A novel method for skeletal age estimation based on cranial suture analysis

1 Introduction

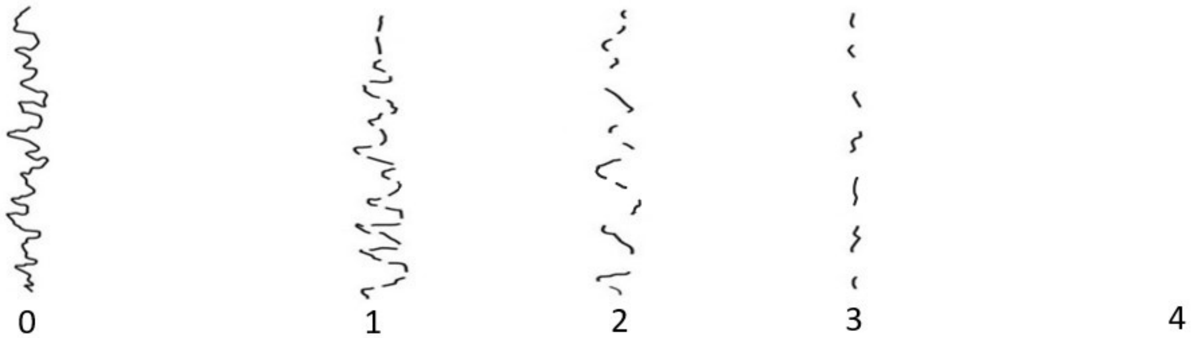


Figure 1: Example of a surface rating scale

Such rating scales assess the **continuity** of the suture on the surface.

2 Project process

2.1 Image generation

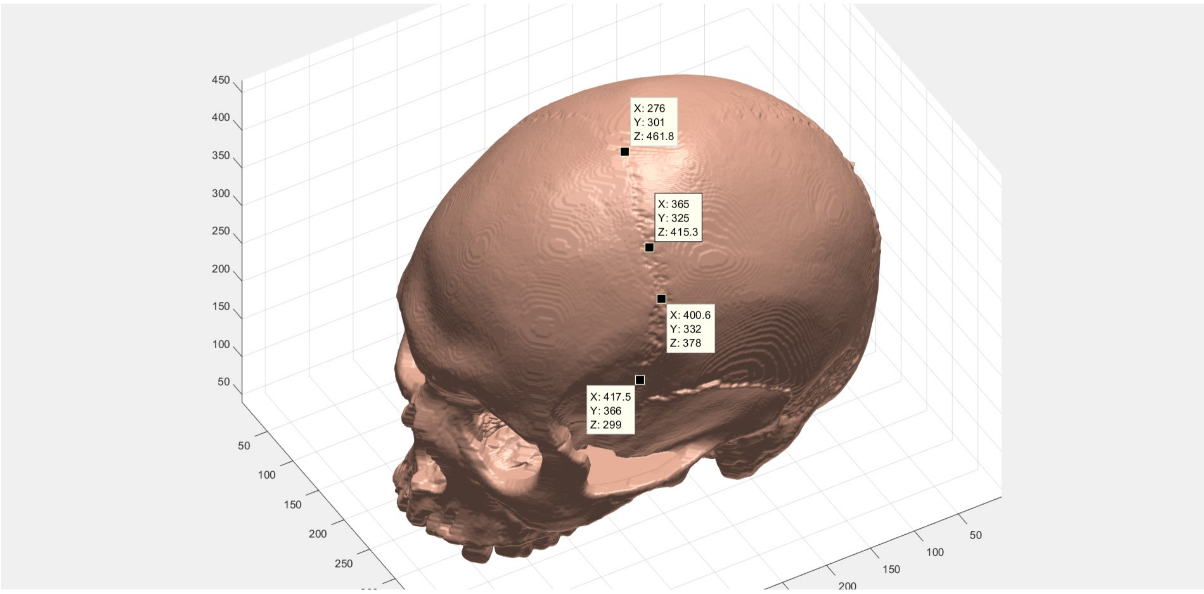


Figure 2: Suture path definition

The figure bellow shows a comparison between normals produced with different values of **N**.

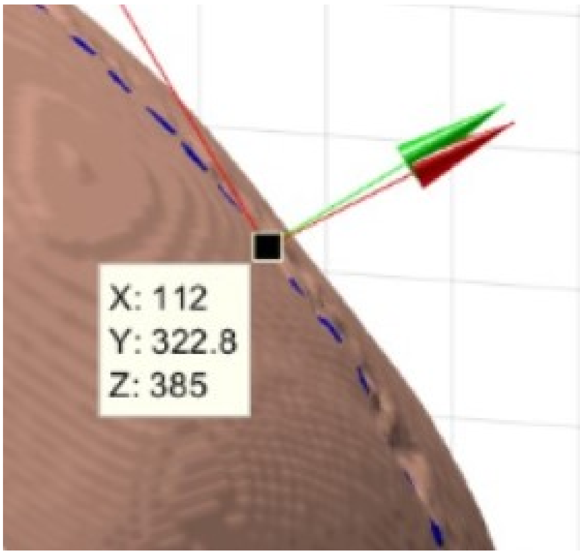


Figure 3: N = 20 (Green) N = 50 (Red)

The larger value of N, while being more reliable for the calculation of the normal vector, doubles the execution time of the function.

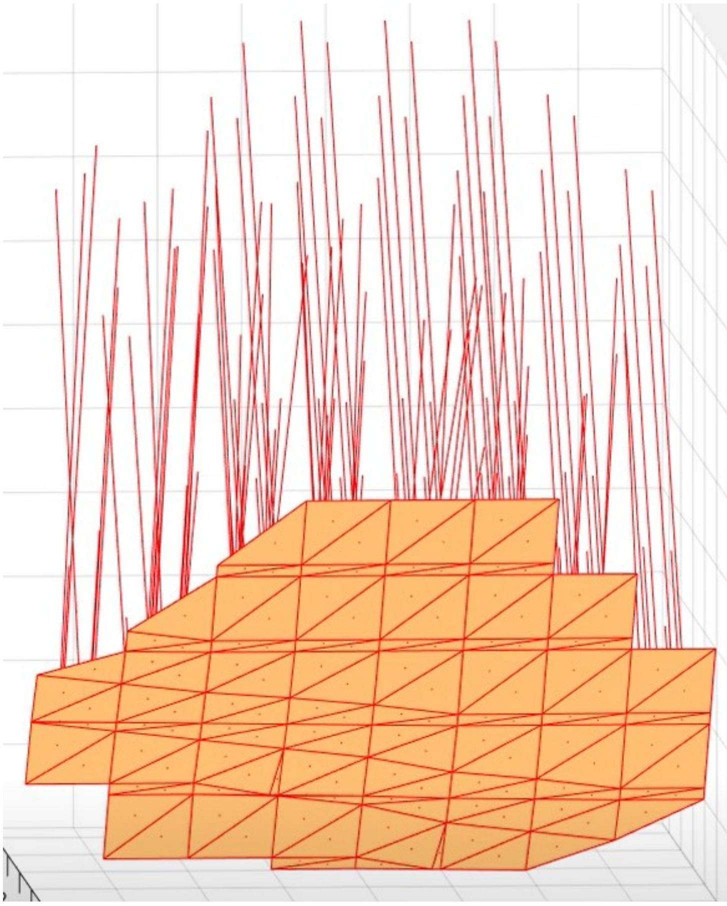


Figure 4: Triangular vector mesh for computing a single surface normal

2.2 Suture processing

2.2.1 Cross ratio measurement

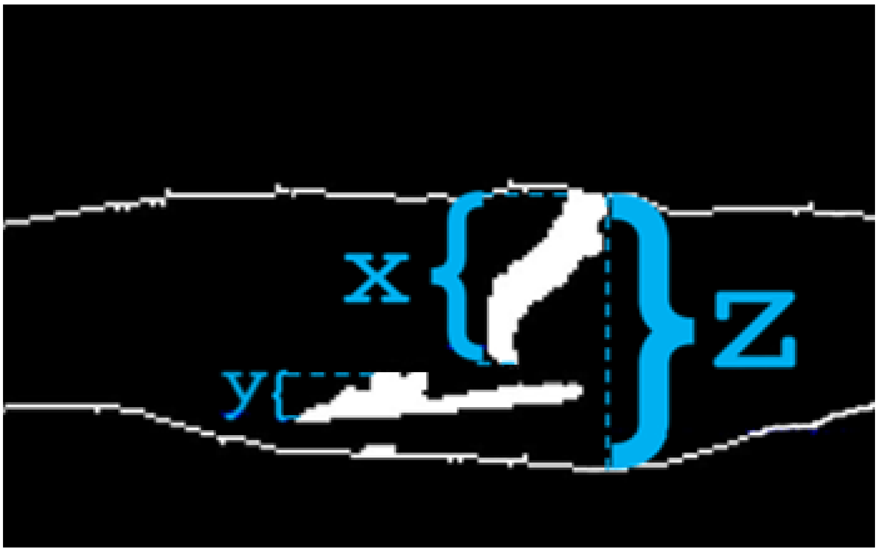


Figure 5: In the example, the original image has been processed with the *Canny* [2] edge-detection algorithm

Let's call the Z orientation the **line of depth**. The **line of depth** is used to determine what percentage of the bone cross-section is occupied by a suture. It represents a line, perpendicular to the bone width. To find the orientation of a line parallel to the bone length, the MATLAB *regionprops* function has been used.

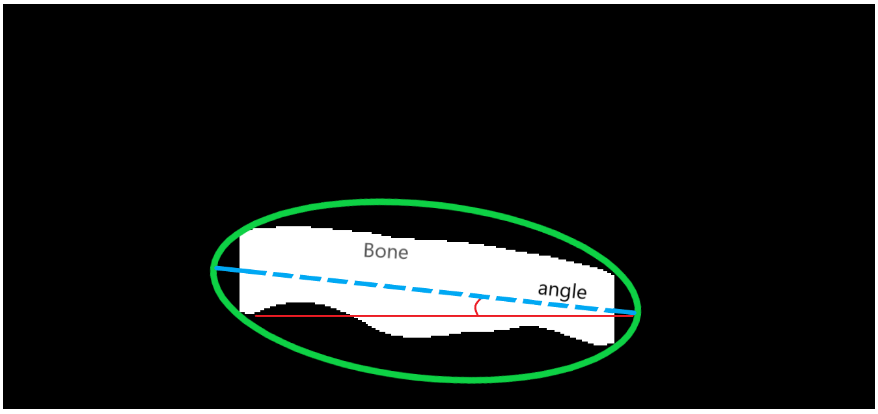


Figure 6: The original image has been binarized in this example

The output is a variable **angle**, which is described as the angle between the **line of best fit** through the bone and the horizontal. The gradient of the **line of best fit** is found from the given **angle**.

$$\mathrm{m} = -\tan\alpha$$

Where α is the **angle** between the **line of best fit** and the horizontal

The **line of depth** is perpendicular to the **line of best fit**, so it's gradient can be calculated as $\frac{-1}{m}$.

Ideally, the algorithm should compare the occupied by a suture cross-sectional length, to the entire cross-section length at the same position in the bone. This is due to the bone thickness not being uniform throughout the bone width. Therefore, the equation of the **line of depth** is made to pass through the midpoint of the suture region. The equation of the **line of depth** is of the form $y = mx + c$

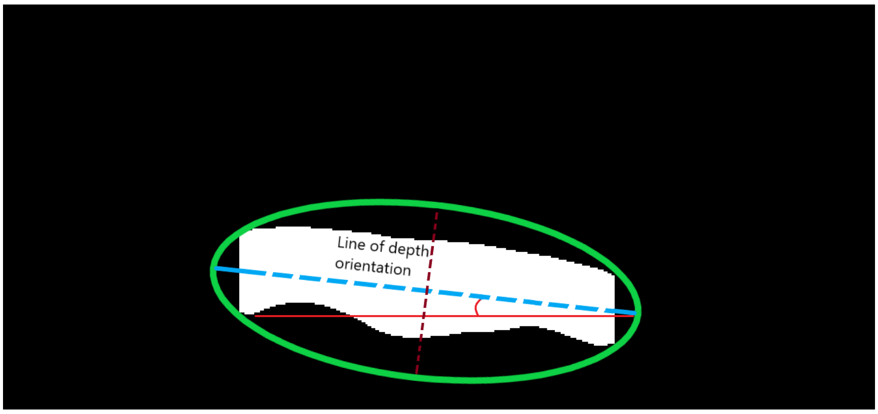


Figure 7

The next part computes the points on the most outer part of the bone (**defining points**), which lie on the **line of depth**. Those points will be used to define the Z orientation.
To find the **defining points** the algorithm uses the *improfile* MATLAB function, which generates n equally spaced points along the **line of depth** within the image, where the chosen value is $n = 100$ to ensure accurate placement of the **defining points**. Those points are stored in the **line points** array. The two points furthest from the midpoint and within the bone boundary are taken as the **defining points**.

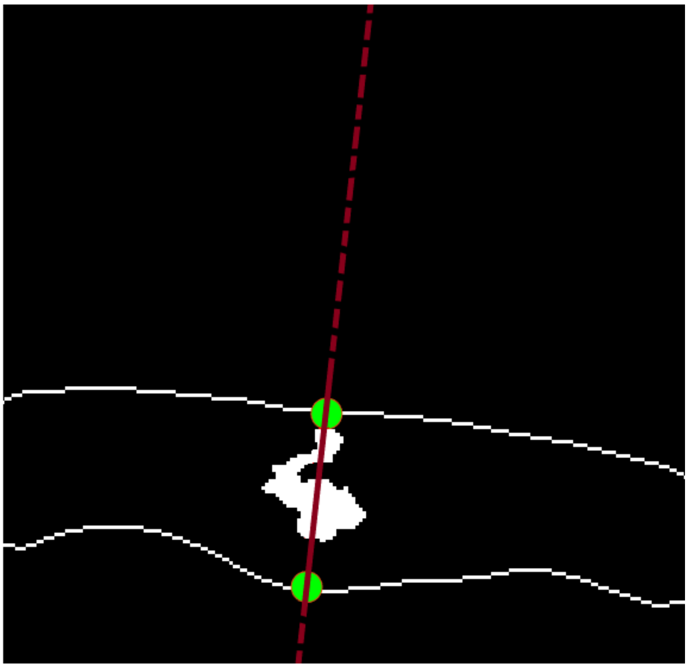


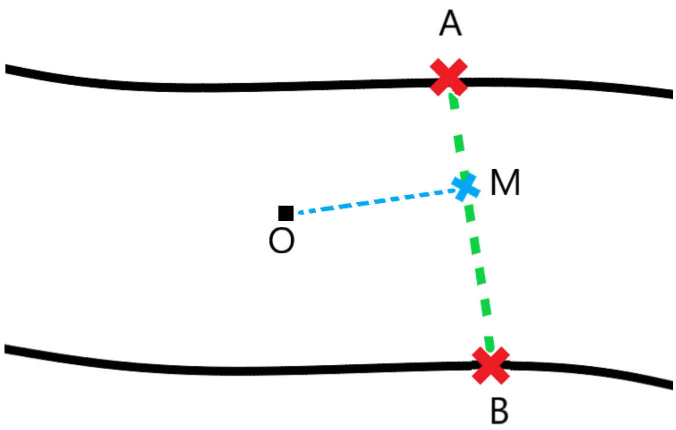
Figure 8: In the example, the original image has been processed with the *Canny* [2] edge-detection algorithm.

The two green points on *Figure 8* are taken as defining the **line of depth**, which is the **Z** orientation on *Figure 5*. Every pixel, classified as part of the suture has **X** and **Y** coordinates on the image plane. Groups of such suture pixels are marked by **X** and **Y** on *Figure 5*. From each suture pixel, a perpendicular projection to the **line of depth** is found.

O - a pixel classified as part of the suture on the image grid

A *and* B - the defining points of the **line of depth**

M - foot of perpendicular from O to $\overrightarrow{AB}$



$$\overrightarrow{MO} \perp \overrightarrow{AB}$$
$$\overrightarrow{MO} = ?$$
$$|\overrightarrow{AM}| = \frac{\overrightarrow{AO} \cdot \overrightarrow{AB}}{|\overrightarrow{AB}|} \qquad \frac{|\overrightarrow{AM}|}{|\overrightarrow{AB}|} = C$$
$$M = A + C \times \overrightarrow{AB}$$
$$\overrightarrow{MO} = O - M$$

Figure 9

The coordinates of the foot of the perpendicular M are recorded. The process is repeated for every suture pixel and the coordinates of M are stored in the **suture points** array. The elements in the array are rounded to the nearest integer, so that they are in discrete format like the image grid.
The elements of the **line points** array are also rounded to integers for the same reason. Any repeated elements in both arrays are discarded. The next figure represents the points contained in the **line points** array.

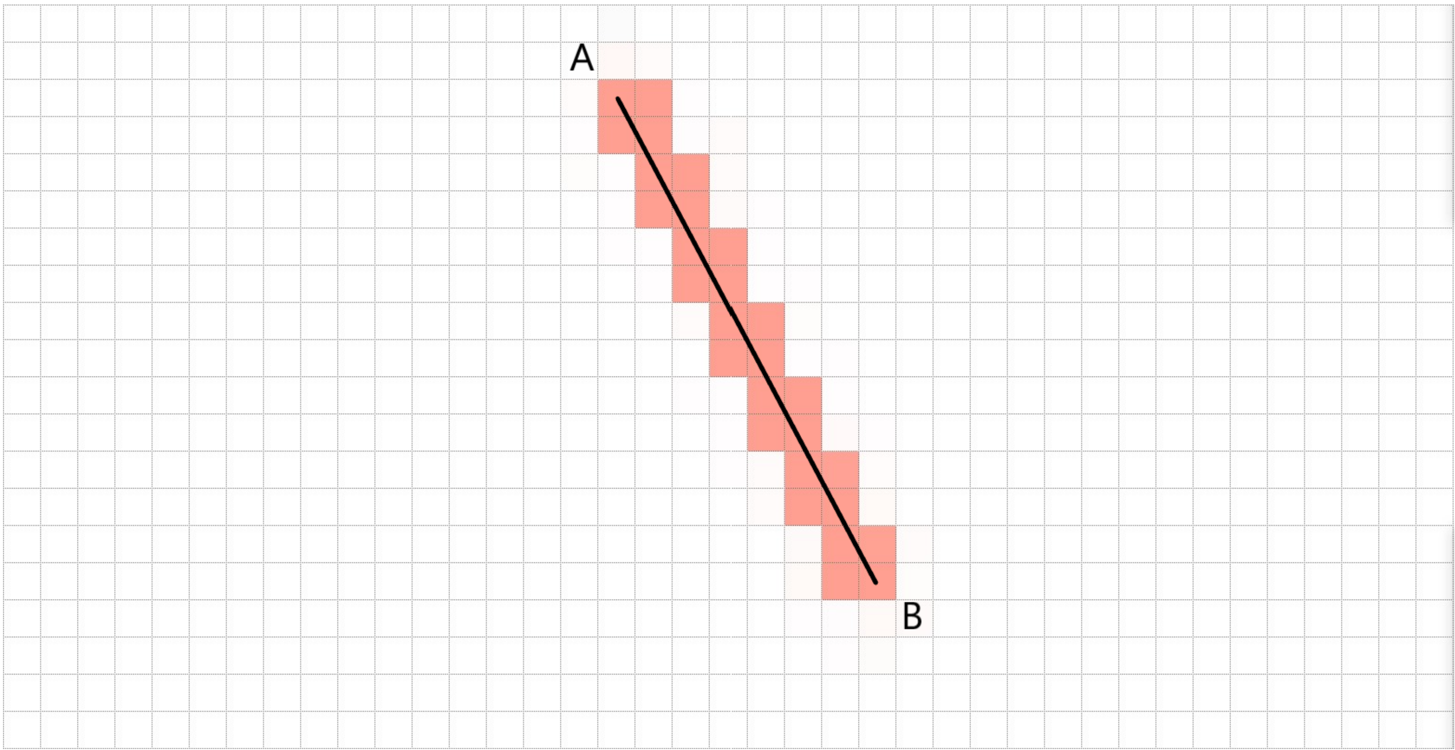


Figure 10

The **Cross ratio** is measured as

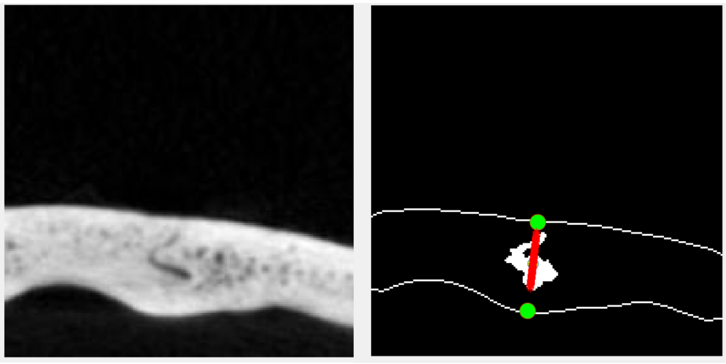
S - Number of elements from **suture points** array matching with an element from **line points**

L - Number of elements in **line points** array

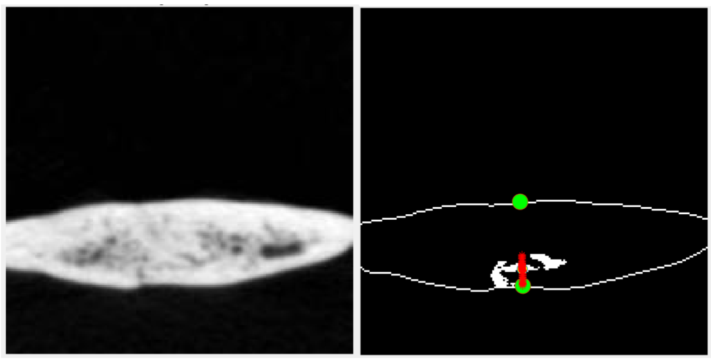
$$\text{Cross ratio} = \frac{S}{L}$$

On the following examples, the red line marks that places where the perpendicular from the pixels to the **line of depth** intersects it.

Examples of Cross ratio values for different sutures

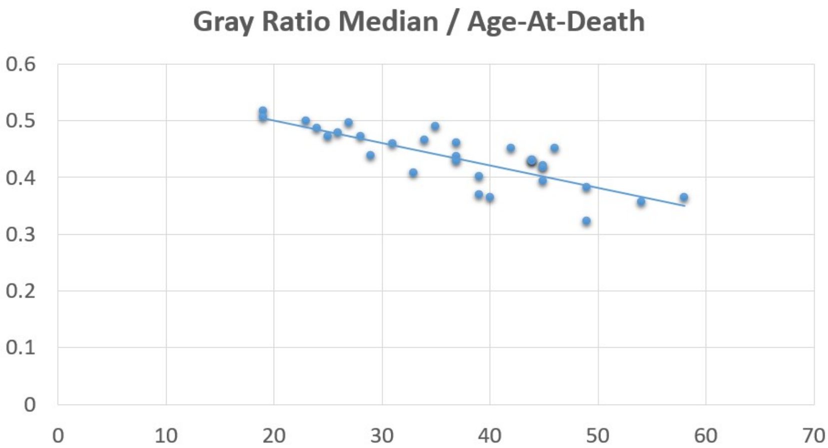


Cross ratio = 0.72



Cross ratio = 0.32

3 Statistical Analysis



p – population correlation coefficient
r – Product Moment Correlation Coefficient
$H_0: \quad p = 0$
$H_1: \quad p < 0$
Critical value for n=31 : -0.4421
1-tailed test, at the 0.5 % significance level

$$r = r_{xy} = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{\sqrt{(\sum x_i^2 - n\bar{x}^2)}\sqrt{(\sum y_i^2 - n\bar{y}^2)}}$$

$r = -0.80653$

$-0.80653 < -0.4421$, reject H_0, accept H_1

Figure 11

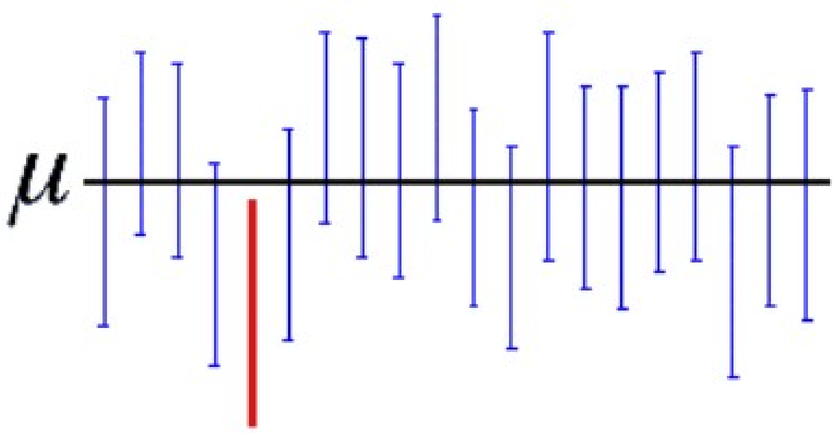


Figure 12: 95% Confidence Interval for population mean AAD

The **95% confidence interval** for the AAD of only 1 (red) individual does not contain the true mean AAD for an individual with such metric values.

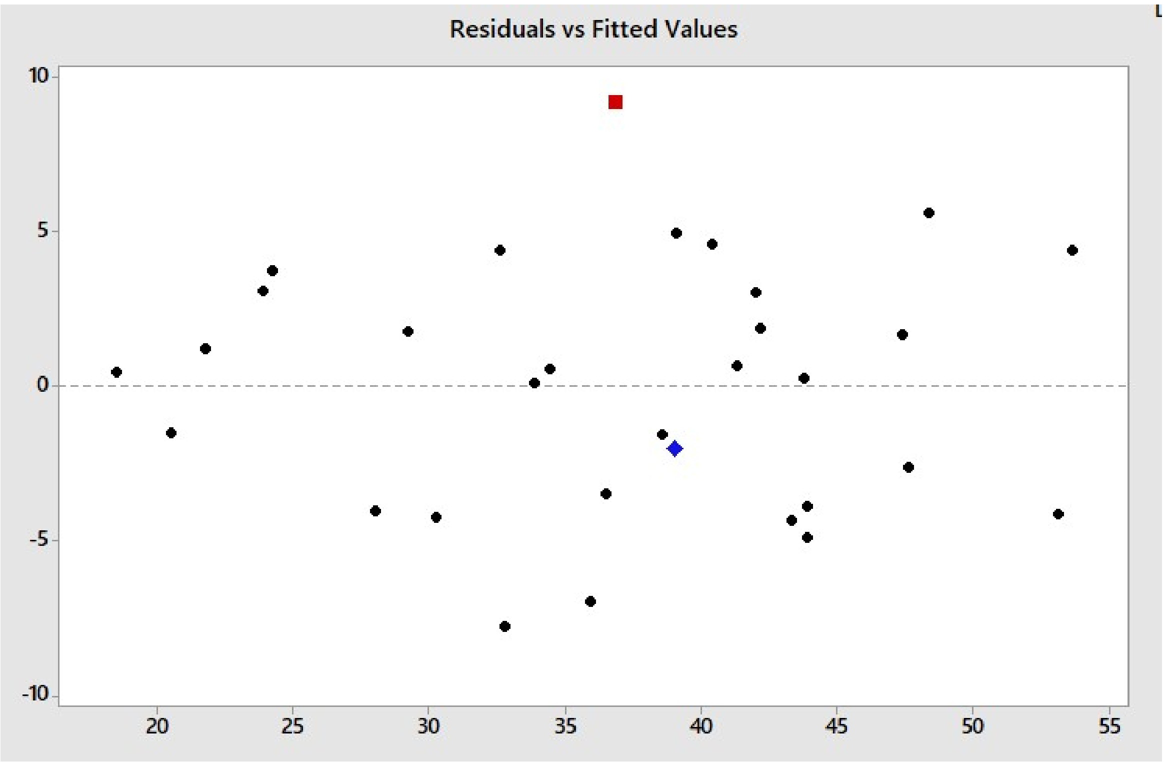


Figure 13

Standard Error = 3.2

4 Technologies and resources

1. The CT data for this project is provided by an industrial µCT system Nikon XT H 225, developed by Nikon Metrology.
2. For the implementation of the cross-sectional image generator, the image processing and the Semantic Segmentation neural network, I've used *MATLAB R2018a*.
3. For the statistical analysis, I've used *Minitab 17*.
4. For part of the data labeling, I've used *Labelbox* (https://labelbox.com/)

References

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