Which Hand? – 22GO5

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BACKGROUND

Focused Ultrasound Treatment (FUS) is a promising treatment for movement disorders such as Essential Tremor (ET) and Parkinson's Disease (PD). FUS is a non-invasive treatment that functions by delivering sound waves to the patient's thalamus, the part of the brain responsible for relaying sensory and motor signals, resulting in the formation of a permanent lesion in this region of the brain [1][2]. This lesion interrupts abnormal brain activity, reducing uncontrollable movements associated with ET and PD. FUS is only performed on one side of the brain, thus it only improves the movement on one side of the body. This treatment has been seen to result in immediate reduction in tremor in the side of the body receiving treatment. This study will focus on FUS as a treatment for patients with ET and PD in an attempt to determine whether the treatment is successful in reducing tremor, slowing the progression of these conditions.

AIM

Quantitatively investigate the efficacy of the FUS treatment by investigating computational and statistical analysis of spiral drawings. Provide insight about the extent that these results can be used to assess the severity of tremor on the patient's treated or untreated side after the treatment.
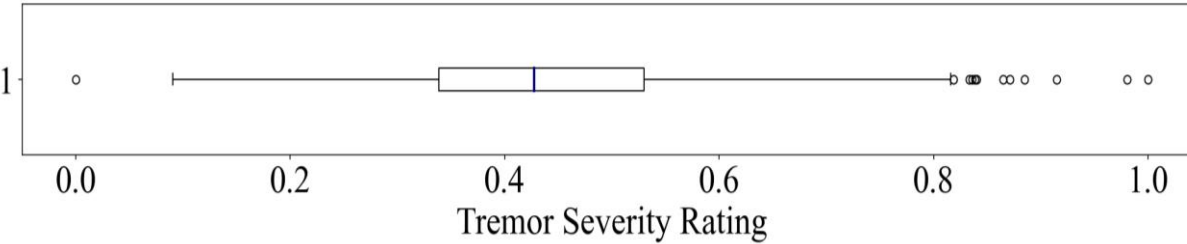
DATA

The Rambam Medical Centre, Haifa Israel, has provided fully anonymised data of patients' hand drawn shapes over time of treatment with both treated and untreated hand. Out of the 122 patients, 34 are undergoing treatment for Parkinson's Disease, and the remaining 88 for Essential Tremor, however, this project does not differentiate between disease/disorder, but only on success of treatment.

DATA PRE-PROCESSING

Data Analysis
- Each patient fills in the same template with both hands before and after receiving treatment. These paper drawings are scanned and saved as a PDF.
- Some scans are pixelated, rotated or contain erroneous markings.
- Each scan is converted to JPEG format.

Basic Cropping
- OpenCV EAST Text Detection [4] detects the corner coordinates of the "Drawing A", "Drawing B" and "Drawing C" text.
- The relative position of spiral A, spiral B, and line-block C is determined using the best available combination of the text coordinates.
- Each new image is cropped and resized to ensure consistent pixel distribution for better comparison further.

Further Correction
- To remove any erroneous markings, each cropped image is converted to greyscale. Then all dark pixels are converted to black and the remainder to white.
- OpenCV is used to identify the solid black rectangles in line-block C images [5] to correct any rotation or perspective warp [6]. Only the top most line is saved.

Final Clean-up
- A high rate of acceptably cropped and corrected images was produced.
- Erroneous results occurred due to poor quality inputted scans.
- These were manually removed or corrected if possible.

Completed template

Identified text coordinates

Relative crop positions

Cropped spirals

Drawing C needing rotation

Cropped line

METHOD 1: SPIRAL DRAWING TREMOR QUANTIFICATION

The severity of the spiral drawings was assessed using edge detection to determine the gradient of every pixel in the spiral. This gradient was used to find the orientation of each edge in the spiral relative to the centre of the spiral. The relative orientation of each edge provided the means to determine the distribution of edge angles throughout the drawing, providing insight on the tremor severity of the hand drawn spiral.

Sobel Edge Detection
- Noise reduction was performed to suppress as much noise as possible without interfering with the edges.
- Sobel edge detection was used to find the gradient of edges separated by light and dark colours in the image. Two 9x9 Sobel filters, S_x and S_y were used. S_x was used to find the horizontal changes and S_y was used to find the vertical changes. These gradients were found by convolving the filters with the image array (I) [3][7].

$$G_x = S_x * I \qquad G_y = S_y * I$$

The orientation of the gradients, or the edge angles, were found by taking the inverse tangent of the ratio between the vertical gradients and the horizontal gradients:.

$$\varphi = \arctan\left(\frac{G_y}{G_x}\right)$$

Pixel Angles
- The centre of the spiral was calculated by taking the median of the x and y coordinates of the non-white image pixels.
- The angle between each pixel point and the centre of the spiral was calculated by taking the inverse tangent of the ratio of the vertical distance from the centre for each pixel and the horizontal distance from the centre for each pixel.[7].

$$\alpha = \arctan\left(\frac{y-ycentre}{x-xcentre}\right)$$

Relative Orientation
The relative orientation of all the edges were calculated by subtracting the pixel angles from the edge angles: $\theta = \varphi - \alpha$

Tremor Quantification
The distribution of the relative orientation angles was plotted in the form of a histogram to outline the distribution of edge angles. The main indication of high tremor is a high standard deviation. A more widely distributed histogram indicates that the edge angles in the spiral vary considerably. The standard deviations for each spiral for each patient were determined and normalised to form a dataset quantifying each spiral tremor for each patient.

Spiral A1

Spiral A2

Relative Orientation Distributions

Normalised Standard Deviations of Relative Orientations

	Spiral A1	Spiral A2
Normalised Standard Deviation	0.64	0.15

Tremor Severities Box and Whisker Plot for Both Hands

METHOD 2: LINE DRAWING TREMOR QUANTIFICATION

Extracting the Hand-Drawn Line
The line image is analysed and the x- and y-coordinates of non-white pixels are extracted and stored in sorted arrays. The y-values are shifted to be centred around the horizontal axis.
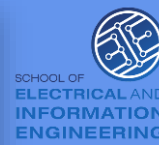
Noise Reduction
The real one-dimensional Fourier Transform is computed to identify the small range of useful frequencies. The higher unwanted frequencies, caused by pixelated/blurry input or erroneous markings on the original drawing, are discarded.

The inverse discrete Fourier transform is computed producing data that is noise free. All maximum (peak) and minimum (trough) points are found to count the number of tremors as well as the distance between each adjacent peak and trough.

Determining a Tremor Severity Measure
1. The number of peaks is an indication of the frequency of the patient's tremors. In general, more peaks indicates a worse tremor.

2. The distance between each adjacent peak and trough indicate the severity of the tremor. A larger distance only indicates a worse tremor when occurring with a high number of peaks.
   A large distance with a very low number of peaks could be an indication of a line image that has been incorrectly cropped (slanted).

Since these two variables are proportionally linked to the severity of a tremor, the product of the two variables is used as an indication of tremor severity.
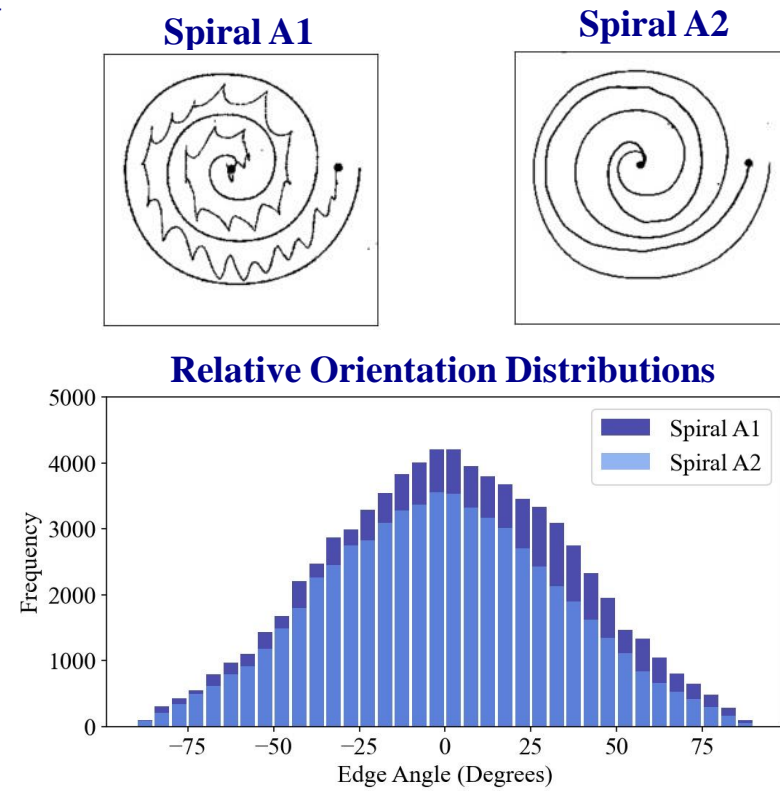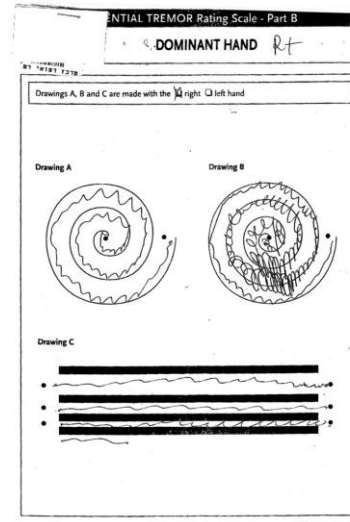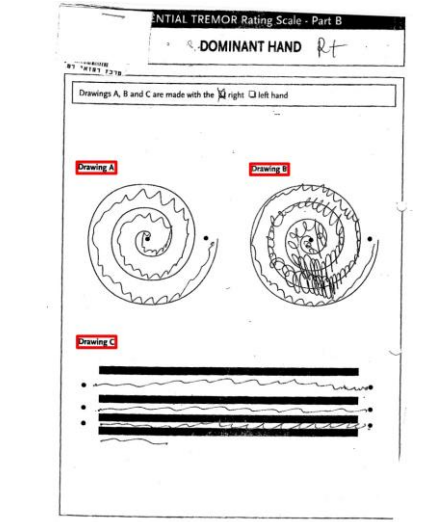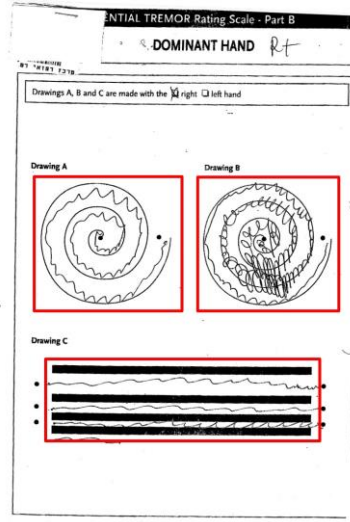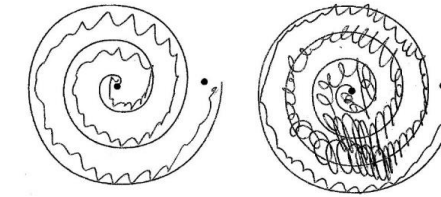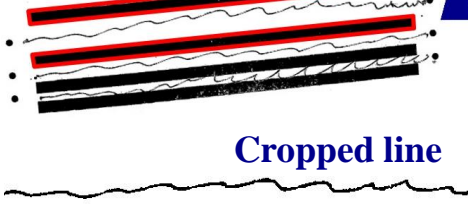
Patient #5 Treated Hand: Extracted line images

BEFORE TREATMENT

AFTER 1 YEAR

RFFT of line coordinate array before treatment and after 1 year

MAX: 11087.03

MAX: 2093.07

Noise-free data (orange) and original data points (blue) before treatment and after 1 year

Patient #5 Treated Hand: Final calculation of tremor severity using method 2

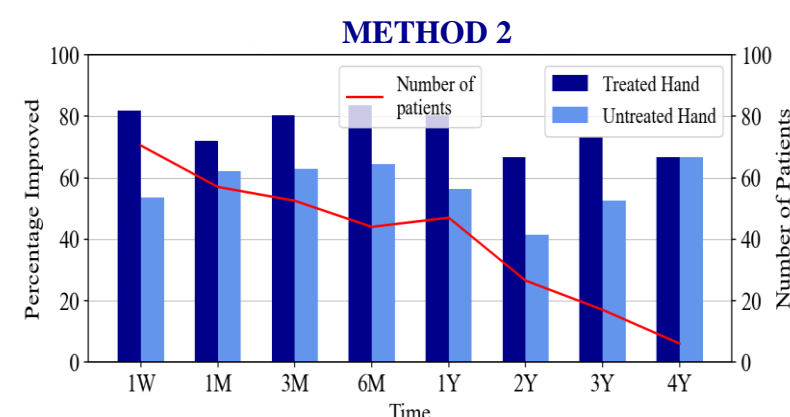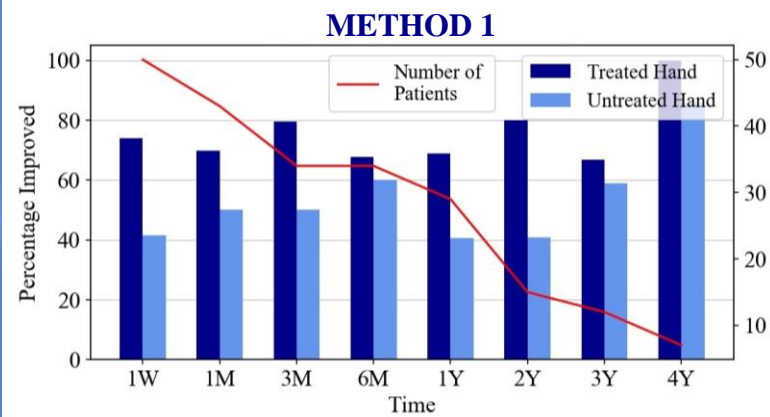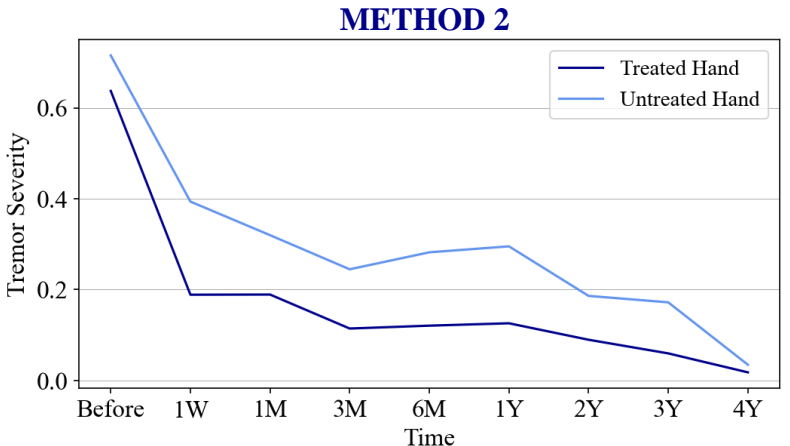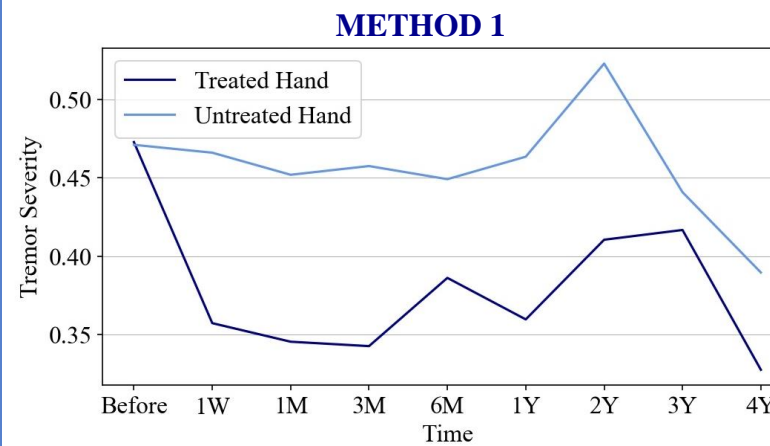| Before treatment	After 1 year
12 peaks*5.81 avg. peak adjacent distance = 69.67 tremor severity	7 peaks*2.43 avg. peak adjacent distance = 17.02 tremor severity

DISCUSSION OF RESULTS

The tremor severity ratings were determined for each patient's treated and untreated hand over various time periods. Method 1 used the normalised standard deviations of the relative orientation distributions of spiral A. Method 2 used the product of the number of peaks and average peak-to-trough distance of line C.

Percentage of Patients with Tremor Before Treatment that Improved After Various Treatment Times.

METHOD 1

METHOD 2

Average Tremor Severities for Each Hand

METHOD 1

METHOD 2

To determine whether these methods are effective indications of the treatment's success, the average tremor severity rating as well as percentage of patients whose tremor improved, was determined.

The number of patients with treatment results decreases over time which affects the reliability of the later years' results.

Method 1 indicates that FUS treatment is successful, with an average of 76% of the treated hands seeing an immediate improvement in tremor severity after treatment. Method 2 has similar results with 76% of treated hands seeing improvement after treatment. There is also an immediate decrease in the average tremor severity of the treated hand for both methods 1 and 2, indicating that treatment is successful over time.

REFERENCES

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[3] University of Auckland, New Zealand, "Edge Detection."

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[6] jdhao, "Cropping Rotated Rectangles from Image with OpenCV," jdhao's digital space, 23 February 2019. [Online]. Available: https://jdhao.github.io/2019/02/23/crop_rotated_rectangle_opencv/. [Accessed 26 July 2022].

[7] Wille, M. Sangaré, and S. Winter, "Analysis of patterns in tremor diagnosis spiral drawings for automated classification," *Biomedical Engineering / Biomedizinische Technik*, 2013.