3D Brain Mapping of TMS, MRI, and Real Time Muscle Response

Dalton Bermudez[1], Ziva Rubinstein[1], Zhiying Zhu[1], Bethold Owusu[1], Joshua Khoo[1]

Dr. Dylan Edwards[2], Dr. Maribel Vazquez 1, Dr. Marom Bikson[1],Dr. Jeffrey Garanich[1]

[1]Department of Biomedical Engineering, The City College of New York/CUNY, New York, NY; [2]Laboratory of Brain Stimulation and Robotics, Burke Rehabilitation Hospital, White Plains, NY

Introduction

- Stroke is the 5th leading cause of death in the U.S [7]. Loss of muscle functions and coordination are the main symptoms experienced by stroke victims.

- Some stroke patients are able to recover given the brain's plasticity function, an innate ability of the brain to rewire and repair.

- Brain map is one of the current approach to understand the connection between muscle movement and brain activity.

- Brain map requires 3 types of patient data: Magnetic Resonance Imaging (MRI), Transcranial Magnetic Stimulation (TMS), Electromyography (EMG).

- Brain maps allow post-stroke assessment after therapy and help physicians to predict which patients are mostly likely to recover on their own and which will need the most intensive therapy.

Project Goal

- To develop a continuous brain map of the primary motor cortex from the compiled TMS, MRI, and EMG data

Prior Arts

Figure 1. Neural-Navigated TMS [1]

1. Neural-Navigated TMS Map

Pros:
- Good accuracy

Cons:
- Requires the presence of the patient
- Requires long mapping time
- Requires the purchase of a special hardware for mapping
- No continuous mapping

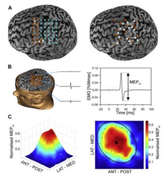


Figure 2. Rapid Brain Mapping [2]

2. Rapid Brain Mapping

Pros:
- Short mapping

Cons:
- Requires the presence of the patient
- Lacks high levels of accuracy
- No continuous mapping

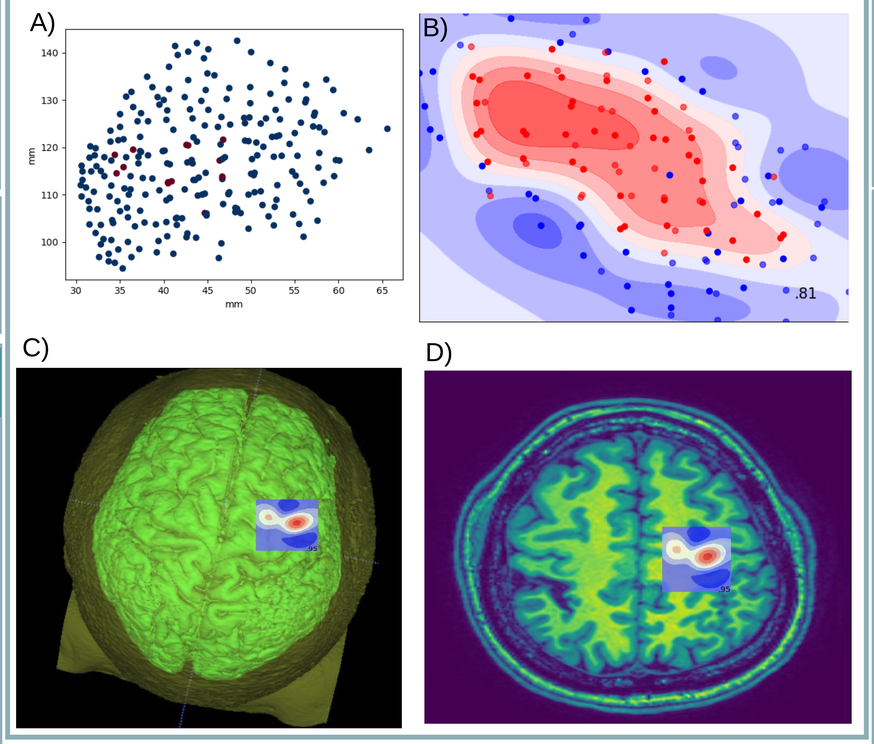
Design Specifications

Table 1: Project Design Specifications

Specification	Value	Test	Pass	Fail
Accuracy of Classifier	> 50%	Calculate average classifier for all patient data	> 50%	< 50%
Success Rate of Thresholding	> 50%	Divide the number of successes by the total number of attempts	> 50%	< 50%

Final Designs

Figure 3. A thresholded binary Motor Evoke Potential (MEP) brain map. A) The MEP values were normalized and thresholded at a cut-off of 80% of the highest normalized MEP. MEP values below the cut-off were assigned with a value of 0 and showed as a blue dot on the map. MEP values above the cut-off value were assigned with a value of 1 and showed as a red dot on the map. Regions with red dots were likely to find a significant muscle response, whereas regions with blue dots were not likely to find a significant muscle response. B) Naïve Bayes physiological machine learning classifier was used for data characterization to produce a continuous map. C) A 3D continuous brain map. D) a 2D continuous brain map.



User Manual

1. Download Python 3.6 at https://www.python.org/
2. Store each of the MRI and EMG files in a folder
3. Segment the MRI using ITK-SNAP [3] and MATLAB code [4]
4. Specify the path and name of the MRI image
5. Specify the path and name of the CSV file
6. Specify the threshold value for both the hand and the forearm
7. Specify the angle of interest to tilt the image for correct mapping registration
8. Click on the image and select the point of TMS stimulation

```
Do you want to see MEP maps in 2D structures or 3D structure (type:2D or 3D): 3D
Specify the Path to 3D structure image?:/media/daltonhbermudez/PACKUP/Senior_Design_2
What is the name of file?:MRI_3D.png
Do you want to specify a new Path to files?[Y or enter key to keep the previous]:Y
Specify the Path of all the CSV file:/media/daltonhbermudez/PACKUP/MATLAB_2/Real_CSV_Tables_Backup/
Specify the Patient file name to be processed:001-U-POST
Input a Threshold value between 0.01 and 1 (for Hand): 0.3
Input a Threshold value between 0.0 and 1 (for Forearm): 0.3
Orientation of 3D structures of the brain needs to lie vertically
What angle you want to tilt the image to 3D Brain structures verticle? (- angle is clockwise):10
Select one point in the area of TMS stimulation
Select one point in the area of TMS stimulation
```

Figure 4. Sample code of our brain mapping algorithm

Validation Test Results

Table 2: Validation Results of MEP Classifier Accuracy

	Percent Accuracy of the MEP Classifier
Hand	75.96 %
Forearm	70.36 %

Table 3: Validation Results of Thresholding Success Rate

	Fail	Success	Percent of Success Rate
Hand	16	84	84 %
Forearm	13	87	87 %

Discussion and Future Works

- Our brain map satisfied all project design specifications with a minimum percent accuracy 70% and a minimum percent success rate of 84%.
- Advantages of our product include: continuous mapping, no cost, high data classifying accuracy, high success rate, rapid mapping time, and no need for the presence of a patient.
- Limitations of our product include: the separate use of MATLAB and Python for brain segmentation, the lack of prediction of the amount of muscle response on brain regions with no measured data, and the requirement of manual user clicking for the selection of stimulation point.
- Future works include to continue to improve on our current product limitations as well as to incorporate a more advanced algorithm in our product to track patient's previous and current muscle response for the assessment of patient improvement.

References

[1] Symbiotic Devices ©, Brainsight TMS Neuronavigation
[2] Van de Ruit M, et al (2015) TMS brain mapping in less than two minutes. Brain Stimul 8:231– 239. doi:10.1016/j. brs.2014.10.020
[3] Paul A., et al. (2006) User-guided 3D active contour segmentation of anatomical structures: Significantly improved efficiency and reliability. Neuroimage. 2006 Jul 1; 31(3):1116-28.
[4] Huang, Y., et al. (2013). Automated MRI Segmentation for Individualized Modeling of Current Flow in the Human Head. *Journal of Neural Engineering*, *10*(6), 10.1088/1741–2560/10/6/066004.
[5] Kitamura, Yuri T., Kisou Kubota, Yujiro Seike, Mikio Imabayashi, Ichiro Miyai, Tsunehiko Suzuki, and Toshio Yanagida. "Motor-evoked Potentials following Transcranial Magnetic Stimulation during Recovery after a Stroke." *International Congress Series* 1232 (2002): 907-14.
[6] Eliassen, James C., Erin L. Boespflug, Martine Lamy, Jane Allendorfer, Wen-Jang Chu, and Jerzy P. Szaflarski. "Brain-Mapping Techniques for Evaluating Poststroke Recovery and Rehabilitation: A Review." *Topics in Stroke Rehabilitation* 15.5 (2008): 427-50. Web.
[7] CDC Stroke, 2014.

Acknowledgements

The authors would like to thank Shawn Mishra and Dennis Truong from Department of Biomedical Engineering at CCNY for valuable discussion and assistance in machine learning, MRI segmentation, volume rendering, and images overlaying