Which Hand? – 22PO5

Robyn Gebbie and Jesse van der Merwe

SCHOOL OF ELECTRICAL AND INFORMATION ENGINEERING

WITS UNIVERSITY 1922 2022

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 new treatment technique that has proven to have a therapeutic effect on brain disorders. 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.

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:

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

The result of this operation was a 500x500 array containing the angles each pixel in the image was forming due to the gradient of each edge.

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.

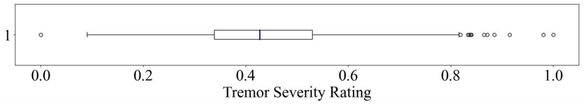
Spiral A1

Spiral A2

TABLE 1: Normalised Standard Deviations of Relative Orientations

	Spiral A1	Spiral A2
Normalised Standard Deviation	0.63	0.19

Tremor Severities Box and Whisker Plot for Both Hands



METHOD 2: LINE DRAWING TREMOR QUANTIFICATION

Extracting the Hand-Drawn Line

The line image is inputted using the cv2 *imread( )* function. NumPy *argwhere( )* function extracts the x- and y-coordinates of every pixel that is not white. These pixels are stored in arrays sorted according to the x-axis. Each y-value is shifted by the average y-value to centre the line around the horizontal axis.

Noise Reduction

Since all y-values are real, the faster SciPy *rfft( )* function is used to compute the one-dimensional Fourier Transform. It can be seen that there is a very small range of useful frequencies. The higher unwanted frequencies – caused by pixelated/blurry input or erroneous markings on the original drawing – are discarded.

The SciPy *irfft( )* function is used to return the inverse discrete Fourier transform once again. The data is now noise free and the Signal *find_peaks( )* function is used to find all maximum (peak) and minimum (trough) points in order 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 in the function 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 tremor's peaks and troughs 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.

TABLE 2:

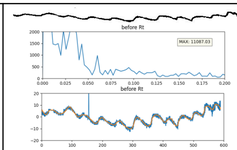
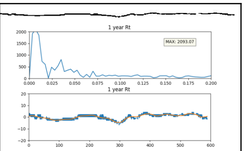
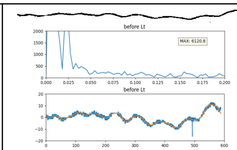
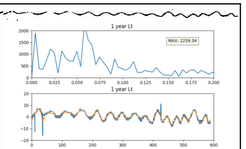
	Treated Hand BEFORE	Treated Hand 1 YEAR
Original drawing		
RFFT		
IIR bandpass filter		
Result	12 peaks * 5.81 avg. peak adjacent distance = 69.67 tremor severity	7 peaks * 2.43 avg. peak adjacent distance = 17.02 tremor severity

TABLE 3:

	Untreated Hand BEFORE	Untreated Hand 1 YEAR
Original drawing		
RFFT		
IIR bandpass filter		
Result	8 peaks * 4.95 avg. peak adjacent distance = 39.58 tremor severity	16 peaks * 6.18 avg. peak adjacent distance = 98.81 tremor severity

DATA

The Rambam Medical Centre, Haifa Israel, has provided data that comprises of 122 fully anonymised hand drawn shapes on paper that patients and drew over time of treatment with both their 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, it was decided to group all patients together as the aim of this project does not differentiate between disease/disorder, but only on success of treatment.

DATA PRE-PROCESSING

Data Analysis

- Each patient completes multiple template drawings with both hands at various time intervals before and after receiving treatment. These physical drawings are scanned and saved as a PDF.
- Some scans are pixelated, rotated or contain erroneous markings.
- Each scan is converted to JPE format using Pdf2Image *convert_from_path( ).*

Basic Cropping

- OpenCV EAST Text Detection [4] detects the corner coordinates of the "Drawing A", "Drawing B" and "Drawing C" text on each image.
- 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.

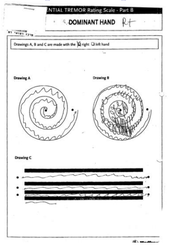
Further Correction

- In order to remove any erroneous markings and save only the template and hand-drawn markings, each cropped image is converted to greyscale. Then all dark pixels are converted to black and all light pixels to white.
- OpenCV is used to identify the solid black rectangles in the line-block images [5] to correct any rotation or perspective warp [6]. Only the top most line is saved.

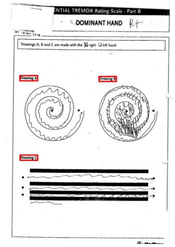
Final Clean-up

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

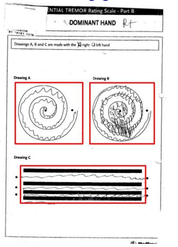
Completed template



Identified text coordinates

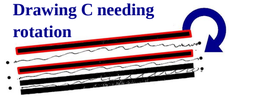


Relative crop positions



Cropped spirals

Drawing C needing rotation



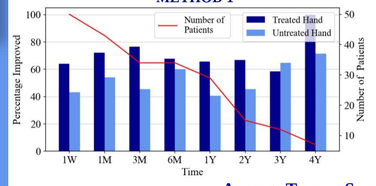
Cropped line

DISCUSSION OF RESULTS

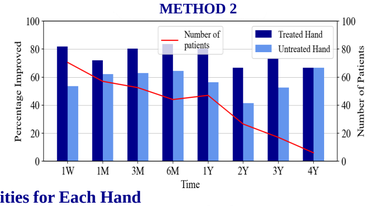
The tremor severity ratings were determined for each patient's treated and untreated hands for each given treatment period. Method 1 uses the normalised standard deviations of the relative orientation distributions. Method 2 uses the product of the number of peaks and average peak-to-trough adjacent distance.

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

METHOD 1



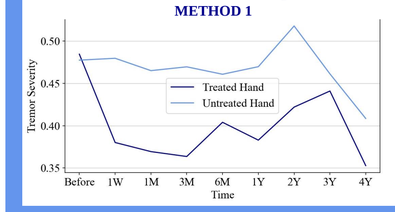
METHOD 2



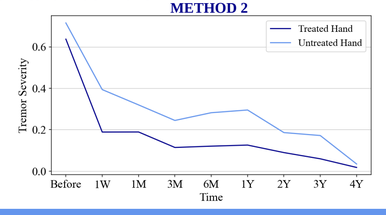
The percentage of patients whose tremor improved was determined for each time period, as well as the average severity for each treatment period. It is important to note that the number of patients that went for treatment greatly decreases as time progresses which affects the reliability of the later years' results.

Average Tremor Severities for Each Hand

METHOD 1



METHOD 2



Overall, method 1 indicates that FUS treatment is successful, with an average of 71% of the treated hands seeing an immediate improvement in tremor severity after treatment and an immediate decrease in the average tremor severity of the treated hand spirals after treatment begins is evident in the Average Tremor Severities graph. Method 2 has similar results with 76% of treated hands seeing improvement after treatment.

REFERENCES

[1] H. Baek, D. Lockwood, E. J. Mason, E. Obusez, M. Poturalski, R. Rammo, S. J. Nagel and S. E. Jones, "Clinical Intervention Using Focused Ultrasound (FUS) Stimulation of the Brain in Diverse Neurological Disorders," *Frontiers in Neurology*, vol. 13, 2022.
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[3] University of Auckland, New Zealand, "Edge Detection."
[4] A. Rosebrock, "OpenCV Text Detection (EAST text detector) - PyImageSearch," PyImageSearch, 20 August 2018. [Online]. Available: https://pyimagesearch.com/2018/08/20/opencv-text-detection-east-text-detector/. [Accessed 16 July 2022].
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[7] Wille, M. Sangaré, and S. Winter, "Analysis of patterns in tremor diagnosis spiral drawings for automated classification," *Biomedical Engineering / Biomedizinische Technik*, 2013.