EEG Pre-Processing Signals for Epilepsy

Kian Rafati Sajedi 401107913
Signals and Systems Project
Prof. H. Aghajan

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Contents

1 Theoretical Foundations

1.1 Introduction to EEG

Electroencephalogram (EEG) is a non-invasive technique used to measure electrical activity in the brain. It involves placing electrodes on the scalp to record brain waves. Key points about EEG include:

- Brain cells communicate through electrical impulses, which appear as wavy lines on an EEG recording.
- EEG captures brain activity during rest and in response to stimuli.
- It helps diagnose conditions like epilepsy, brain tumors, and sleep disorders.
- EEG can also confirm brain death and assist in anesthesia management.

1.2 Significance of EEG

EEG plays a crucial role in:

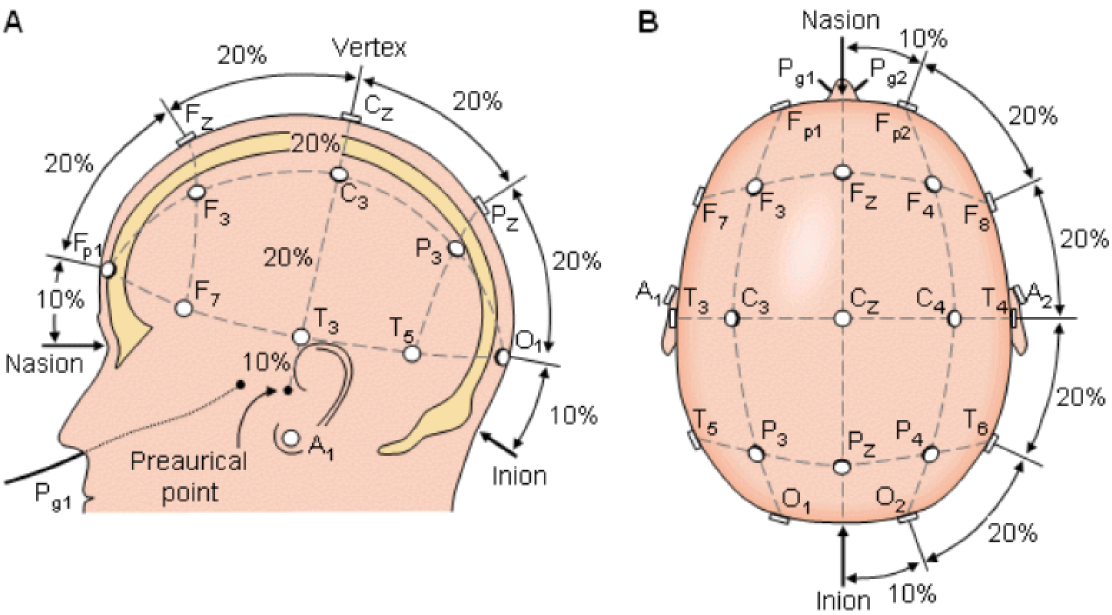
- Diagnosing epilepsy by identifying abnormal brain activity patterns associated with seizures.
- Investigating brain function in various conditions.
- Exploring ways to predict seizures, although challenges remain.

1.3 Epilepsy

Epilepsy is a group of non-communicable neurological disorders characterized by recurrent epileptic seizures.An epileptic seizure is the clinical manifestation of an abnormal, excessive, and synchronized electrical discharge in the neurons.The occurrence of two or more unprovoked seizures defines epilepsy. The occurrence of just one seizure may warrant the definition (set out by the International League Against Epilepsy) in a more clinical usage where recurrence may be able to be prejudged.Epileptic seizures can vary from brief and nearly undetectable periods to long periods of vigorous shaking due to abnormal electrical activity in the brain.These episodes can result in physical injuries, either directly such as broken bones or through causing accidents. In epilepsy, seizures tend to recur and may have no detectable underlying cause. Isolated seizures that are provoked by a specific cause such as poisoning are not deemed to represent epilepsy. People with epilepsy may be treated differently in various areas of the world and experience varying degrees of social stigma due to the alarming nature of their symptoms.

1.4 Electrode Labeling

Based on the picture above, what does each electrode's name stand for? Explain the naming method used in the 10-20 EEG system.



In the 10-20 EEG system, the naming of electrodes follows a systematic approach based on their locations relative to anatomical landmarks on the skull. The naming convention includes a combination of letters and numbers:
1. Letters: Represent the brain region or lobe where the electrode is placed:
   - Fp: Frontal pole
   - F: Frontal lobe
   - T: Temporal lobe
   - C: Central region (between frontal and parietal lobes)
   - P: Parietal lobe
   - O: Occipital lobe
2. Numbers and Odd/Even Identification: Indicate the hemisphere and lateral position:
   - Odd numbers: Electrodes on the left side of the head (e.g., $F3$, $C3$, $P3$).
   - Even numbers: Electrodes on the right side of the head (e.g., $F4$, $C4$, $P4$).
   - Z (Zero): Electrodes placed along the midline of the head (e.g., Fz, Cz, Pz).

1.5 Frequency Bands of EEG

- **Delta (0–4 Hz):** Delta waves are the lowest frequency component and include all the waves in the EEG below 4 Hz. They are typically associated with deep sleep, unconsciousness, and restorative processes in the brain .
- **Theta (4–8 Hz):** Theta waves are observed during drowsiness, light sleep, and meditation. They are also associated with memory consolidation and creative thinking .
- **Alpha (8–13 Hz):** The alpha rhythm is an obligate feature of normal wakefulness. It has considerable variations and is commonly seen when a person is awake but relaxed, with eyes closed. Abnormal alpha rhythm may be slow, asymmetric, or unreactive .
- **Beta (14–30 Hz):** Beta waves are associated with active thinking, problem-solving, and alertness. Excessive beta activity can be linked to stress or the use of sedative medications .
- **Gamma (30–63 Hz):** Gamma waves are involved in higher cognitive functions, perception, and conscious awareness. They are associated with intense mental activity and sensory processing .

1.6 Sampling Frequency

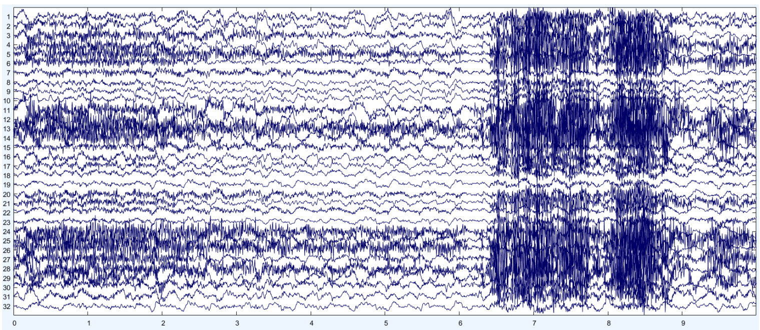
Based on the Nyquist criterion, sampling frequency of EEG signals must be greater or equal to 200Hz.

2 Loading Datasets

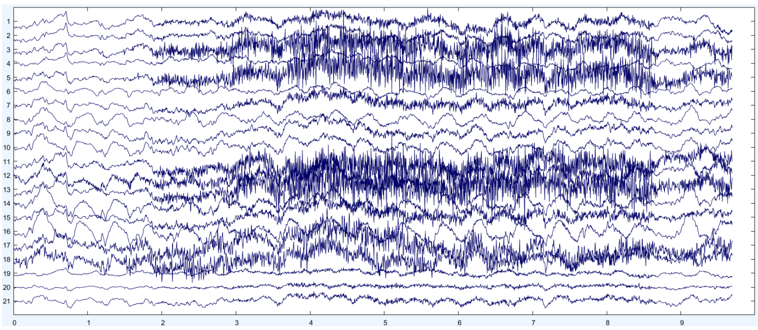
I am given two datasets. The first one ontains EEG signals from a subject experiencing non-seizure epileptic activity. The data includes 32 channels of EEG signals with added noise at a Signal-to-Noise Ratio (SNR) of -20 dB. This means that the signals have been mixed with various types of noise, including muscle artifacts and EEG background noise.

The second one contains EEG signals from a subject that might include seizure activity. The data includes 21 channels of EEG signals with different noise components. This dataset requires careful examination to identify and preprocess the seizure-related signals.

I have loaded both of them in figure 1. Figure 1-a features the dataset for subjects that are not experiencing any epileptic seizures. Figure 1-b contains the dataset representing the patients who probably are experiencing epileptic seizures.



(a) EEG signals of Dataset 1



(b) EEG signals of Dataset 2

Figure 1: Plotted EEG signals of the two datasets

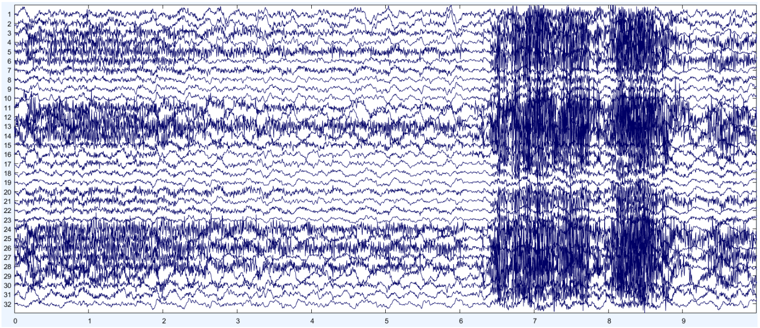
These datasets are to be filtered and re-referenced then have their artifacts removed. These tasks will be accomplished in the following sections.

3 Applying Filters

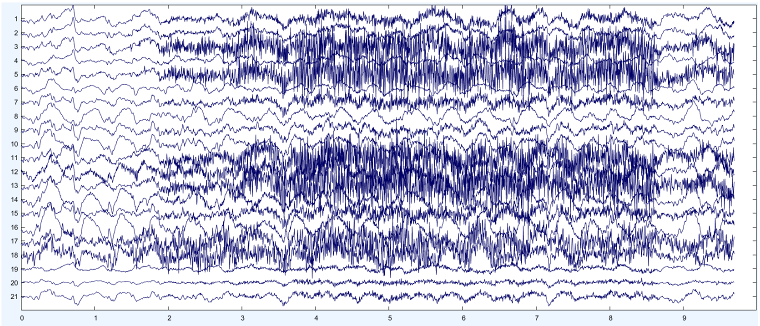
These datasets contain noise (baseline drifts, power line noise, muscle movement noise, etc). Before any processing, I need today pass these databases through filters to remove their noise.

3.1 1Hz High-Pass Filter

Figure 2-a and 2-b captures the 1Hz high-passed dataset 1 and 2 respectivly.



(a) High-passed signals of Dataset 1

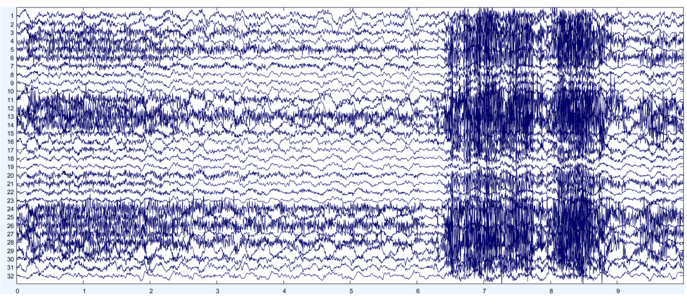


(b) High-passed signals of Dataset 2

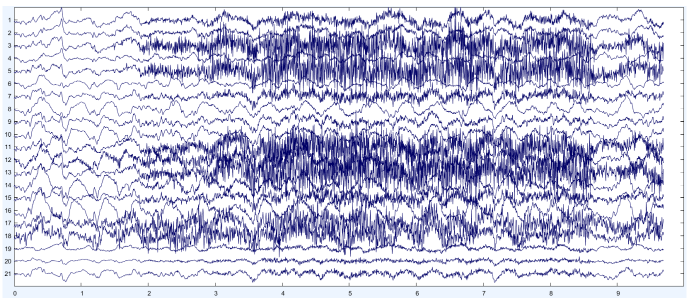
Figure 2: Plotted High-passed signals of the two datasets

3.2 50Hz Notch Filter

Figure 3-a and 3-b captures the 50 Hz notch-passed variations of dataset 1 and 2 respectivly that went through a 1Hz high-pass filter.



(a) HP and NP passed signals of Dataset 1



(b) HP and NP passed signals of Dataset 2

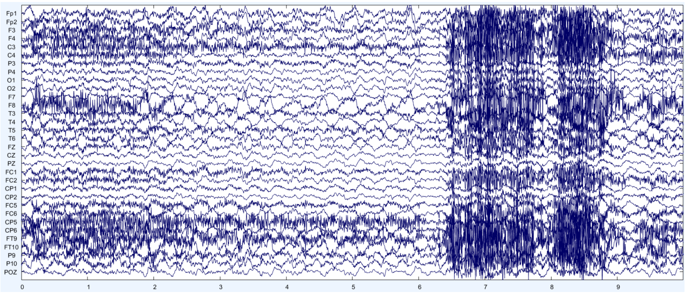
Figure 3: Plotted Notch passed signals of the two datasets

With these filters I have removed baseline drift and power line noise.

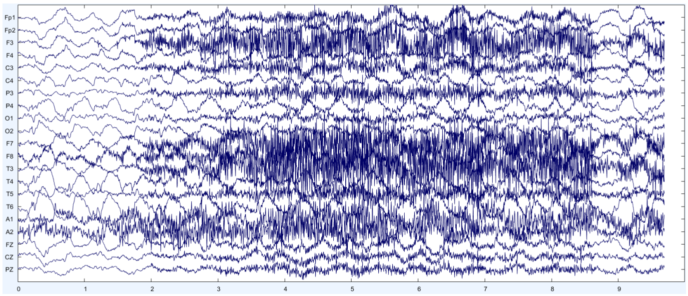
4 Re-Referencing the EEG Data

4.1 Initial Re-Referencing

Now to remove the additional noises I re-reference the datasets.



(a) Re-referenced signals of Dataset 1

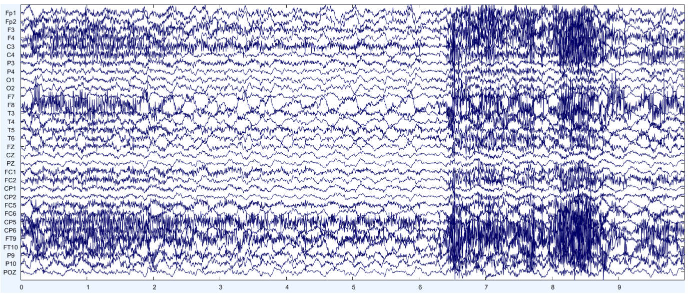


(b) Re-referenced signals of Dataset 2

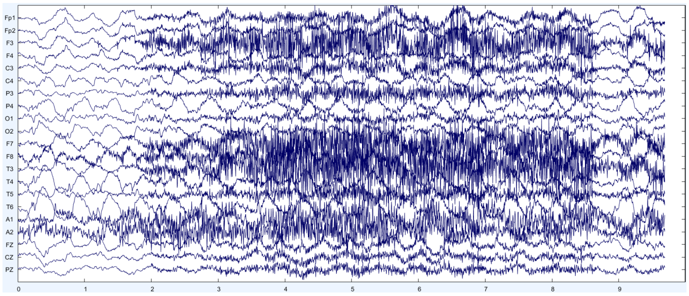
Figure 4: Plotted Re-referenced datasets

4.2 Artifact Removal

After an Initial re-referencing, I remove the artifacts to enhance the quality of the image. These artifacts are a result of muscle movements and eye twitches.



(a) Artifact-removed signals of Dataset 1

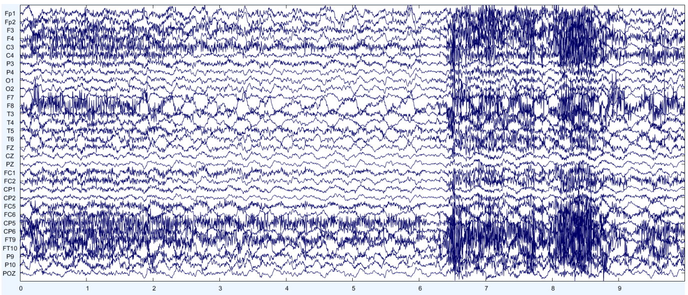


(b) Artifact-removed signals of Dataset 2

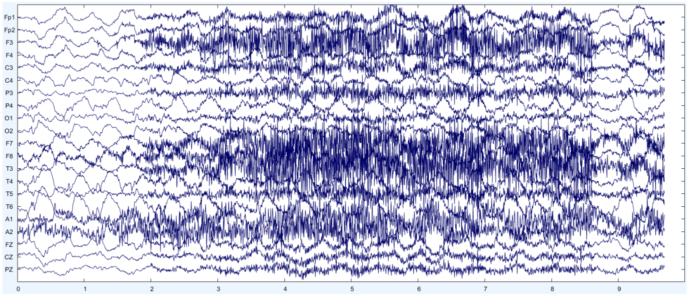
Figure 5: Plotted Artifact-removed datasets

4.3 Final Re-Referencing

Finally to ensure consistant referencing post-artifact removal and to improve the quality of the datasets I re-reference the datasets again.



(a) final re-referenced signals of Dataset 1

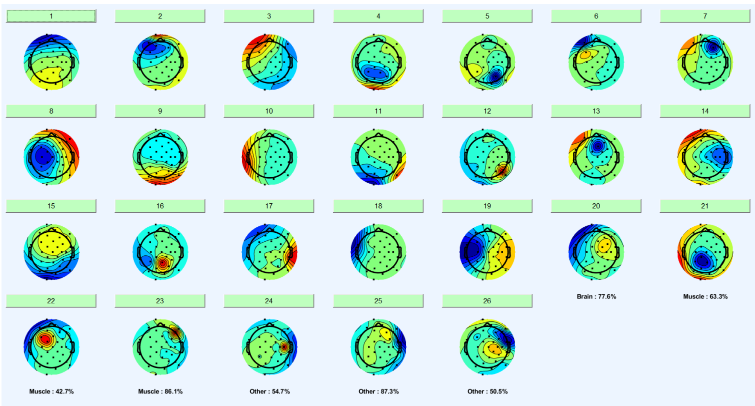


(b) final re-referenced signals of Dataset 2

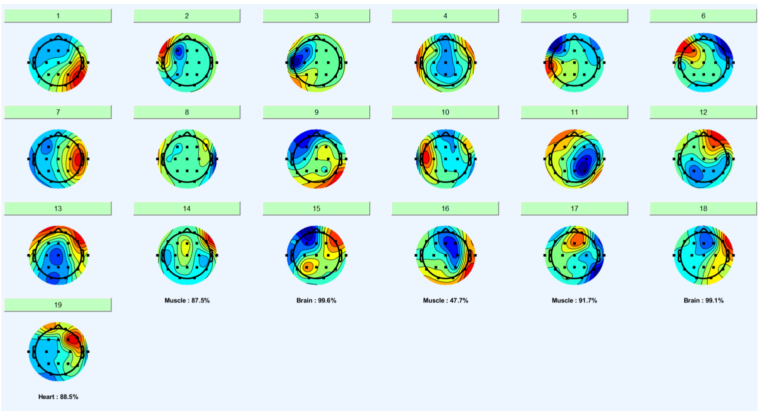
Figure 6: Plotted re-referenced artifact removed datasets

5 Independent Component Analysis (ICA)

To identify what sources caused which channel signals, I run ICA. ICA will estimate the source matrix $\hat{S}$ and the mixing matrix A to identify the Independent components.



(a) Components of Dataset 1



(b) Components of Dataset 2

Figure 7: Plotted components of both datasets

As an example in Figure 8, I showcased one of the components in detail.

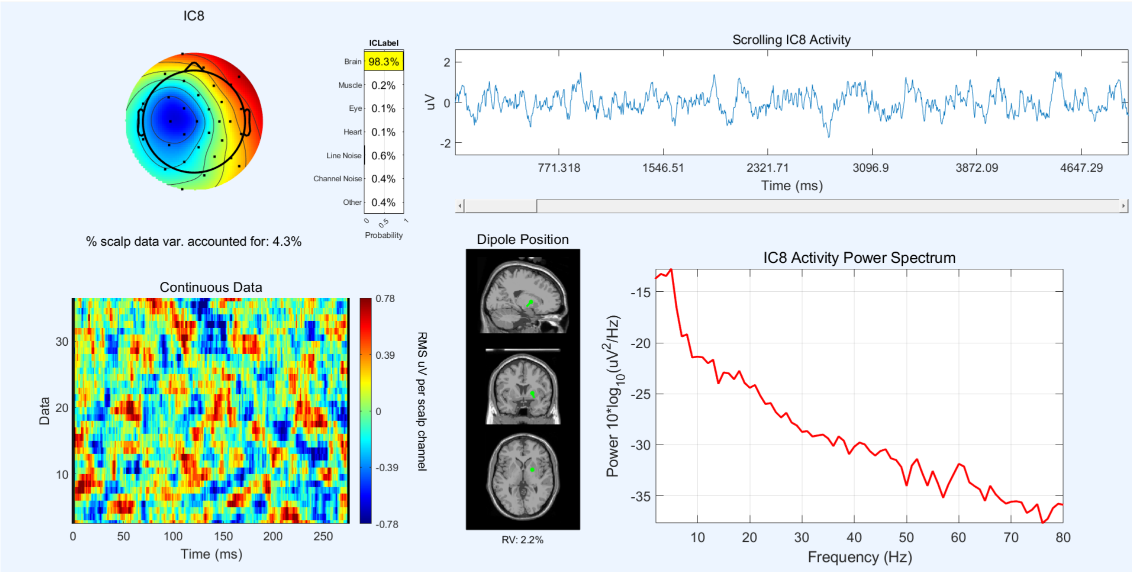
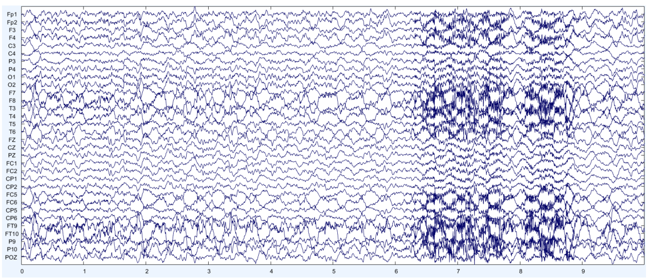
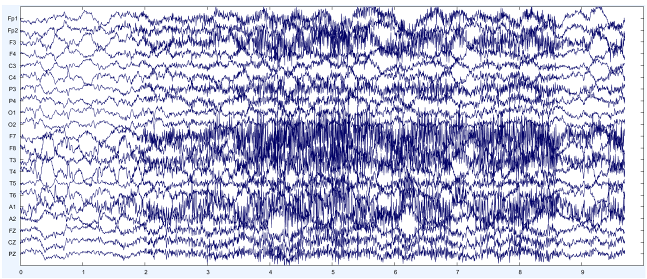


Figure 8: Component regarding Brain activity

To continue our noise removal procedure, I need to remove the non-brain components from the channels to get to the next stage. Figure 9, has plotted the signals after ICA.



(a) Dataset 1 after ICA

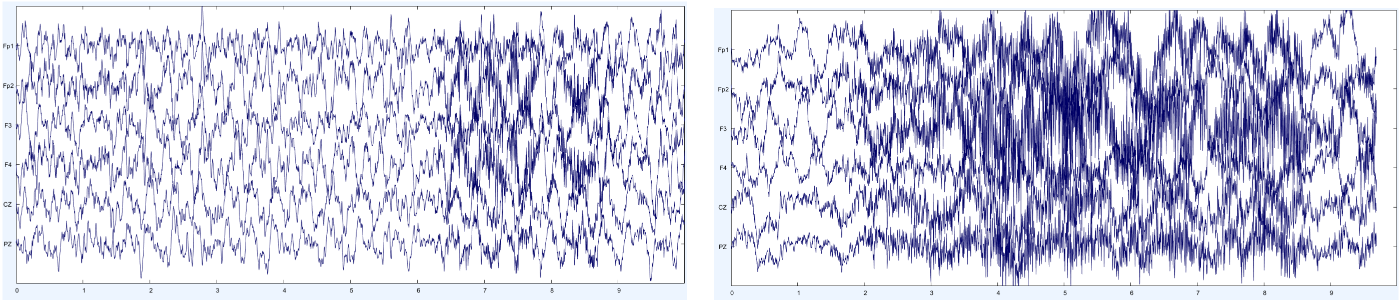


(b) Dataset 2 after ICA

Figure 9: Plotted datasets after ICA

6 Subsampling and Final Data

Finally, I select the 6 channels responsible for Epilepsy (F_{p1}, F_{p2}, F_3, F_4, C_Z, P_Z) of both datasets and saved them in `ds1_final.set` and `ds2_final.set`. Of course, all the datasets throughout this process have been saved in the project report's directory.



(a) Final Dataset 1 (b) Final Dataset 2

Figure 10: Datasets after pre-processing

The altered datasets are in the `Data_Phase1` directory. The images used in this report and the `.tex` file can be found in the `Report` directory.