Volume 6, Issue 6, June 2016 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Pattern Classification of Autistic Individuals using Brain Imaging Data: A Review

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Abstract— Autism is a neuro-developmental disorder characterized by impairments in social interaction and communications along the presence of unusual behaviours and interests. It is seen in children below the age of five and is usually identified through behavioural symptoms exhibited by them. Functional magnetic resonance imaging (fMRI), since its development has become one of the leading research tools for mapping brain activity. Machine learning techniques like support vector machines and neural network classifiers can be adopted for the classification of autistic from the controls in the given fMRI data. A review on different approaches to bring out pattern classification of autistic persons using brain imaging data would throw some light on the current research outputs and further bring out areas in which better accuracy can be achieved.

Keywords— Autism, fMRI, pattern classification, machine learning, Support Vector Machine

I. INTRODUCTION

Autism is a neuro-developmental disorder that affects the normal cognitive development of an individual. It is a spectrum disorder that usually appears in the first three years and would last throughout an individual's life with a wide range of severity. Autism, Asperger's syndrome, and Pervasive Developmental Disorder -Not Otherwise Specified are together referred to as autism spectrum disorder or ASD. The prevalence of autism is about 1–2 per 1,000 people worldwide. India itself is home to about 10 million people with autism and the disability has shown an increase over the past few years. The Centres for Disease Control and Prevention (CDC) report 2012, indicates that about 1 in 68, amongst eight-year old children in multiple areas of the United States have ASDs [40].

The rise in ASD cases in last decade, makes early diagnosis and effective treatment a major health concern. But the heterogeneity present in individuals with ASD makes identifying a singular neuro pathological cause and bringing out treatments very challenging. Thus, a major goal of research on ASD is to learn the neurobiological background of ASD from a multi-dimensional perspective. That is investigating how brain anatomy, connectivity and function are altered in ASD and how they are different among individuals.

With the recent brain imaging studies, scientists are getting a better idea of the neural connectivity involved in autism spectrum disorders. Indeed, functional brain imaging such as positron emission tomography, single photon emission tomography and fMRI (functional Magnetic Resonance Imaging) have opened a new perspective to study normal and pathological brain functioning.

Pattern recognition and classification of autistic individuals remains a challenging endeavour across many disciplines such as pattern recognition, signal processing, machine learning and neurology/psychiatry. Early identification and intervention can make the critical difference for children with autism, which would help in early diagnosis & devises early intervention programs for autistic children.

II. AUTISM SPECTRUM DISORDER (ASD)

Autism was first identified by Leo Kanner in 1943 [1]. In his original paper [1] he presented 11 children (up to the age of 11) with unusual behaviour patterns that had been present from early childhood: his paper gave detailed descriptions highlighting extreme autism, obsessiveness, good relationships with objects, a desire for sameness and stereotypy in individuals each of whom the author considered to have good cognitive potentialities. A year later Asperger published a research paper in which he described 4 slightly older and very intellectually able individuals [2].

Though most symptoms of autism are deficits by nature, some people with autism known as savants display special abilities as a result of their condition. Savant abilities are not just special; they are extraordinarily abilities that cannot be duplicated by most other human beings. These special abilities commonly coexist with the other severe disabilities that characterize moderate to severe forms of autism [3].

The term 'savant syndrome' refers to these individuals who display an exceptional mental ability despite a low level of general cognitive ability [4]. These savant capacities are more frequently observed in persons with autism, than in the non-autistic population [5]. The hidden potential of autistic people seems to fall in common areas—tasks that involve pattern recognition, logical reasoning and picking out irregularities in data or arguments. Exceptional abilities also include musical skills, mental calculation, outstanding mnemonic skills and extraordinary drawing abilities [6].

There has been some study to investigate brain mechanisms in a sample of autistic subjects with outstanding memory. There are numerous case reports of individuals who are able to memorize astonishing amounts of information [6]-[10]. In one of the few group studies of savant syndrome, O'Connor and Hermelin [11] found that autistic savant mnemonists exhibited some semantic organization of their long-term memory that was, however, differently structured compared to controls. In paper [12], seven savants with high-functioning autism spectrum disorder were investigated along with seven controls with 151-channel whole-head magnet encephalography in a continuous old–new paradigm.

In one of the reports, authors have tried to map the exceptional calendar capacity of a man with primary autism [13]. Positron emission tomography was used to map brain activity in a 22-year old savant with prodigious calendar capacities who despite severe behavioural and cognitive impairment, was able to generate in a few seconds, a weekday corresponding to a date. During the task, the left hippocampus, the left frontal cortex and the left middle temporal lobe were activated. They concluded saying the cerebral circuit involved in this man's prodigious calendar skill is similar to that normally involved in memory retrieval tasks. These results suggest that the prodigious capacities may be sustained by memory processing.

Superior ability in drawing, even though not at the savant level, has also been reported in individuals with autism spectrum disorder (ASD). There is a case study of a 10-year-old child of normal intelligence diagnosed with autism [14]. He experienced expressive language delay, but showed special talents in both drawing and visual imagery. Results revealed that autistic kid had superior local but poor global processing. This pattern of performance provides stronger support for weak central coherence than for enhanced perceptual functioning.

III. BRAIN MAPPING TECHNIQUES

Brain Mapping can be defined as the study of the anatomy and function of the brain and spinal cord through the use of imaging. Brain mapping techniques are constantly evolving, and rely on the development and refinement of image acquisition, representation, analysis, visualization and interpretation techniques. Functional and structural neuroimaging are at the core of the mapping aspect of brain mapping.

Neuroimaging and neuro-pathological studies have revealed a great deal concerning the pathogenesis of autism. The advent of functional brain imaging techniques, such as positron emission tomography (PET), single photon emission tomography (SPECT) and functional MRI (fMRI), have opened a new and promising way to study brain dysfunction in childhood autism. Both emission tomography techniques allow non-invasive and accurate measurements of cerebral glucose metabolism and/or cerebral blood flow (CBF). However, unlike PET and SPECT, fMRI provides superior spatial resolution and does not use radioactive nuclei which can be a health hazard. Therefore it has been the imaging method of choice for studying brain function.

A. Electroencephalography (EEG)

EEG is a non-invasive electrophysiological monitoring technique to record electrical activity of the brain. It measures voltage fluctuations resulting from ionic current within the neurons of the brain. EEG can also be looked into as the recording of the brain's spontaneous electrical activity over a period of time. EEG is used to diagnose many brain disorders like epilepsy, sleep disorders, encephalopathy, and brain death. The use of EEG decreased with the advent of high-resolution imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI).

EEG provides superior temporal resolution as compared to fMRI, but its spatial resolution is extremely poor. One of research papers is on EEG based diagnosis and tracing its changes to brain electromagnetic signals (BEMS), seeking the cause of autism and the brain regions of its origin [15]. The time- and frequency domain and principal component analysis (PCA) of these EEG signals with a Multilayer Perception Neural Network (MLP) identifies an autistic subject and helps improve classification accuracy. It shows differences between a working brain and a relaxed brain, especially in the Alpha waves used for diagnosis. Despite poor spatial resolution, EEG continues to be a useful tool for diagnosis and research, especially when millisecond-range temporal resolution is required.

B. Positron emission tomography (PET)

This is a functional imaging technique used to observe metabolic processes in the body. In this method positron-emitting radionuclide is introduced into the body on an active molecule. Pairs of gamma rays emitted by them is detected. Three-dimensional images of positron-emitting radionuclide (tracer) concentration are then constructed by computer analysis. The advantages of PET scanning is the fact that different compounds can show blood flow, oxygen and glucose metabolism in the tissues of the brain, which in turn reflects the amount of brain activity in the various regions of the brain. In terms of resolution and speed of completion, PET scans were superior to other imaging methods. One of the drawbacks of PET scanning is that it is limited to monitoring short tasks because the rapid radioactive decay.

C. Computed Axial Tomography (CAT)

CT scanning makes use of a series of x-rays of the taken from several different directions. It uses a computer program that does a numerical integral calculation on the measured x-ray series to obtain the amount of an x-ray beam absorbed in a given volume of the brain. CT scanning is typically used to detect tumours, infarction, haemorrhage, calcifications and bone trauma.

D. Magnetic resonance imaging (MRI)

MRI is a medical imaging technique to image the physiological processes and anatomy of the body. Since its development, MRI has proven to be a highly versatile imaging modality. MRI scanners use strong magnetic fields, radio waves, and field gradients to form images of the body. MRI is based upon Nuclear Magnetic Resonance (NMR). Few atomic nuclei like hydrogen atoms, can absorb and emit radio frequency energy when placed in a magnetic field. Hydrogen atoms generate a detectable radio-frequency signal that is received by antennas. Radio wave pulses are used to excite the nuclear spin, and magnetic field gradients localizes the signal in space. By changing the parameters of pulse sequence, different contrasts can be generated between tissues. MRI is used to investigate neurological cancers, as it has better resolution than CT and offers better visualization. The contrast provided between white and grey matter makes it the better choice for many conditions of the nervous system.

Using MRI, The authors of [16] have presented classification techniques that allow the discrimination between autistic and typically developing brains. These approaches are motivated by the reported abnormal anatomy of the white matter (WM) and the corpus callosum (CC) in autistic individuals. Statistical features were carefully extracted from the MRIs and helped to discriminate between the two groups. In [17] objective of the proposed image analysis approach was to quantify the differences between the shape of cerebral white matter gyrifications for autistic subjects and controls (normal), without using traditional volumetric measurements. Most of these studies have reported increased brain weight and volume (macroencephaly) in autistic patients [1],[18].

Despite these evidences for a cerebral dysfunction underlying autism, the first-generation studies using brain imaging have failed to report consistently localized neocortical brain alterations in this disorder.

E. functional Magnetic Resonance Imaging (fMRI)

Since the early 1990s, functional Magnetic Resonance Imaging (fMRI) has come to dominate brain mapping research because it does not require people to undergo shots, surgery, or to ingest substances, or be exposed to radiation. It is a tool to study brain functional activity by measuring a blood oxygen level dependent (BOLD) signal, and using it to localize areas that change activity under given tasks [19]-[21]. i.e., based on a series of multi-slice images of the brain, fMRI provides the information for detection and analysis of functionally different parts of the brain [22],[23]. Through the analysis of dynamic views of brain activities, the functions and high-level cognitive tasks can be studied. Resting state fMRI (rsfMRI or R-fMRI) is a powerful method of functional brain imaging that can be used to evaluate regional interactions that occur when a subject is not performing an explicit task [37].

Researchers have written about suitability of MRI for functional brain mapping [41]. They have successfully implemented BOLD fMRI in awake humans as well as animals like cats, rats and monkeys. They have also proved, MRI visible tracers and micro stimulation to be ideal for the connectivity study in living animals.

To state a few applications of fMRI, physicians use fMRI to assess how risky brain surgery or similar invasive treatment is for a patient and to learn how a normal, diseased or injured brain is functioning. They map the brain with fMRI to identify regions linked to critical functions. Ohnishi [24] shows that the classification of morphologic changes in the brain with normal aging and Alzheimer disease are different [25]. Gallaghera [26] provides functional imaging studies to identify distinct active regions. Soo-Yeon [27] shows how fMRI can be applied for detecting dyslexia. Authors in [44] have proposed a fully data-driven, voxel-based approach applied to two different fMRI experiments, to investigate on neural markers which distinguish persons with ASD from controls. [42] Also focusses on identification of neural connectivity signatures of autistic individuals using fMRI time series. Availability of large fMRI dataset of autistic individuals has aided in understanding the brain network of these individuals better.

IV. PATTERN CLASSIFICATION TECHNIQUES

Machine learning techniques can be employed for the classification of autistic from the controls in the given brain imaging data. Pattern classification is generally divided depending on the type of learning procedure used to classify the input data set. Supervised learning needs a training data or the training set. A learning procedure then generates a model that should Perform well on the training data, and classify as well as possible with the new input data. Unsupervised learning, on the other hand, assumes the training data, and attempts to find inherent patterns within it, which would be further used to determine the output value for new data inputs.

A. Learning vector quantization (LVQ)

LVQ is one of the supervised classification algorithms. LVQ is the supervised counterpart for vector quantization. It can also be seen as special case of artificial neural network & variation of Self Organizing Map (SOM). The classifier in LVQ is parameterized in terms of labelled prototypes representing the classes in input space in combination with a distance measure. To classify an input sample, the classifier does a nearest prototype classification, wherein the input is assigned to the class represented by the closest prototype with regard to distance measure. LVQ has its own positives like: Classifiers are sparse and outline clustering of the data distribution with prototypes. Multi-class problems can be handled by LVQ with no modification to learning algorithm. Further, unlike other neural classification schemes like feed-forward networks or support vector machine, LVQ classifiers do not exhibit the black box character. The prototypes reflect the characteristic class-specific attributes of the input samples. Hence, the models provide further insight into the nature of the data. LVQ is useful with complex real life applications, such as image analysis, bioinformatics and satellite remote sensing.

B. Support Vector Machines (SVM)

A SVM are supervised learning methods that analyze data to perform pattern classification and regression analysis. SVM is a non-probabilistic two class linear classifier. Standard SVM takes a collection of input data and makes a prediction, which of the class the data falls into. With a set of training data given, an SVM algorithm will be able to assign any new data given into one category or the other.

One of the papers, extracts texture features for autistic and controls, and further validates using both the above mentioned neural classifiers, Learning Vector Quantization (LVQ) and Support Vector Machines (SVM). Six features, energy, contrast, entropy, inverse differential moment, directional moment, homogeneity and correlation were taken for autistic and control groups. The system was trained using the LVQ and SVM. Finally, validation was carried out by the researchers where in LVQ gave classification accuracy of 87.7% and SVM, 97.8% of accuracy [40].

There has been a study where in 15 high-functioning adolescents and adults with ASD and15 control participants viewed a series of comic strip in the MRI scanner and were asked to pick the logical end to the story from three choices. The mean time series, extracted from 18 activated ROI (Region of Interest), were processed using multivariate autoregressive model (MVAR) to get the causality matrices for 30 participants. Further recursive cluster elimination based support vector machine classifier was used to determine the accuracy with which the classifier can predict a group to which the participant belongs [Fig.1]. It was found that the classification accuracy was 95.9% with 19 features [42]. Authors of [44] have also found SVM RFE based classification improved accuracy when they were classifying autistic individuals from controls.

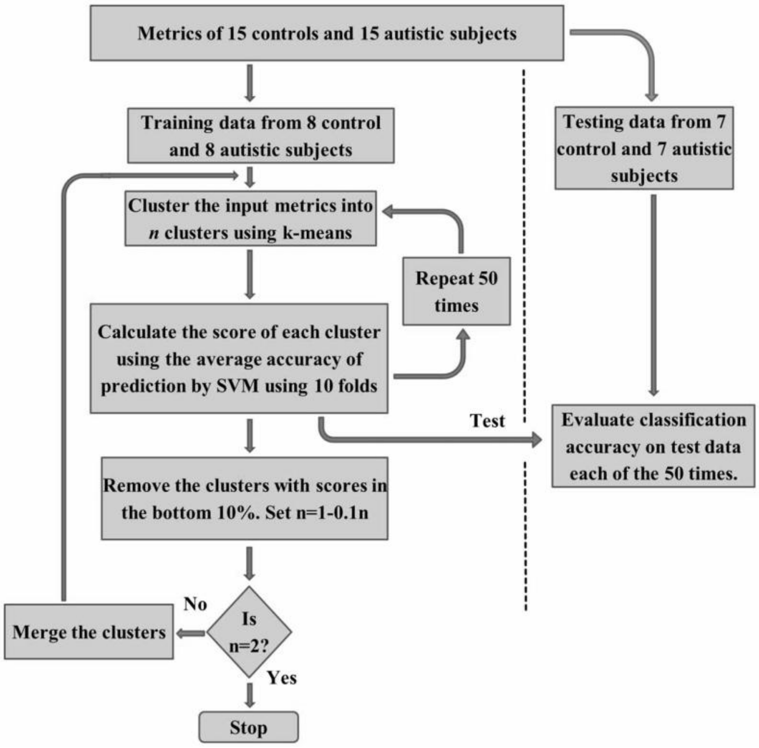

Fig. 1. Flow chart depicting Recursive Cluster Elimination based Support Vector Machine procedure used in [42]

C. Neural Network Classification

Neural networks are one of the most important tools for classification. Studies on neural classification have proved that neural networks are a promising alternative to different classification methods. The advantages of neural networks can be summarized with these aspects [43], neural networks are data driven and self-adaptive methods, which means they adjust themselves to the data and do not need any explicit specification of functional or distributional form. These are also universal functional approximations which can approximate any given function with certain accuracy. Also neural networks are nonlinear models, which makes them suitable to model complex real world applications. Finally, they can estimate the posterior probabilities, which in turn becomes the basis for framing classification rules and performing statistical analysis. With its supervised and unsupervised techniques, neural networks play a major role in classifications. Self-Organizing Maps (SOM) of neural networks are very useful in cluster based classification of medical images

Theories on causes of autism, based on properties of artificial neural networks, have been presented by Cohen [31] and Gustafsson [32]. The authors in one of the papers examine how the attention shift impairment and familiarity preference, influence the self-organization of an artificial neural network and discuss the characteristics of the resulting maps [33]. Gerardo [34] presents self-organizing maps based models of brain mechanisms that may be potentially related to the emergence of autism.

Authors of [35] have tabulated the topological changes for all possible thresholds to obtain a more complete characterization of the brain network. One of the articles [36] states, human brain is organized into a collection of interacting networks with specialized functions to support various cognitive functions. It states, resting state fMRI (R-fMRI) detects fluctuations in brain activity of a person at rest and can be employed to locate coordinated networks within the brain. It also gives increasing body of evidence indicating autism exhibit abnormal brain connections. In article [38], focus is on graph theoretical approaches to the analysis of complex networks that could provide a powerful new way of quantifying the brain's structural and functional systems.

V. CONCLUSIONS

Pattern recognition and classification of autistic individuals will help in understanding the brain network of persons with autism spectrum disorder. It will also be possible to differentiate between the control & autism brain networks purely based on imaging data. This will further help families of autistic individuals & doctors for early detection of autism, so further course of diagnosis & intervention programs can be carried out. This paper reviews the different brain mapping techniques along with pattern classification methods that can be used to classify autistic persons from the control population. In comparison to other neuroimaging modalities, fMRI has proven to be the best method to assess the brain functional connectivity. Also, it is noninvasive and there is a wealth of existing fMRI dataset that can be used for classification. It was also found that Support Vector Machine has shown better classification accuracy during classification of autistic individuals and controls.

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