A Fast GPU-based Method for Image Segmentation

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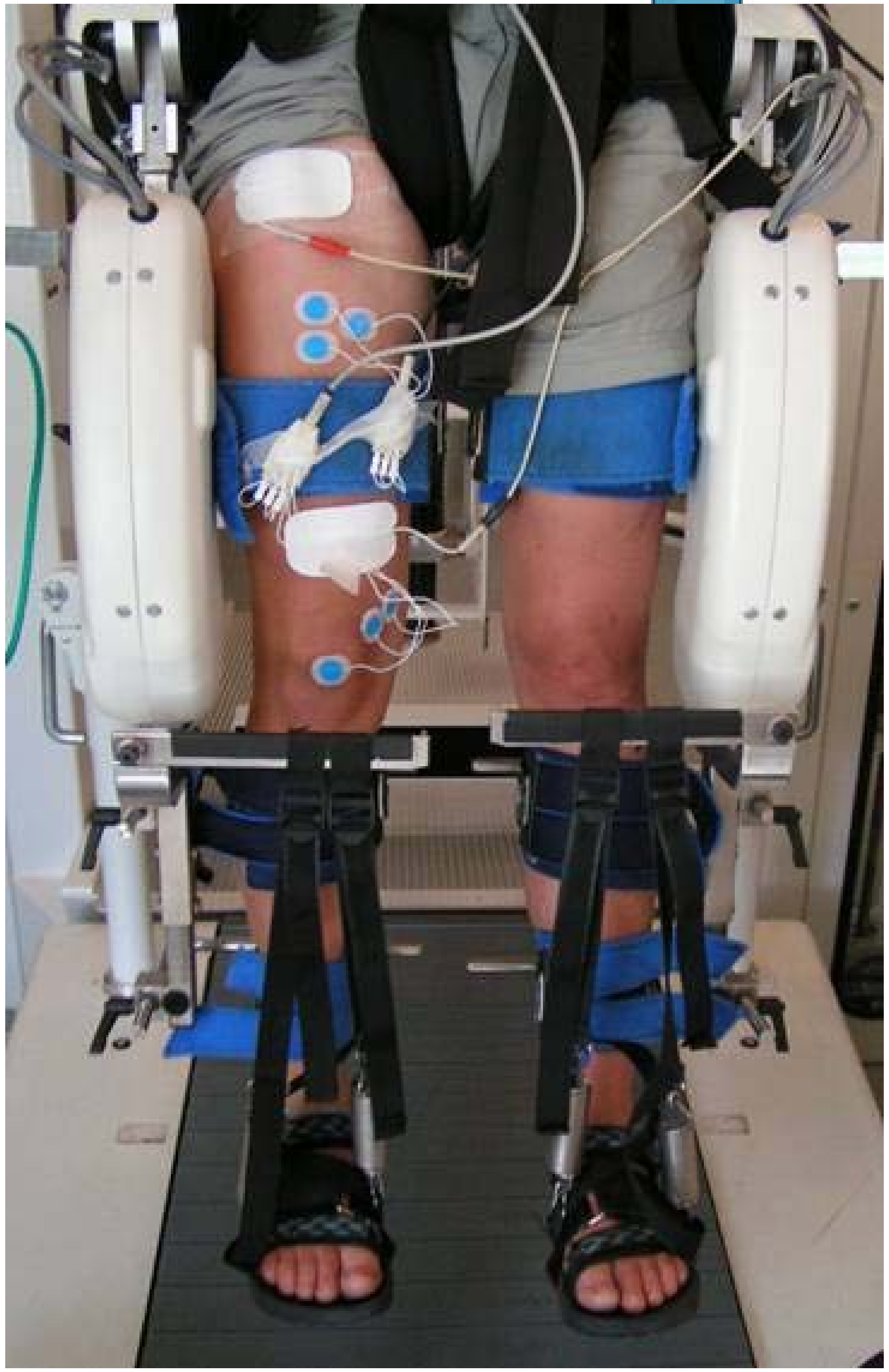
Contents

FES

APPLICATION

Functional Electrical Stimulation

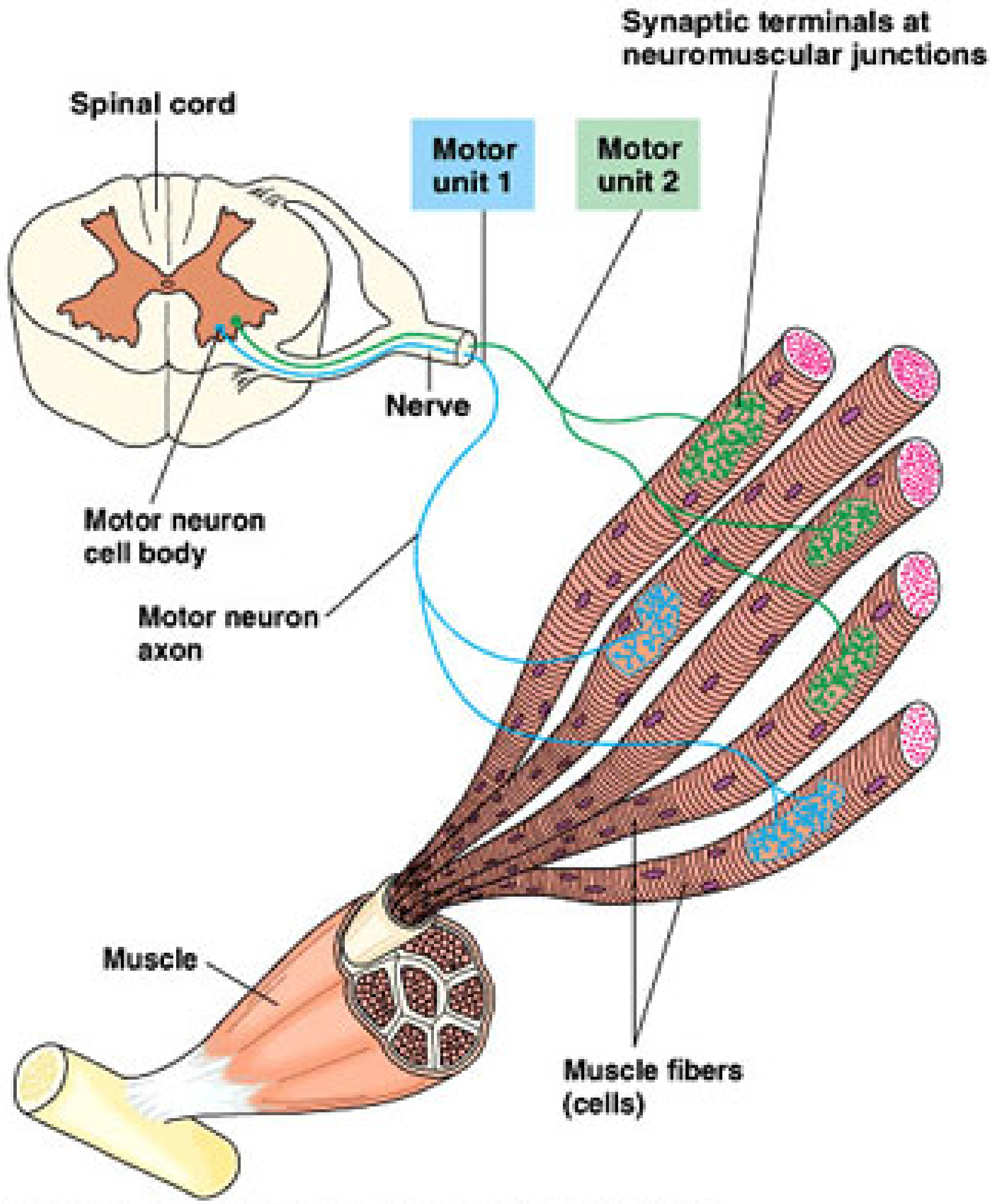
- Goal of FES is to obtain an externally induced contraction of a muscle by means of electrical stimulation.
- Areas of application:
  - Surface or neural Stimulation
  - Movement augmentation for sufferers of neural damage
  - Muscle (re-)training
  - Meat processing



Picture downloaded from:
http://control.ee.ethz.ch/~fes

From Geometry To Physiology

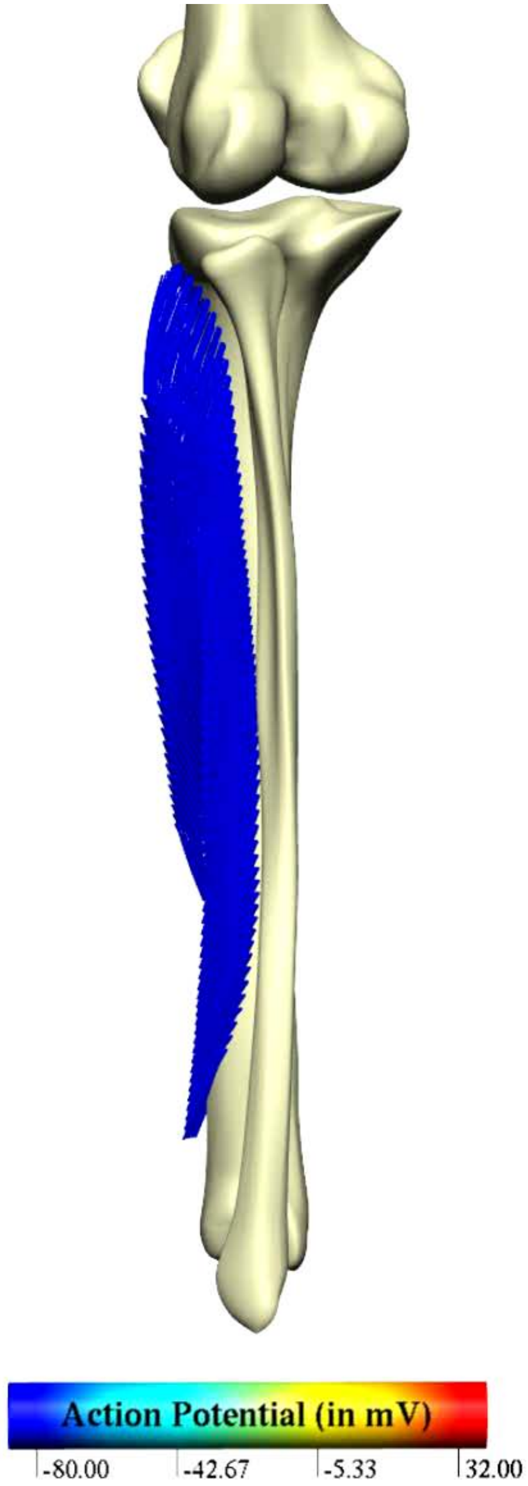
- A skeletal muscle fibre is activated by an action potential.
- Muscle fibres within a motor unit are excited (activated) simultaneously.
- Muscle fibres of a particular motor unit can potentially be spread over the muscle.
- All skeletal muscle fibres are electrically isolated, but mechanically coupled

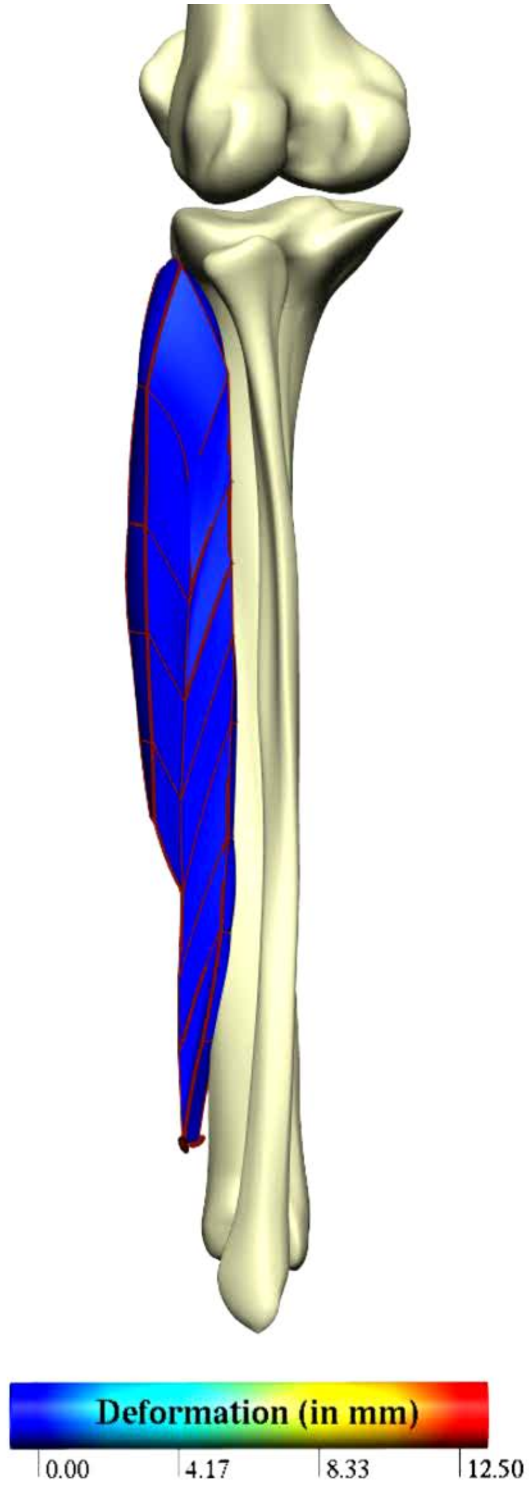


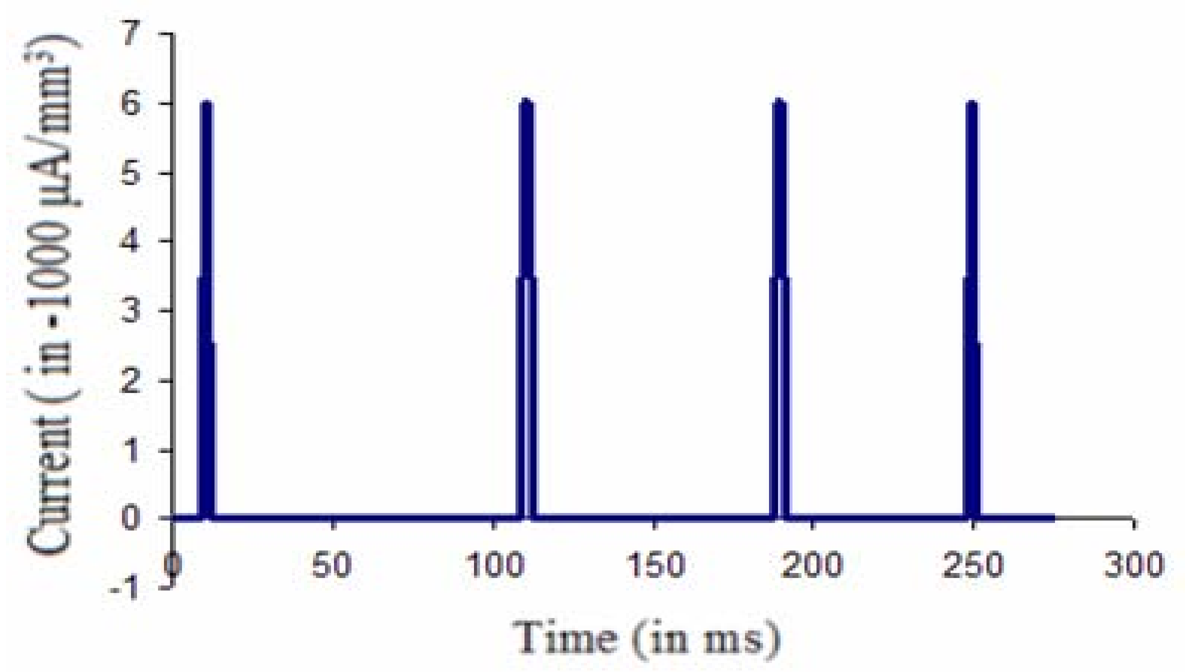
A Single Fibre Cellular Model

- The “0D” cell model consists of 53 coupled ODEs to represent the relevant cellular processes at a point (developed in collaboration with AgResearch, Hamilton, NZ).
- Implemented within CellML, a markup language that is designed as a framework allowing platform-independent exchange of models (http://www.cellml.org).
- The 1D bidomain equations are solved to represent those cellular processes along a skeletal muscle fibre.

„External“ Simulation







Input: Stimulation protocol

O. Röhrle, *“Simulating the Electro-Mechanical Behavior of Skeletal Muscles”*, IEEE Computing in Science and Engineering, DOI 10.1109/MCSE.2010.30

Method

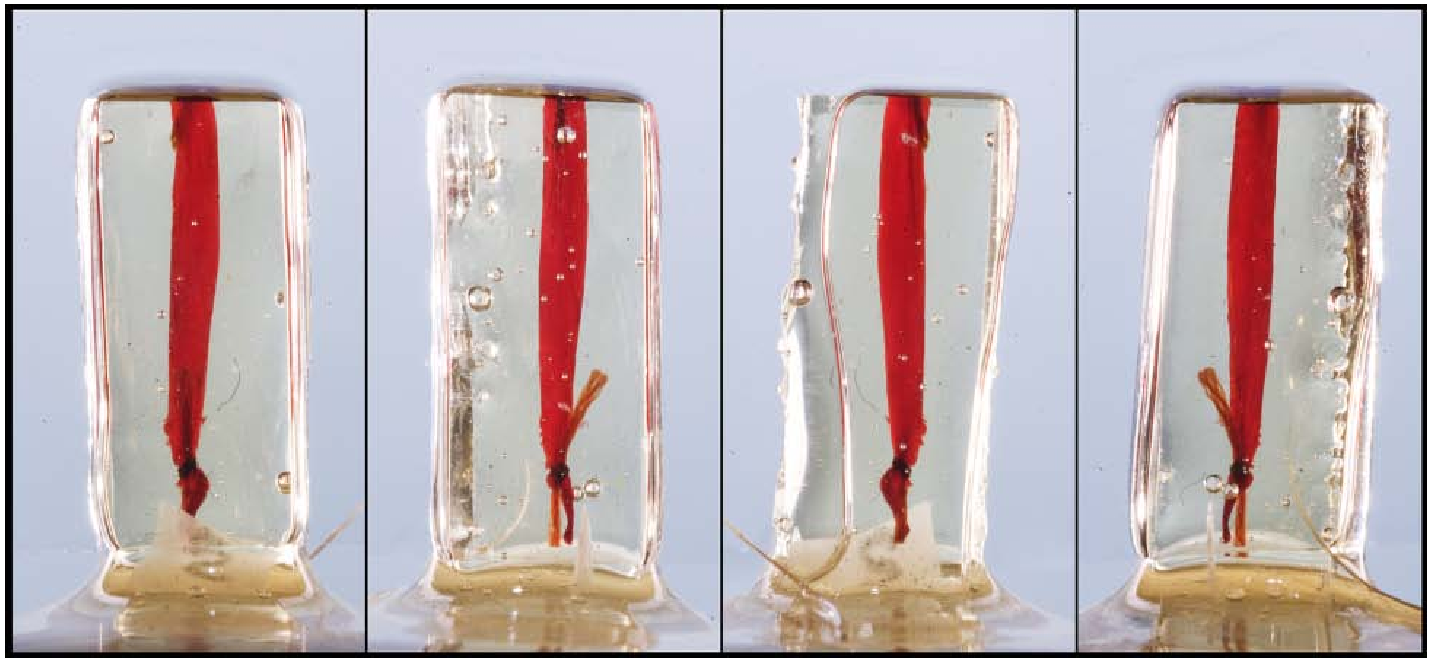
IMAGE SEGMENTATION

Motivation for Segmentation

- Goal: Investigate function and structure of skeletal muscle.
- Input Data: High-resolution structural images of a mouse muscle obtained from extended volume imaging.
- Objective: Use of (Semi-) automatic segmentation processes to extract single (multiple/all) fibres from the high-resolution structural imaging to provide anatomically realistic input to electro-mechanically coupled models of skeletal muscles (extend the simulation to full 3D!).

Extended Volume Imaging

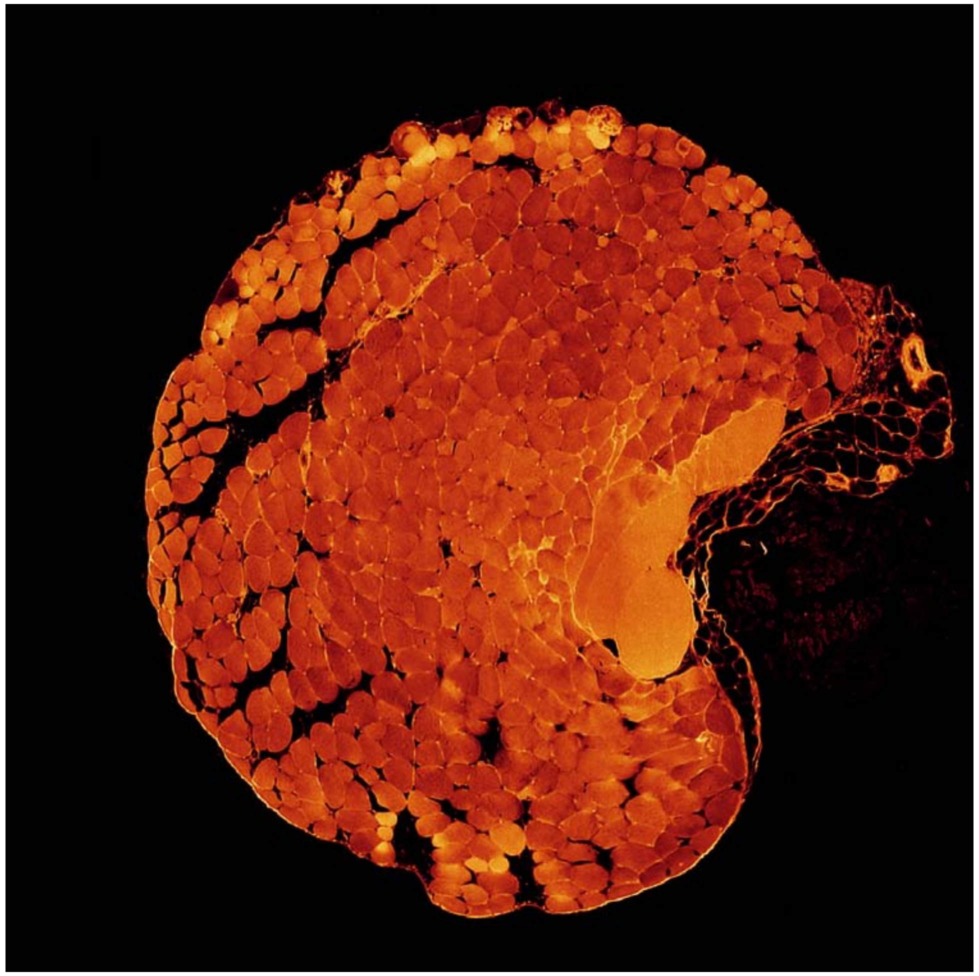
- A mouse EDL muscle was stretched to its optimal length and retained at this length for fixation.
- The specimen was perfusion-stained for collagen, before fixating it in resin for imaging.
- The Welcome Trust extended-volume imaging system developed at the Auckland Bioengineering Institute (The University of Auckland, New Zealand) was used for imaging



Special thanks to Dane Gerneke from the Auckland Bioengineering Institute at the University of Auckland, New Zealand, for his tremendous effort, help, and expertise in preparing and imaging the skeletal muscle sample.

Extended Volume Imaging

- High resolution cross-sectional images of the entire specimen were obtained.
- The in-plane image resolution was 1µm.
- In the longitudinal direction, cross-sectional images have been taken at least every 50µm.
- In the middle section of the muscle, cross-sectional images were obtained at a much higher density, viz. a 1µm slice distance. This was achieved over a length of 350µm.



Challenges And Approaches

- **Challenges:**
  - → Large data sets
  - → Inter-slice variability with respect to contrast at edges of objects and colouring

- **Approaches:**
  - (i) Improving images/imaging
  - (ii) Pre-processing the images to enhance its quality and include additional a priori knowledge on size and shape of objects.

Segmentation Process

The following steps are employed during the segmentation process:

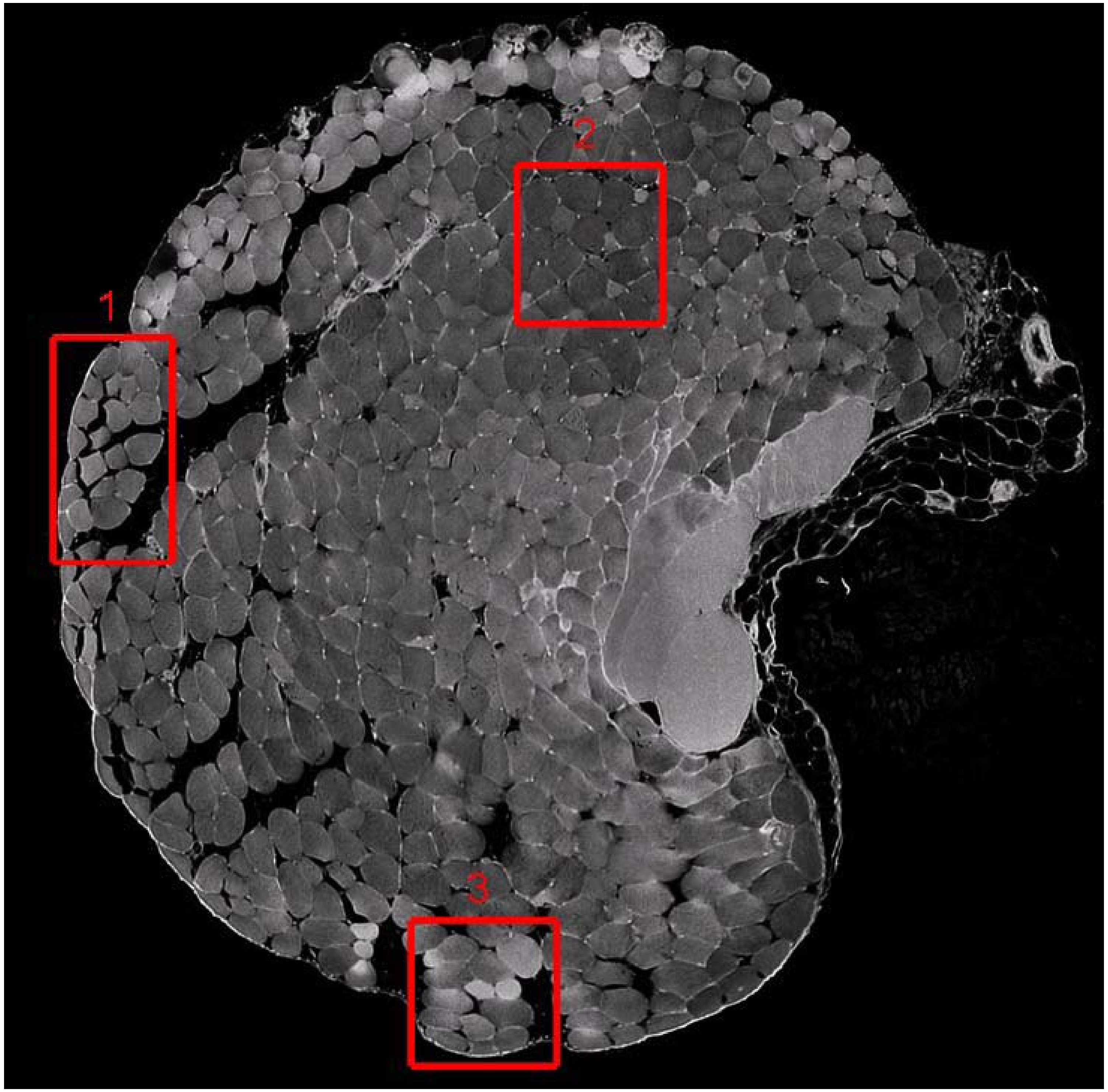
Step 1: Pre-filtering of raw image data

Step 2: Circle detection as initial rough approximation to the shape of a fibre

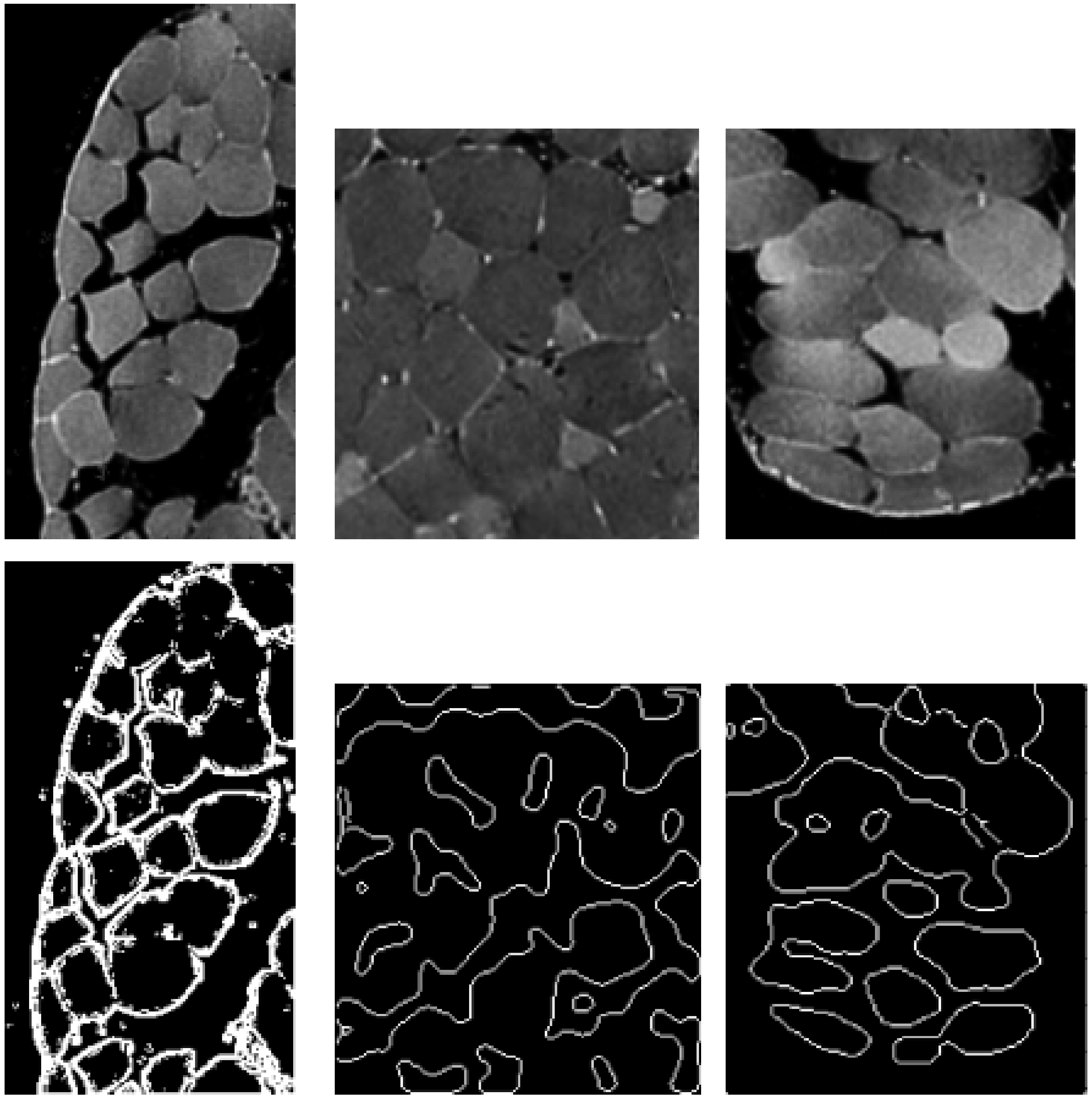
Step 3: Finding the final contours of the muscle fibres by the method of active contours

Step 4: Post-processing

Segmentation Process



Step 1 – Pre-Filtering



Region 1 Region 2 Region 3

<u>Region 1:</u>

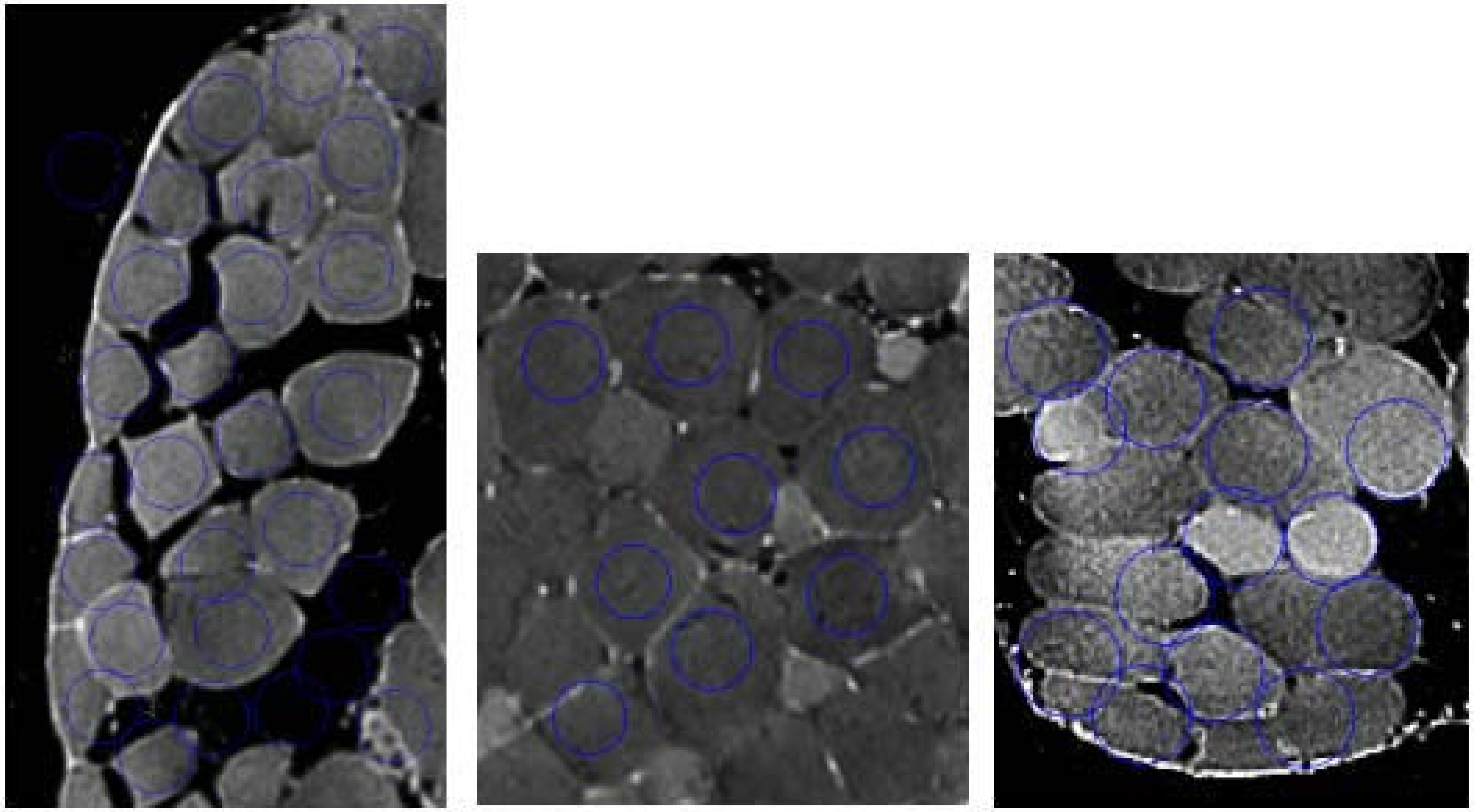
standard Sobel-filter and thresholding

<u>Region 2/3:</u>

Additionally to the Sobel-filter and thresholding, dilatation, a Canny Edge Filter, and a median filter is necessary.

Step 2 – Hough Transform

- The circle detection is done by a circular Hough transform
- Circles serve as input for the initialization step of the active contours method (number of circles should be equivalent to the number of cells and the centre of the circles should approximately correspond to the cell centre)



Region 1 Region 2 Region 3

Figure shows for Regions 1-3 the circles detected by this method.

Step 3 – Active Contours

- Active contours or snakes describe the contour of an object by an explicit deformable curve c.
- An iterative process deforms c until a certain stopping criterion is reached.

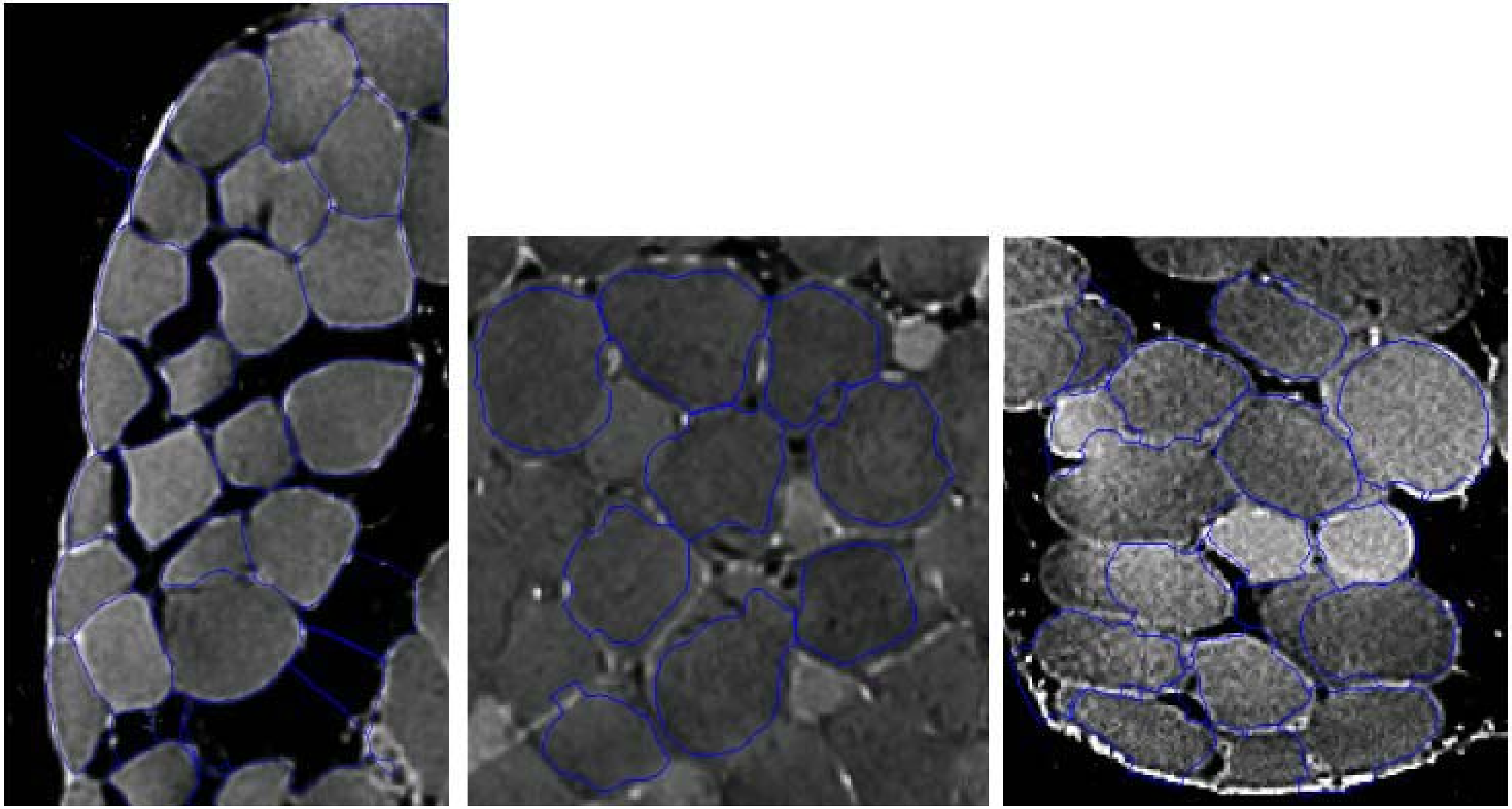
$$E(c) = \underbrace{\frac{1}{2}\int_0^1 w_1 \left|\frac{\partial c}{\partial s}\right|^2 + w_2 \left|\frac{\partial^2 c}{\partial s^2}\right|^2 ds}_{S(c)} + \underbrace{\int_0^1 P(c(s))ds}_{P(c)}$$

S(c): inner energy (describes the shape of the active contour)
P(c): outer energy (contains information on the image, e.g. Edges)
w_1, w_2: control the elasticity and stiffness of the snake

- Minimization of the energy (deformation) is done by solving the Euler-Lagrange equations corresponding to E(c) using variational calculus and the Finite Volume method.

Step 3 – Active Contours

- The segmented muscle fibre contours after applying active contours algorithm to Region 1-3.

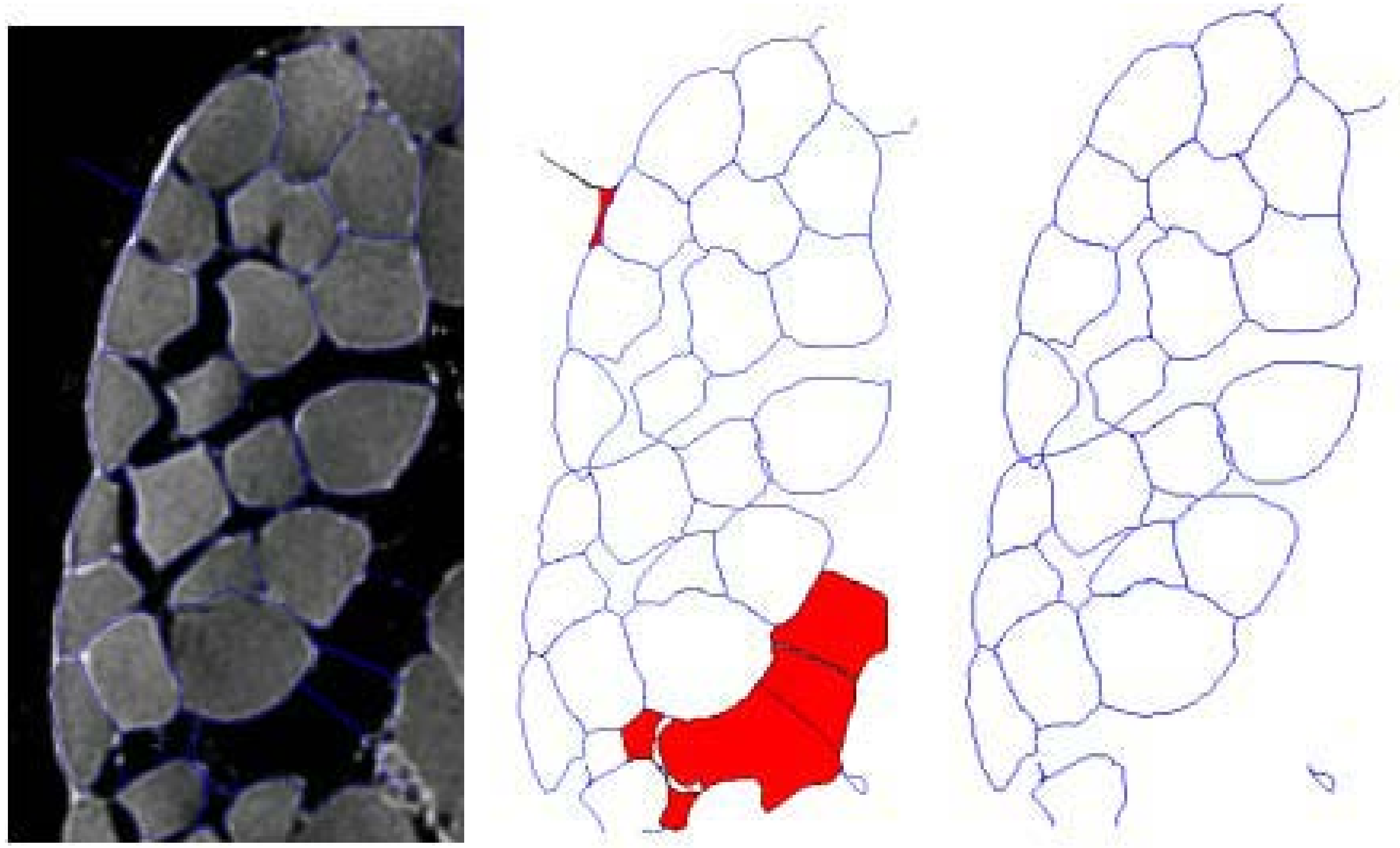


Region 1 Region 2 Region 3

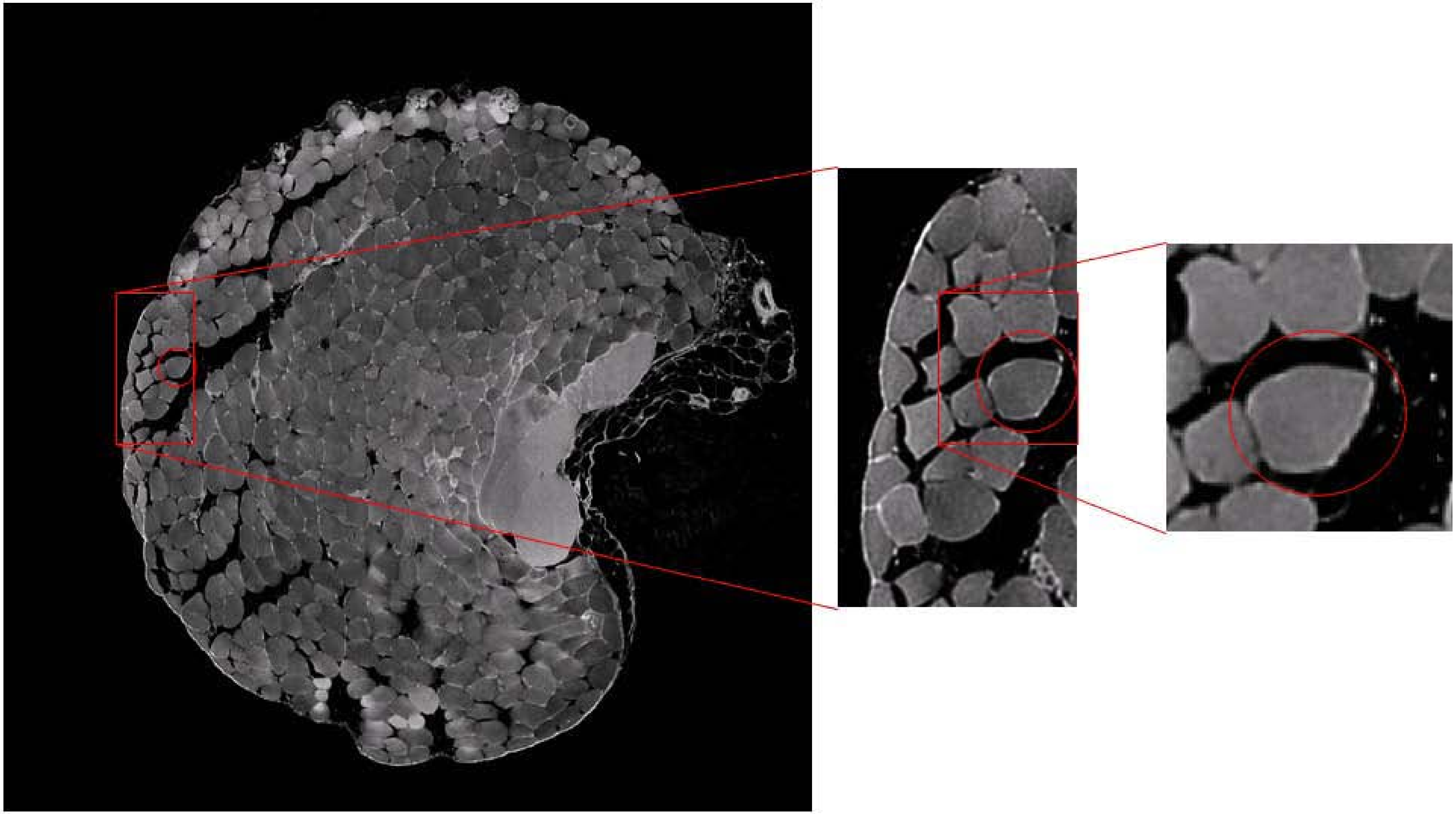
Step 4 – Post-Processing Step

TECHNISCHE FAKULTÄT

- Removing of detected non-fibre cells like the black areas in the lower right of Region 1 (additional threshold filtering)



Errors and Computational Time

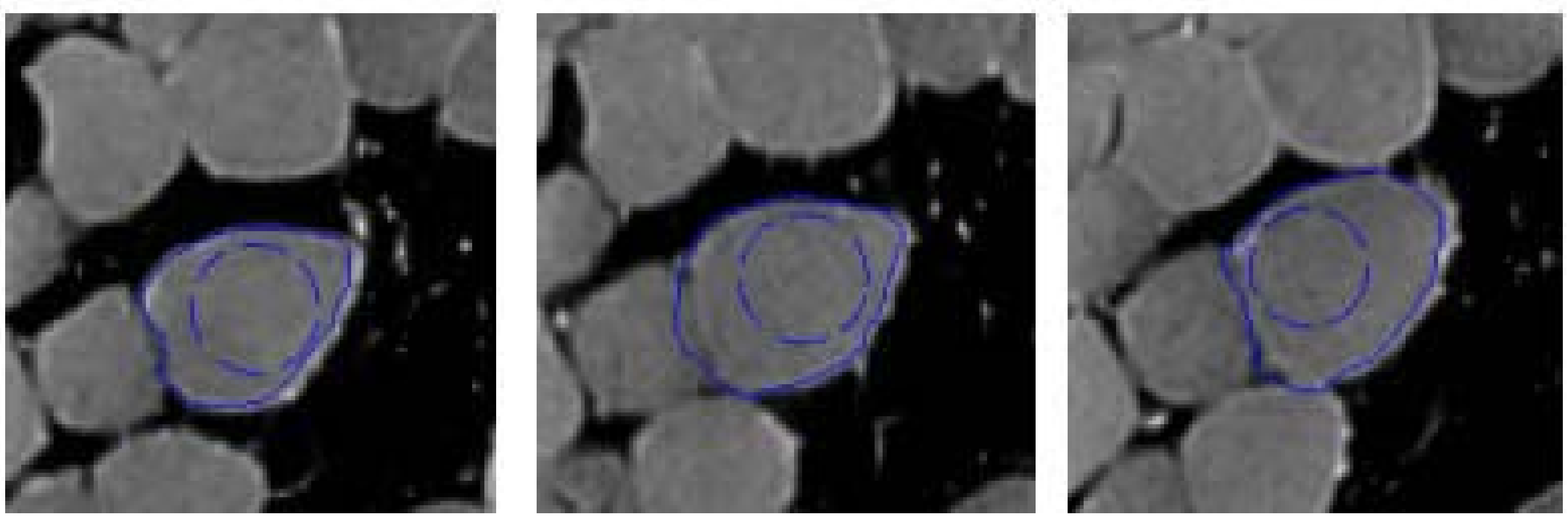


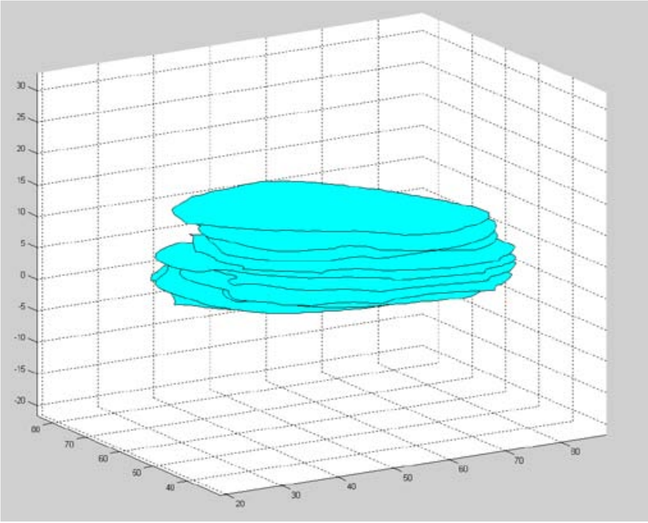
Errors and Computational Time

- The area of one single muscle fibre is computed by manually segmenting it and counting the number of pixels within it: 1304 Pixels.
- After pre-filtering, the same fibre consists of 1050 Pixels in the gradient image → loss of 19.5% of the area.
- The contour found by the active contours method has 1273 Pixels → loss of 2.4%.
- Total time for Region 1 (size 263x143 ≈ 64 K pixel): 12.76s.
  (pre-filtering process took 0.36s, the circle detection 0.27s, and the active contours algorithm 12.13s)
- Algorithms are implemented in MATLAB → C code or GPU code provides a significant speed-up.

Extension to 3D

- To extract the 3D muscle fibre contour we simply run our algorithm on several 2D cross-section images and then merge the results.
- The whole process took 36.7s for a total of 10 images (vs. 12.7s for a single slice).
- Post processing / smoothing needs to be performed.





Initial, middle, and final contours of a stack of 10 cross-sections used to segment a 3D muscle fibre

Future Work

- Performance Engineering
  - Heterogeneous computing
  - OpenCL/CUDA optimization
  - Full segmentation process on GPU
- Segmentation
  - Improve active contours or test other segmentation approaches
  - Full 3D segmentation

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