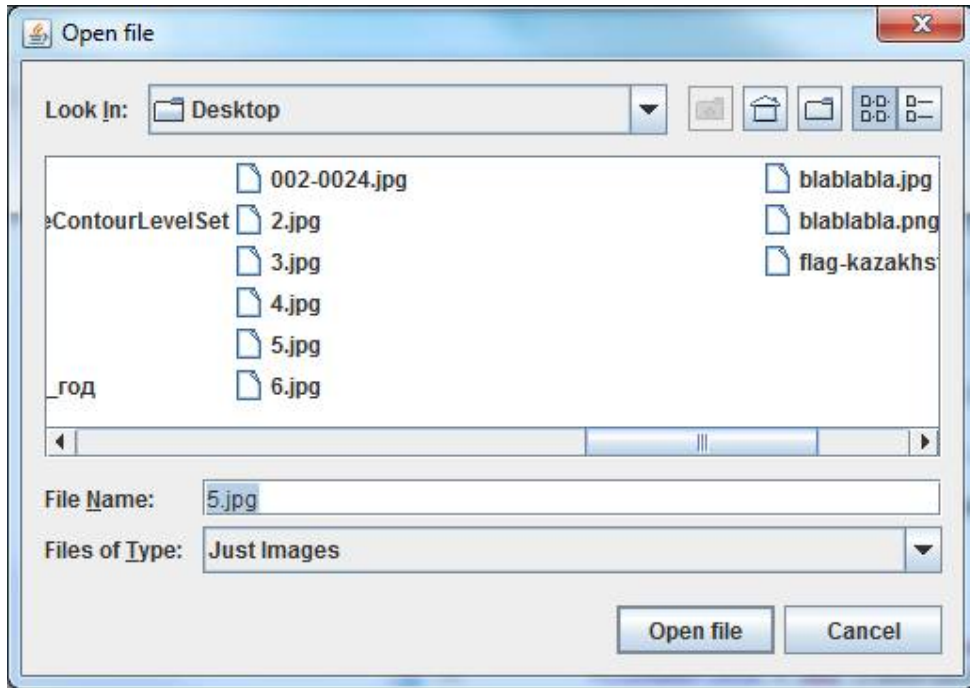


Figure 21. Menu for choosing the file

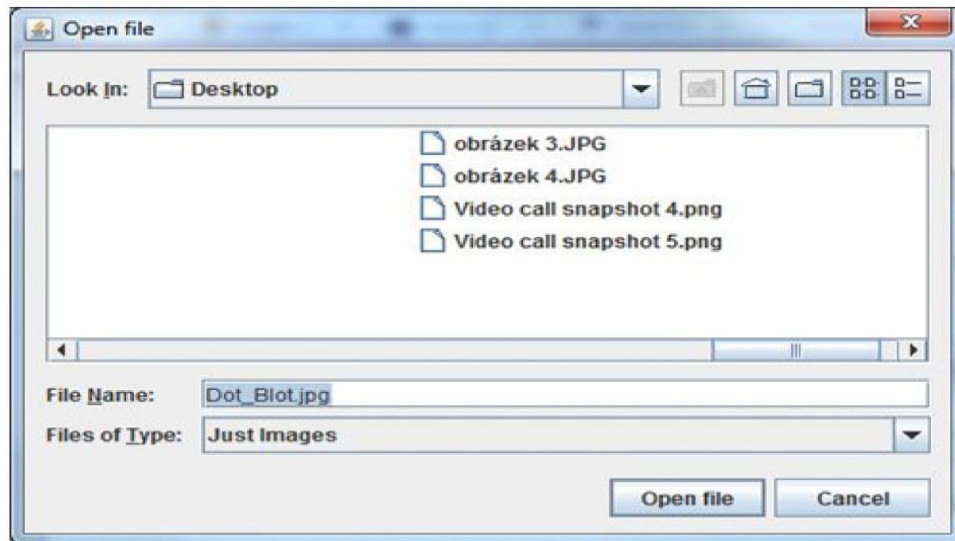


Figure 22. main menu

When using the Change Settings button opens a dialog box that allows you to select parameters for image segmentation

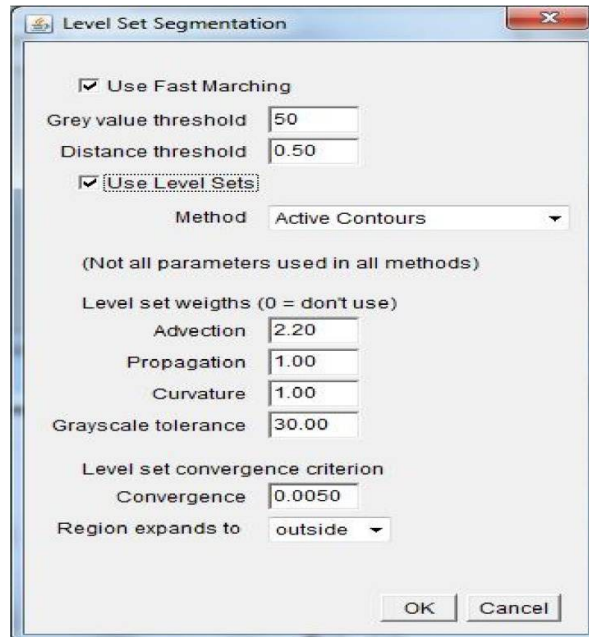


Figure 23. Settings



## 5 ACHIEVED RESULTS

Before the segmentation, all hardware testing was done, a single PC with Intel Core 2duo, processor clock speed 2.1 GHz, 4GB RAM, and the graphics hardware is standard Intel(R).

In Figure 7 the example of human head segmentation is shown. The head data is not so good contrast and dimension  $400 \times 400$  pixels. The time has taken for 70000 iterations, and more than 2 minutes and 45 seconds for this picture.

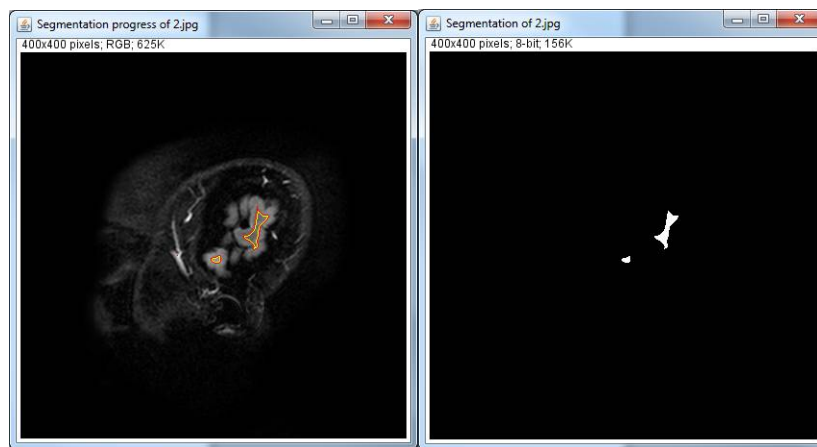


Figure 24. the segmentation of human head, on the right side the algorithm chooses part of the head which will be segmented. On the left side is segmented part

On figure 8 we are able to see just a part of the brain. The time of segmentation was about 7 minutes. As we can see i couldn't reach the 100% segmented brain, it is about 91%, in this case post-processing will need figure 9.

Unfortunately, as much as I have tried, I could not 100% segment the brain. During the launch of the post processing, it does not give the desired results, and improves the segmentation of the area for a couple of percent

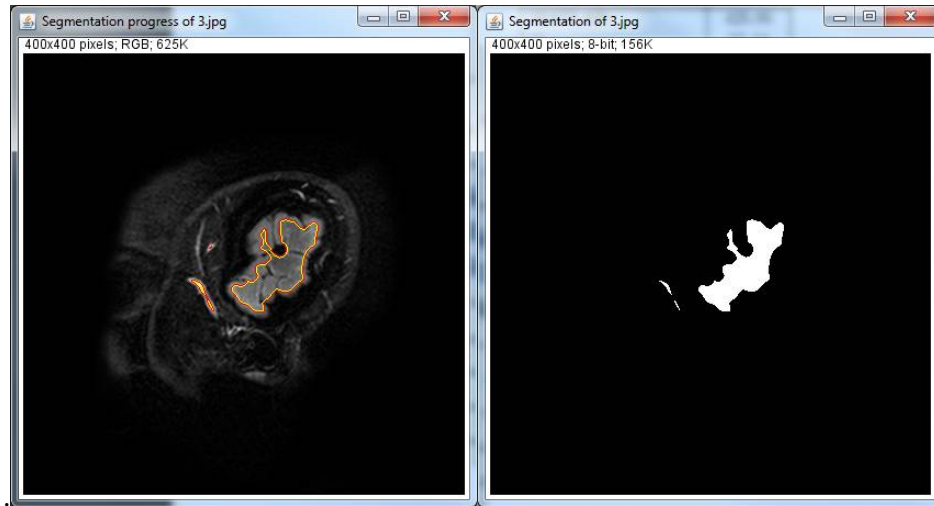


Figure 25 brain segmentation

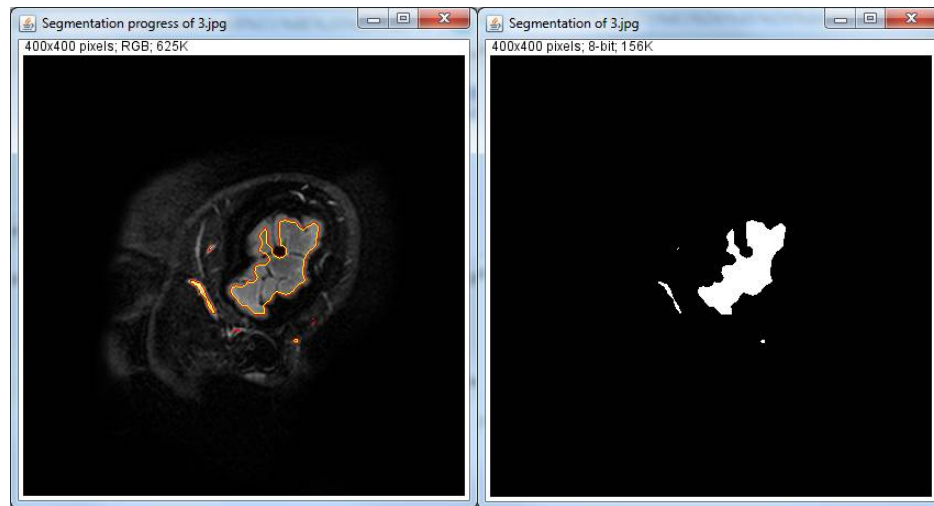


Figure 26 result of post-processing

My algorithm doesn't have the pre-processing algorithm such as blurring or de-noising. Maybe if it pre-processing to shade the shadow part and make more lighter the brain part would be helpful. The effect of different image size, the larger picture, then longer goes segmentation.

## 6 CONCLUSION

This thesis is divided into theoretical and implementation. The theoretical part segmentation techniques, active contours (Snakes) and Level set techniques. The first part is devoted to general knowledge about the segmentation of biomedical images. A particularly images of medical data that are part of this thesis used for the purpose of verifying a function of segmentation techniques Level Set. Another part deals with methods of active contour (Snakes), which are used mainly in the failure of other segmentation methods. There is a section designed for algorithms that describes how develops active contour. The last theoretical part deals with the segmentation technique Level set, which describes its general characteristics. The first part deals with the realization of the creation of modules in Java in the Eclipse program. Ignominiously describes how the program works, and how to create an executable plug-ins for image processing. Since the assignment clearly implies that it should be made simple GUI. Therefore it was necessary to insert in the program library of Fiji. For this reason, you will not be needed before the GUI run a separate program. Another part is devoted to independent java code that implements module method Level Set. There are all classes and their associated methods. Mainly focuses on the segmentation of the cerebral cortex. From methods it shows that very much depends on the setting of parameters and the number of iterations to achieve an overall image segmentation. The algorithm implemented in this project was considerably less complex than many existing versions of the level set and fast marching methods. There are several known improvements to the methods employed here that are outside the scope of this project. However, in order to replace manual tracing with automated numerical identification of the shape boundaries.

Level set method, which is one of the most advanced methods of image segmentation requires more knowledge than previously described basic methods, thats why this idea should be developed.

It is important to mention the method for segment the image, which is spelled correctly but although compliance with the reference and segmented pictures is around 85-95

percent. When starting the post-processing it gives that same identity or a couple of percent more.

I think that the work completed only for 80 percent, because i have never worked with Level Set method for image segmentation before and also have never done such a things in Java.

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# LIST OF SYMBOLS, VALUES AND GLOSSARY

$T$	is a central intensity value of the region to be segmented
$\epsilon$	is intensity deviation around $T \pm \epsilon$
$F$	velocity is term which describes the evolution of level set function
$\phi(x,t)$	level set function
$\Gamma$	interface
$E_{mag}$	image energy
$E_{grad}$	gradient energy
$e_{jk}$	elements of the energy matrix
$n_i$	vector can be found by turning the vector $t_i$ to 90 degrees:
$E_{bal}(v_i)$	bursting energy
$E_{con}$	smoothing energy
$D(I)$	the data function
JPEG	Photographic Experts Group
BMP	Windows Btmap
GIF	Graphics Interchange Format
TIF	Tag image Format
JDK	Java Developmen Kit
JAVA	programing language

# LIST OF ATTACHMENTS

A) Bachelor thesis

B) CD:

- 1) program Level Set
- 2) Java source code
- 3) original images before segmentation
- 4) the images after segmentation
- 5) mask
- 5) mask