Chapter

Preprocessing Techniques for Neuroimaging Modalities: An In-Depth Analysis

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Abstract

Neuroimage analysis and data processing from various neuro-imaging modalities have been a multidisciplinary research field for a long time. Numerous types of research have been carried out in the area for multiple applications of neuroimaging and intelligent techniques to make faster and more accurate results. Different modalities gather information for detecting, treating, and identifying various neurological disorders. Each modality generates different kinds of data, including images and signals. Applying artificial intelligence-based techniques for analysing the inputs from the neuroimaging modalities requires preprocessing. Preprocessing techniques are used to fine-tune the data for better results and the application of intelligent methods. Various techniques and pipelines/workflows (steps for preprocessing the data from the imaging modalities) have been developed and followed by multiple researchers for the preprocessing of neuroimaging data. The preprocessing steps include the steps followed in removing noisy data from the inputs, converting the data to a different format, and adding additional information to improve the performance of the algorithm on the data. In this chapter, we compare the various neuroimaging techniques, the type of data they generate and the preprocessing techniques that various researchers frequently use to process data to apply them in artificial intelligence-based algorithms for the classification, prediction, and prognosis of various neurological disorders.

Keywords: neuroimaging, brain imaging, preprocessing techniques, neuroimaging modalities, neurological disorders

1. Introduction

Neuroimaging or BRAIN Imaging is a technology used to capture the brain's structure or part of the nervous system by various imaging techniques. Each neuroimaging technique has unique methods of capturing the brain's snapshot and helping doctors diagnose neurological disorders. Different techniques are used for the identification and confirmation of these neurological disorders. The doctors use multiple parameters apart from the results from the neuroimaging modalities for concluding the disease; however, the neuroimaging data plays a significant role in validating and helping the doctors to form conclusions.

Neuroimaging uses quantitative methods to concentrate on the construction and understanding of the capability of the focal sensory system, created as an objective approach to logically focus on the sound human cerebrum harmlessly. Progressively it is likewise being utilised for quantitative investigations of mind infection and mental sickness. Neuroimaging is an exceptionally multidisciplinary research field and is certainly not a clinical claim to fame.

Neuroimaging is likewise assisting us with understanding how the cerebrum creates from the outset through adulthood. Formative neuroscientists concentrate on the neurobiological underpinnings of mental turn of events. Joining utilitarian proportions of mind movement with social measures, they investigate what subtle early put-downs to the sensory system mean for mental and profound capability further down the road — for instance, the impacts of maternal ailment or youth disregard on learning, memory and consideration further down the road. Imaging devices can also take care of in the study hall: Utilising such devices, proficiency specialists have shown that an extended period of severe and deliberate perusing guidance makes the cerebrums of high-risk look capable like those of additional talented youthful people.

Making the computer learn from these imaging data and creating models that can classify and predict the symptoms of neurological disorders is challenging as imaging techniques provide data in different formats. The data passed as input for Machine Learning (ML) and Deep Learning (DL) requires significant preprocessing to understand these imaging data. Since the data generated from other imaging techniques are additional, each design has unique methods for capturing and processing data.

Current neuroimaging strategies uncover both structure and capability. They discover the cerebrum's life systems, including the honesty of mind structures and their interconnections. They clarify its science, physiology, and electrical and metabolic action. The most up-to-date devices show how various districts of the mind associate and impart. They could show with split-second timing the grouping of occasions during a particular cycle, like perusing or recalling.

For efficient data analysis, classification of the data points into categories or any such application of any data, preprocessing is an essential step in preparing data for analysis; the data from neuroimaging modalities must be equipped with the help of various preprocessing steps to make it convenient for the machines to process and analyse. Analysing and identifying the appropriate preprocessing techniques helps improve the data's applicability from the imaging techniques on ML and DL techniques. Various neuroimaging modalities and preprocessing techniques are discussed in this chapter to help understand the best practices across multiple use cases.

2. Neuroimaging modalities

Neuroimaging is the utilisation of neuroimaging innovation to gauge a part of mind capability, frequently with the end goal of figuring out the connection between movement in specific cerebrum regions and explicit mental abilities. It is an exploration device in cognitive neuroscience, mental brain science, neuropsychology, and social neuroscience [1]. Neuroimaging is a field of medication that includes utilising different strategies to envision and concentrate on the construction and capability of the cerebrum and sensory system. Several other neuroimaging modalities are used, each with novel qualities and advantages.

The neurological disorder is identified, and the doctors plan the treatment with the help of results from various neuroimaging techniques. Neuroimaging helps in

DOI: http://dx.doi.org/10.5772/intechopen.109803

gathering the structure and function of the brain. Different neuroimaging techniques used for the prognosis of neurological diseases are discussed across many research articles; [2, 3] listed various neuroimaging techniques and are mentioned in **Table 1**.

Out of the various neuroimaging techniques, the prominent neuroimaging modalities used to study the brain and its functions are the below-mentioned techniques.

1. *Magnetic resonance imaging (MRI):* MRI imaging uses a strong magnetic field and radio waves to create detailed images of the brain and other body parts. It is a non-invasive procedure commonly used to diagnose and monitor various neurological conditions.

2. *Computed tomography (CT):* CT scans use X-rays to create detailed images of the brain and other body parts. It is often used to diagnose brain injuries like concussions or haemorrhages.

3. *Positron emission tomography (PET):* PET scans use a small amount of a radioactive tracer to produce detailed images of the brain's metabolic activity. It can be used to identify brain tumours, evaluate the effectiveness of treatments for neurological disorders, and study brain function.

4. *Single-photon emission computed tomography (SPECT):* SPECT scans use a radioactive tracer to produce detailed images of brain activity. It is often used to diagnose brain likes, such as stroke and brain tumours.

Neuroimaging Techniques
Magnetic Resonance Imaging (MRI)
Functional magnetic resonance imaging [fMRI]
Positron Emission Tomography (PET)
Magnetoencephalography [MEG]
Single-photon emission computed tomography [SPECT]
Electroencephalography [EEG]
Functional neuroimaging
Transcranial magnetic stimulation
In vivo magnetic resonance spectroscopy
Near-infrared spectroscopy [NIRS]
Functional near-infrared spectroscopy
Magnetic resonance imaging of the brain
Diffusion Tensor Imaging [DTI]
Diffuse Optical Imaging
Cranial ultrasound
Computerised Tomography (CT)
Optical coherence tomography (OCT)

Table 1.
Neuroimaging techniques.

5. *Electroencephalography (EEG):* EEG measures brain activity by recording the brain's electrical activity through electrodes placed on the scalp. It is often used to diagnose epilepsy and other disorders that affect brain function.

6. *Functional magnetic resonance imaging (fMRI):* fMRI uses MRI technology to measure changes in blood flow to specific brain areas, which can indicate brain activity. It is often used to study brain function and to identify brain abnormalities.

7. *Magnetoencephalography (MEG):* MEG uses special sensors to measure the magnetic fields produced by brain activity. It is often used to study brain function and to diagnose brain disorders.

A neurological problem is a condition that influences the cerebrum, spinal rope, and nerves and can disturb the body's capabilities. Various imaging techniques mentioned above have a significant role in capturing neurological information for the prognosis of various neurological disorders. The doctors use the results from multiple imaging techniques to conclude the type of neurological disorders. Each method has a unique way of capturing imaging information from the brain; some techniques capture the magnetic activity in the brain, and electron activity, while some methods use X-rays to capture the images from the brain and to give the current overview of what is happening in the brain concerning the neurological disorder.

There are various neurological disorders; some commonly identified and researched neurological disorders [4] are listed in **Table 2**.

Out of the above-listed neurological disorders, the below-mentioned are the most commonly found and studied neurological disorders [5–11]. Various imaging techniques mentioned above are used in the diagnosis of these disorders.

- *Stroke:* Stroke occurs when blood flow to the brain is disrupted, causing brain cells to die. Strokes can cause problems with movement, speech, and other functions.

- *Epilepsy:* Epilepsy is a disorder that causes seizures and sudden bursts of electrical activity in the brain. It can cause various symptoms, including convulsions, loss of consciousness, and behavioural changes.

- *Multiple sclerosis (MS):* MS is a disease that damages the protective covering around nerve fibres in the brain and spinal cord. This damage can cause various symptoms, including muscle weakness, problems with balance and coordination, and vision changes.

- *Alzheimer's Disease:* Alzheimer's is a progressive brain disorder that causes memory loss and problems with thinking and behaviour. It is the most common cause of dementia in older adults.

- *Parkinson's Disease:* Parkinson's disease affects a person's movement. It is caused by the loss of brain cells that produce a dopamine chemical, which helps control movement.

- *Migraine:* Migraines are severe headaches often accompanied by other symptoms such as nausea, vomiting, and sensitivity to light and sound.

Neurological Disorders
Epilepsy
Parkinson's disease
Dementia
Autism
Alzheimer's disease
Brain Tumours
Cerebral palsy
Multiple Sclerosis
Stroke (Brain Attack)
Narcolepsy
Attention deficit hyperactivity disorder
Obsessive Compulsive Disorder
Migraine
Brain injury
Tourette's syndrome

Table 2.
Neurological disorders.

- *Brain injury:* A brain injury is any brain damage caused by an external force, such as a car accident or fall. Brain injuries can cause various symptoms, including problems with movement, speech, and cognition.
- *Autism:* Autism is a developmental disorder that affects communication and social interaction. It is usually diagnosed in childhood and can cause various symptoms, including difficulty with social interaction and communication, repetitive behaviours, and problems with sensory processing.
- *Tourette's syndrome:* Tourette's syndrome is a disorder that causes involuntary movements and vocalisations called tics. Tics can include eye blinks, facial grimaces, and shoulder shrugs.

Neurological disorders are not easy to be identified from other physical observations. They are closely associated with the brain, and nervous system, with a close association between nerve-related diseases and other medical conditions connected to psychiatry and mental disorders. The treatment for them can also be identified with imaging. One or more of the imaging techniques mentioned in the list of neuroimaging techniques are used to conclude the patient's neurological disorder. Disorders also share properties as they impact the patient's brain or the nervous system.

An overview of the neurological disorders, and imaging techniques used, can be deduced from **Table 3**.

Various neurological disorders and imaging techniques are discussed, and many researchers have identified and used various imaging techniques for diagnosing different neurological diseases. Different imaging techniques rule out the chances of other dementias, as many diseases share common neuro activities factors. It is evident

Neurological Disorder	Type of Imaging technique used
Alzheimer's Disease [AD]	MRI and CT are used in early-stage AD diagnosis [12]. PET and MRI are used for image analysis of AD [13]. CT and MRI have diagnostic value for AD [14].
Parkinson's Disease [PD]	MRI, PET, and fMRI are used to detect PD [15]. MRI and PET are used to identify PD early [16] MRI and its variations are widely used for PD detection [17]
Epilepsy	CT, MRI, EEG, PET, SPECT and MEG are used to detect Epilepsy [18]. MRI performs better than CT in detecting Epilepsy [19]. CT, MRI, PET, SPECT and fMRI are the modalities that can be used to detect Epilepsy [20].
Schizophrenia	DTI, fMRI, PET, SPECT, and fMRI are used to detect Schizophrenia [21].
Autism	MRI and its variations, fMRI, and DTI are the various modalities commonly used for the detection of Autism [22].
Multiple Sclerosis [MS]	MRI, PET, OCT, and other neuroimaging modalities are used for MS detection [23].
Brain Tumour	MRI and its variations, CT, SPECT, PET, and fMRI, are used to identify Brain Tumours [24].

Table 3.
Neurological disorders and neuroimaging techniques.

from **Table 3** that neurological disorders can be detected with multiple imaging techniques and the physician need to evaluate various test results to conclude the type of disorder the patient possesses.

Table 4 concludes the data type, the nature of the data and the primary technique used by the imaging technique to capture the data or the method the data is based on from the brain. The results help in planning the preprocessing strategies and processing the data for the application and study of ML and DL techniques.

The data captured from the various imaging modalities have a different structure; most have been images which doctors can quickly process. There are much preprocessing techniques and processes which are used for cleaning the data to

Neuroimaging technique	Data generated	Technique data is based on	Reference
MRI	Images	Captures pathologies, tissue properties, brain activity and blood flow velocity.	[25, 26]
fMRI	Images	Brain activity by detecting changes in blood flow.	[27]
PET	Images	The metabolic or biomedical function of tissues.	[28, 29]
EEG	Signals	Recording of the electrical activity of the brain from the scalp.	[30]
CT	Images	X-Ray images are taken from different angles and create cross-sectional images.	[31]
SPECT	Images	A nuclear imaging test using a radioactive substance and a special camera to create a 3D picture.	[32]

Table 4.
Neuroimaging techniques and the data.

DOI: http://dx.doi.org/10.5772/intechopen.109803

remove the nose elements in them. The following section will see various preprocessing techniques specific to multiple imaging modalities.

3. Preprocessing techniques

Various preprocessing techniques are used to capture the data from the imaging technique to generate images that depict the imaging results. The imaging data is then processed to make it proper and understandable for the ML algorithms to process and extract features from these images. Mainly the preprocessing techniques help the models understand the type of neurological disorder since most diseases can be identified from the commonly used imaging techniques. Preparing the data is required to effectively process the neuroimaging data captured using various imaging techniques.

The preprocessing of neuroimaging data is an important step that is usually performed before further analysis; the preprocessing process helps the data to be effectively structured to reduce the impact of external factors and artefacts in the image. Neuroimaging data preprocessing generally involves the following steps:

- *Quality assurance:* This step involves checking the quality of the raw data to ensure that it is suitable for further analysis. This can include checking for artefacts or other issues that may affect the accuracy of the data.

- *Slice timing correction:* In functional magnetic resonance imaging (fMRI) data, the acquisition of slices may be out of synchronisation with the actual temporal sequence of the brain activity. Slice timing correction aligns the pieces to the exact time sequence of the brain activity, allowing for more accurate analysis.

- *Motion correction:* This step involves correcting for head movements or other body parts during the scanning session. This is important because activities can introduce artefacts into the data that may affect the accuracy of the analysis.

- *Spatial normalisation:* This step involves aligning the data to a common coordinate space, typically a template brain. This allows for data comparison across different subjects or sessions and can also be used to identify brain structures or regions of interest.

- *Smoothing:* This step involves applying a spatial filter to the data to smooth out noise and improve the signal-to-noise ratio. This can be useful for improving the statistical power of the analysis, but it can also introduce spatial blurring and may not be appropriate in all cases.

- *Detrending:* This step involves removing trends from the data that may be caused by low-frequency drifts or other sources of variance. Detrending can help improve the analysis's statistical power and reduce the risk of false positives.

- *Denoising/Noise Reduction:* Denoising techniques aim to remove noise and other artefacts from the data, such as motion-related artefacts or physiological noise. Denoising can be achieved through various regression-based approaches or more advanced techniques such as independent component analysis.

- *Image registration:* This technique aligns images from different acquisitions or modalities to a standard reference frame. Image registration can improve the accuracy of analysis by reducing misalignment errors.

- *Intensity normalisation:* This technique ensures that image intensity values are consistent across different acquisitions or modalities. Intensity normalisation can help correct variations in scanner performance and improve the accuracy of the analysis.

- *Skull stripping:* This technique removes non-brain tissue, such as the scalp and skull, from the images, allowing for a more accurate analysis of brain tissue.

- *Segmentation:* This technique divides the images into tissue types, such as grey matter, white matter, and cerebrospinal fluid. Segmentation can be used to create maps of brain anatomy and identify specific regions of interest.

- *Correction for head movement:* Head movement during imaging can cause misalignment of images and affect the accuracy of the analysis. Correction for head movement can be accomplished through realignment of the images or by modelling and removing the effects of head movement.

These are just a few preprocessing steps that may be performed on neuroimaging data. The measures will depend on the analysis's particular goals and the data's characteristics. Applying preprocessing techniques helps to reduce noise, enhance contrast, and correct geometric distortions. **Table 5** contains the various imaging techniques and the preprocessing techniques used concerning the imaging technique for the processing with ML and DL algorithms.

Neuroimaging technique	**Preprocessing**
MRI	**Noise reduction**: MRI images can be affected by various noise sources, such as electrical interference and variations in the magnetic field. Noise reduction techniques can help reduce the amount of noise in the images, resulting in more precise and accurate images. **Contrast enhancement**: MRI images often have low contrast, making it difficult to distinguish between different tissues and structures. Contrast enhancement techniques can help to increase the contrast of the images, making it easier to see the details. **Geometric correction**: MRI images can sometimes be distorted due to the complex nature of the magnetic field used to generate them. Geometric correction techniques can help correct these distortions, making images more accurately aligned with the patient's anatomy. **Registration**: MRI images of different body parts or taken at different time points can be registered or aligned, enabling comparison and analysis. **Segmentation**: MRI images often contain a large amount of data, and it can be helpful to separate different structures or tissues in the image for further analysis. Segmentation techniques can identify and extract specific structures or tissues from the images.
fMRI	**Slice timing correction:** fMRI images are often acquired in a series of slices, and the time it takes to acquire each can vary. Slice timing correction techniques can help align the slices in time, ensuring that the data accurately represents brain activity.

Neuroimaging technique	Preprocessing
	Motion correction: Movement of the head during an fMRI scan can cause artefacts in the images, making it difficult to interpret the data accurately. Motion correction techniques can help to remove these artefacts by aligning the images from different time points. **Spatial smoothing:** fMRI images often have a high noise level, making it difficult to interpret the data accurately. Spatial smoothing techniques can help reduce image noise by averaging the data over a small spatial region. **Normalisation:** fMRI data is often collected from multiple subjects, and it is essential to align the data in a shared space to be compared and analysed. Normalisation techniques can help to align the data from different subjects by transforming it into a standard coordinate system. **Detrending:** fMRI data often contains low-frequency drifts that can affect the accuracy of the results. Detrending techniques can help to remove these drifts by fitting and removing a low-order polynomial from the data.
PET	**Noise reduction:** PET images can be affected by various noise sources, such as electronic interference and variations in the radioactive tracers. Noise reduction techniques can help reduce the amount of noise in the images, resulting in more precise and accurate images. **Attenuation correction:** PET images can be distorted due to the interaction of the radioactive tracers with tissues in the body. Attenuation correction techniques can help correct these distortions, making images more accurately aligned with the patient's anatomy. **Scatter correction:** PET images can also be distorted by scattered radiation, which can cause artefacts in the images. Scatter correction techniques can help remove these artefacts by estimating and correcting for the amount of scattered radiation in the images. **Standardisation:** PET data is often collected from multiple subjects, and it is essential to align the data in a shared space to be compared and analysed. Standardisation techniques can help to align the data from different subjects by transforming it into a standard coordinate system. **Image registration:** PET images of different body parts or taken at different time points can be registered or aligned to enable comparison and analysis.
EEG	**Filtering:** EEG data often contains high-frequency noise and other unwanted signals, such as muscle activity and electrical interference. Filtering techniques can be used to remove these signals and improve the quality of the data. **Artefact correction:** EEG data can be affected by various artefacts, such as eye blinks, muscle movements, and electrical interference. Artefact correction techniques can help to remove these artefacts and improve the accuracy of the data. **Re-referencing:** EEG data is often recorded relative to a reference electrode, but the choice of reference can affect the interpretation of the data. Re-referencing techniques can change the reference of the data, making it easier to compare data from different subjects or sessions. **Epoching:** EEG data is often divided into smaller segments, or epochs, for further analysis. Epoching techniques can be used to identify and extract specific epochs of interest from the data. **Time-frequency analysis:** EEG data contains information about both the time and frequency domains. Time-frequency analysis techniques can be used to extract this information and better understand the brain's activity.
CT	**Noise reduction:** CT images can be affected by various noise sources, such as electronic interference and variations in the x-ray beam. Noise reduction techniques can help reduce the amount of noise in the images, resulting in more precise and accurate images. **Contrast enhancement:** CT images often have low contrast, making it difficult to distinguish between different tissues and structures. Contrast enhancement techniques can help to increase the contrast of the images, making it easier to see the

Neuroimaging technique	Preprocessing
	details. **Geometric correction:** CT images can sometimes be distorted due to the complex nature of the x-ray beam used to generate them. Geometric correction techniques can help correct these distortions, making images more accurately aligned with the patient's anatomy. **Registration:** CT images of different body parts taken at different time points can be registered or aligned to enable comparison and analysis. **Segmentation:** CT images often contain a large amount of data, and it can be helpful to separate different structures or tissues in the image for further analysis. Segmentation techniques can identify and extract specific structures or tissues from the images.
SPECT	**Noise reduction:** SPECT images can be affected by various noise sources, such as electronic interference and variations in the radioactive tracers. Noise reduction techniques can help reduce the amount of noise in the images, resulting in more precise and accurate images. **Attenuation correction:** SPECT images can be distorted due to the interaction of the radioactive tracers with tissues in the body. Attenuation correction techniques can help correct these distortions, making images more accurately aligned with the patient's anatomy. **Scatter correction:** SPECT images can also be distorted by scattered radiation, which can cause artefacts in the images. Scatter correction techniques can help remove these artefacts by estimating and correcting for the amount of scattered radiation in the images. **Standardisation:** SPECT data is often collected from multiple subjects, and it is crucial to align the data in a shared space to be compared and analysed. Standardisation techniques can help to align the data from different subjects by transforming it into a standard coordinate system. **Image registration:** SPECT images of different body parts or taken at other time points can be registered or aligned to enable comparison and analysis.

Table 5.
Neuroimaging techniques and the preprocessing.

The various preprocessing techniques used for preprocessing the different neuroimaging modalities are concluded from [33–47]. **Table 6** gives a list of various preprocessing methods used for preprocessing and organising, and enhancing data from multiple modalities for studying disorders. The preprocessing helps in better inputs for various studies by removing the noise information, improving the quality and contrast of the image and correcting the geometric and other distortions. For each imaging modality, we have to follow a different approach for the preprocessing steps; this is dependent on the process of generating the images.

Various preprocessing techniques are used to capture the data from the imaging technique to generate images that depict the imaging results. The imaging is developed with the help of various mathematical transformations and equations where the input captured by the biological process is processed. Then a final image is generated as the output, which contains the brain's current status. The preprocessing is required to make the images more efficient for analysis by removing noise, enhancing contrast, and correcting geometric distortions. The data is then processed for ML algorithms to create various models for classification and clustering. The computer learns from the images and generates an intelligent decision on the class of neurological disorder or whether the input image depicts a healthy sample or of a patient.

Neuroimage Preprocessing Techniques
Artefact Correction
Attenuation Correction
Contrast Enhancement
Contrast Enhancement
Detrending
Epoching
Filtering
Geometric Correction
Motion Correction
Noise Reduction
Noise Reduction
Normalisation
Registration
Re-Referencing
Scatter Correction
Segmentation
Slice Timing Correction
Spatial Smoothing
Standardisation
Time-Frequency Analysis

Table 6.
Neuroimage data preprocessing techniques.

4. Conclusions

Neuroimaging techniques capture brain activity for detecting and prognosis various neurological disorders. In this chapter, we have come across multiple neuroimaging techniques and neurological diseases that can be determined with the data from these neuroimaging techniques. A detailed comparison of various factors is made among the neuroimaging modalities and the diseases to identify the best practices that can be used. The various preprocessing techniques done on the data from the imaging source are also compared to determine the best preprocessing strategies that are effective for the different methods. It is essential to carefully consider which preprocessing steps are appropriate for your specific dataset and research question, as the choice of preprocessing techniques can significantly impact the analysis results.

Neuroimage preprocessing is the process of preparing neuroimaging data for further analysis or visualisation. Neuroimaging data can be collected using a variety of techniques, such as magnetic resonance imaging (MRI), positron emission tomography (PET), or functional magnetic resonance imaging (fMRI). Preprocessing of neuroimaging data typically involves steps designed to correct for various issues that can affect the accuracy of the data, such as artefacts, movements, or low-frequency drifts. The process of cleaning and preparing the data makes the data clean and adequate for analysis. Each of the neurological disorders shares various common factors. Thus, cleaning and making the process effective will help in easy and accurate results for the study.

The preprocessing techniques help in processing and transforming the data to be applied for the ML and DL algorithms to help the machines classify or cluster patient information when given to the system that can be generated. However, a detailed representation of the various techniques used will help build the preprocessing pipelines/workflows (a sequence of preprocessing techniques aligned one after the other in a sequential order for the preprocessing data from neuroimaging modalities) for the data processing [48–51]. The efficient preprocessing step needs to be identified, depending on multiple factors, including the device configuration and hardware. In future work, multiple preprocessing steps for the images can be combined, and preprocessing pipelines/workflows can be created or proposed for effective noise removal, enhancing contrast, and correcting geometric distortions.

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