VALIDATION OF THE CORTICAL HOMUNCULUS USING FUNCTIONAL MRI

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ABSTRACT

The motor strip in the frontal lobe of the Human Brain is responsible for all bodily movements or "motor functions". In this paper we attempt to map the motor cortex of the Human Brain using fMRI data. The advantages of mapping it are several fold ranging from therapy to epilepsy and stroke patients, to understanding the development of these motor functions from birth. We try to recreate the homunculus, a concept which showed how the real estate of the motor cortex was distributed across these motor functions.

Index Terms— fMRI, Primary Motor Cortex, Homunculus.

1. INTRODUCTION

The Human brain is the most important organ of the body, however we are still not entirely clear about how or why it works the way it does. While understanding the semantics behind our actions will require us to understand the entire human brain, we attempt to solve a much more low level problem of what happens when humans engage in day to day actions. To be more precise, this involves studying the Primary Motor Cortex or the Motor Strip which is responsible for all our motor functions, from our tongue to walking, running etc. Penfield and Boldrey [1] formulated the concept of the **Cortical Homunculus** which is a pictorial representation of the anatomical divisions of the motor strip. It is a fictional body in which the size of each part is directly proportional its allocated volume in the motor strip. An illustration of this is shown in fig-1[1].

We propose to recreate this homunculus using fMRI data. Classical methods have used electrical stimulation to see which part of the motor strip corresponds to which motor function this is obviously not a very practical method. fMRI offers us the advantage of being relatively fast, safe and noninvasive. Another immediate advantage of using fMRI data is that we can apply commonly used image processing techniques to get meaningful information from them. We propose to use a simple region growing algorithm to identify the areas within the motor strip that correspond to the motor function that is being studied.

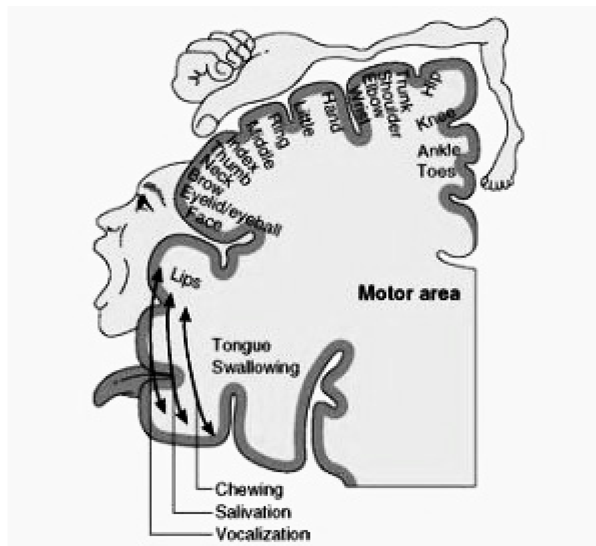

Fig. 1. The idea of the Cortical homunculus as created by Wilder Penfield.

Contributions We propose to study the brain activation areas within the motor strip of the Human Brain to validate the homunculus constructed by Dr. Wilder Penfield in 1937. The main contribution of this study is in reiterating the classical results of Dr. Penfield using modern methods such as the fMRI. A big advantage of using fMRI data apart from being being noninvasive, is that it allows us to use well established image processing techniques to study details of the brain accurately.

Outline In Section 2 we will discuss the preliminaries of the problem and then discuss the image processing techniques used to extract the relevant regions within the fMRI data. This is followed by experiments in Section 3 and Conclusions and Future Work in Section 4.

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[1]Courtesy: McGill University.

2. PRELIMINARIES

2.1. Functional Magnetic Resonance Imaging

The f-MRI is a specialized type of MRI that is used to measure the change in blood flow related to neural activity in the brain or spinal cord of humans or other animals. Recently, this has become the most widely used noninvasive technique to identify the location of the cortical primary motor areas (PMA) preoperatively [2]. It has also been shown that these activated areas shown by the fMRI correlate well with the intraoperative cortical simulation's site of the PMA [3]. This naturally led to MRI techniques being used increasingly by researchers to study brain activation. For neurosurgeons this meant more precision in identifying the tumor affected areas.

2.2. Brief history of the Homunculus

Penfield and Boldrey's important experiment [1] described their effects of electrical simulation of the the cerebral cortex in man. Their attempts to delineate parts of the motor strip into its functional parts was represented in the Homunculus. As described in [4] *"Whilst these now classical studies confirmed and greatly extended what had been known from earlier observations in awake humans and from experiments in animals, the manner of presentation of their findings was remarkable. It was the first time pictorial means of illustrating cortical representation had been attempted; it was thus an entirely new concept, but it was also one which has probed a curious method of illustration and one which gives rise to a number of unforeseen problems"*. However, this representation was very ambiguous for various reasons. A more lucid representation was provided a few years later by Penfield and Rasmussen [5]. However, some of the limitations to the experiment were that it was hard to identify precisely the area which corresponded to a motor function mainly because the stimulating electrodes were of comparatively large-diameter. The results were further made more ambiguous given the fact that most experiments were conducted on patients with brain disease, because normal patients have very different cortical areas from which sensory and motor phenomena can be elicited. Lastly, *plasticity*, which was proven to exist in animals [6] and humans [7, 8], ensures that such generalizations would fail to give accurate information.

There have been several attempts to accurately map the human brain. However, most relied on electrical stimulation [9, 10]. More noninvasive techniques recently include Magnetoencephalography [11], transcranial magnetic stimulation [12, 13], EEG [14] amongst others.

Once we have the data, the next step would be to segment the relevant parts of the image which give us information about how the motor strip is distributed across various motor functions. This can be easily achieved by using classical image segmentation techniques. We used the technique of region growing since it is inherently well suited for the problem.

2.3. Region Growing

Region Growing is a popular technique used in several applications of Image Processing. The algorithm is also guaranteed (by definition) to produce coherent regions and it works from inside out instead of outside in, which is precisely what we intend to do. Region Growing is a pixel-based image segmentation technique that is used to pick out regions around a chosen seed point of some given image. This approach involves looking at the neighboring pixels to see if they are similar to the seed point and keep "adding them to region" based on some similarity measure. The seed points influence the algorithm heavily, but in our problem there is no ambiguity in these since we choose the maximum intensity as the seed point. We intend to grow out from there on until some threshold conditions are met. These conditions are typically threshold values as explained in the algorithm 1. An illustration is also shown in Fig 2.

Algorithm 1 A Typical Region Growing Algorithm

Input Image I and identify the seed point s.
Define threshold $T \leq 1$.
Define Similarity Measure $S(i,j)$ where i,j are pixel intensities and $S(i,j)$ has a value close to 1 if $i \sim j$.
Define **R** as region of s.
for $\forall(i,j) \in Neighborhood(s)$ **do**
  $q = I(i,j)$;
  while $S(s,q) \geq T$ **do**
    $Add(i,j) \rightarrow \mathbf{R}$;
  end while
end for

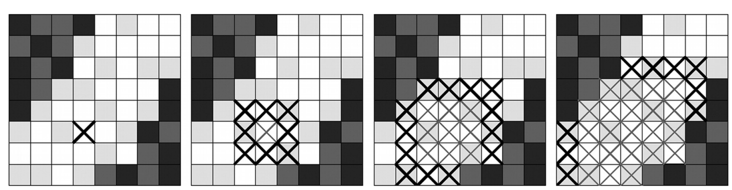

Fig. 2. An Illustration of the region growing method [15]

In our experiments, we will be dealing with 3D scan of the human brain, which can be converted to an $m \times n \times 3$ matrix[16]. Algorithm 1 can easily be extended to a 3D setting by searching in a 3D neighborhood. One of the most common Similarity Measures used is the "average intensity" which is defined here. Let r be the number of pixels in a given neighborhood **R** then S is given by:

$$S = \frac{\sum_{i,j \in \mathbf{R}} I(i,j)}{r} \quad (1)$$

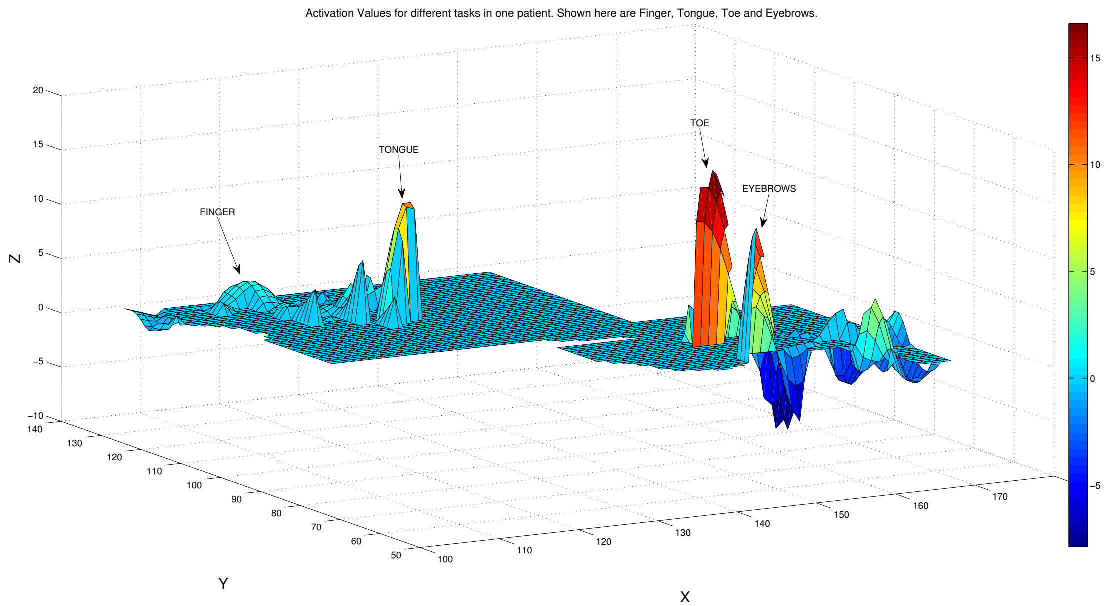

Fig. 3. Activation areas within the Motor Strip. X,Y give the spatial 2D coordinates and Z gives the magnitude of activation.

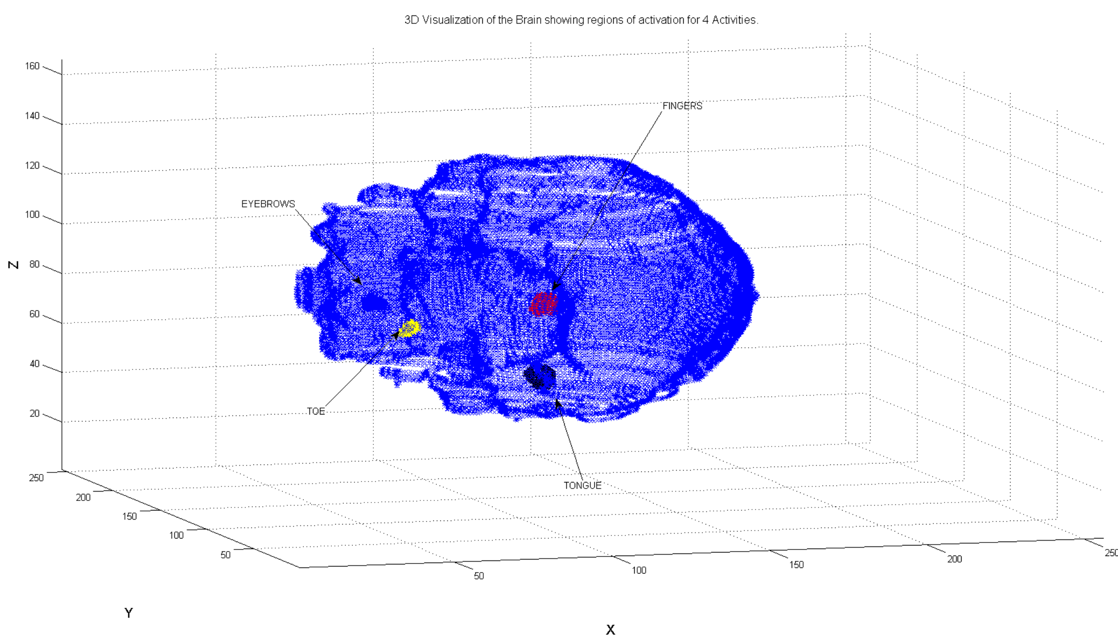

Fig. 4. Regions corresponding to different activities (Blue - Eyebrows, Red- Fingers, Yellow - Toe, Black - Tongue) are shown here. X,Y, Z represent the spatial coordinates.

3. EXPERIMENTS

3.1. Datasets

Data was collected[2] while patients were asked to perform simple repeated tasks such as moving their eyebrows, tapping their fingers etc. The dataset consisted of 4 activities :- Eyebrows, Fingers, Toe and Tongue. Activation areas corresponding to their sensory areas was also collected for these 4 tasks.

[2]Dr. Leslie Baxter of Barrow Neurological Institute, Phoenix, Arizona.

Preprocessing: Most of the preprocessing was done using the Statistical Parametric Mapping, a MATLAB Toolbox that is freely available for download. [16]. To maintain the accuracy of these observations, it is important to exclude activation areas that may have been caused due to distraction amongst the patients taking the task. For example, if a patient looks at another object or moves another part of his body during the experiment, there is a high chance that there will be high activation in parts of the brain other than those that are relevant to us. This is achieved here by using a binary mask that is manually defined in the regions of the motor strip. Applying this mask over the dataset gives us a clean view of only the motor strip, which we can process further.

Results and Observations: Fig 3 shows the activation areas for different tasks. These tasks occur at different points in space but they have been "brought to a common plane" for the sake of visualization. Similarly these 3D plots can be generated for the sensory data as well. Figure 4 shows the regions after they have been grown. These represent the parts of the brain within the motor strip that "light up" when the person is performing the activity associated with the blob. It is interesting to note that, between two activities, if one has a much higher activation and "Blob volume", then it is likely that that activity has a larger representation in the motor strip.

4. CONCLUSION AND FUTURE WORK

The problem of mapping the motor strip of the brain is a classical one, which has been studied by many researchers over the past few decades. However, most methods have been invasive which greatly limits the scope of research. In this paper, we proposed a method to study the motor activation areas corresponding to different activities using fMRI data. While being very non-invasive, this also allows us to apply well understood image processing techniques to analyze the motor strip in more detail. As it can be seen here, the activation areas are clearly discernible. Future work using this method would be to further study a wider range of activities over a larger set of patients. Another interesting problem this research poses, is to see how these motor activation areas vary across different individuals by quantifying these "areas".

5. REFERENCES

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