Machine Learning for Neurodegenerative Diseases Detection

Subjects: Neurosciences

Contributor: Artur Chudzik, Albert Śledzianowski, Andrzej W. Przybyszewski

Neurodegenerative diseases (NDs) such as Alzheimer's Disease (AD) and Parkinson's Disease (PD) are devastating conditions that can develop without noticeable symptoms, causing irreversible damage to neurons before any signs become clinically evident. NDs are a major cause of disability and mortality worldwide. Web and mobile technologies, through the use of machine learning and AI in apps and web-based tools, offer affordable, accessible screening options for cognitive deficits, showing promise in the early detection of neurodegenerative disorders with demonstrated effectiveness.

Keywords: neurodegenerative diseases ; Alzheimer's disease ; Parkinson's disease ; machine learning

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1. Introduction

Aging is a significant risk factor for neurodegenerative diseases (NDs) such as Alzheimer's (AD) and Parkinson's (PD), despite advancements in technology that have improved our quality of life and longevity [1][2][3]. Unfortunately, the complexity of the disease process, involving various contributing factors, presents a challenge in identifying effective remedies [4].

The complexity of NDs lies in a spectrum of disorders characterized by a primary loss of cells, leading to secondary cell loss in other brain regions [5]. Processes correlated with AD begin over 30 years, whereas cognitive changes begin over about 15–11 years, before the first AD symptoms [6][7][8]. Unfortunately, the prevalence of Alzheimer's Disease-related dementia is fast increasing due to our aging population [9].

Sadly, the prevalence worldwide is estimated to be as high as 24 million; by 2050, the AD number could rise to 139 million worldwide [10]. Currently (Q1′24), there is no cure for AD, as during the first clinical symptoms and neurological diagnosis many parts of the brain are already affected without the possibility to recover.

The second (after AD) most common neurodegenerative disease is Parkinson's Disease (PD). This disease is characterized mainly by motor but also by cognitive disorders [11]. The prevalence of Parkinson's Disease is expected to increase significantly by 2050, with estimates suggesting a doubling of the current number of affected individuals. This is due to a combination of factors, including an aging population, declining smoking rates, and increasing industrialization [12][13]. The economic burden of the disease is also projected to rise, with the cost of medical expenses and indirect costs such as reduced employment expected to increase substantially [12]. These projections highlight the urgent need for innovative treatments and a coordinated global response to address the growing impact of Parkinson's Disease.

It is noteworthy that both Alzheimer's Disease and Parkinson's Disease are neurodegenerative diseases characterized by substantial and irreversible neuronal loss, however in different regions of the brain. Commonly, neurodegeneration begins two to three decades before observed symptoms. Hence, the best chance to fight NDs is to estimate the beginning period of the ND-related brain changes [14].

2. Machine Learning Models Support Diagnosis and Monitoring of NDs

It is interesting to note that the brain's functioning is often compared to that of a digital computer or a Universal Turing Machine, which processes symbols [15]. However, psychophysical experiments and our ability to recognize complex objects, such as faces, in various contexts and lighting conditions suggest otherwise. This argues against symbolic representation and instead supports the idea that concept representation based on similarities may be a more appropriate model for how the brain works.

Hence, the researchers propose to direct our eyes to Turning's lesser-known contribution to the field of developmental biology. Turing proposed that natural patterns like stripes, spots, and spirals can arise naturally from the interaction of two or more chemical substances, which he called "morphogens" (that is, the movement of "chemicals" between cells that causes cells to transform/morph into the next "state") [16]. This research explores how complicated patterns, like those seen in zebra stripes, can emerge from relatively elementary biochemical processes.

Applying this concept to brain development, Turing's theory suggests that complex structures and patterns in the brain could emerge from simple, preprogrammed rules at the cellular level. This perspective contrasts with the view of the brain as a Universal Turing Machine, which implies a more fixed, predetermined computational process. Importantly, the shift from viewing the brain as a rigid, symbol-processing Universal Turing Machine to a more fluid, self-organizing system, as suggested by Turing's morphogenetic principles, allows for a more nuanced understanding of cognitive processes.

Interestingly, this approach resonates with the research of Levin et al. (2021) who created the first *living robots*, known as xenobots [17]. Levin's research explores how cells can self-organize into complex structures and forms using basic rules. Using xenobots, he presents how individual cells self-organize into complex tissues and morphologies. This is important in the context of NDs, because changes in cellular patterns and processes could be detectable before clinical symptoms arise, enabling earlier intervention and potentially more effective treatment. Additionally, understanding how cells communicate and organize themselves to regenerate tissue can inform strategies to promote neural regeneration in neurodegenerative diseases.

3. AI and Machine Learning Can Predict Symptoms and Progression of NDs

Recent findings suggest that AI methods predict cognitive patterns in normal subjects, indicating pre-dementia stages. For example, Przybyszewski et al. (2022) used granular computing rules to classify cognitive data from the BIOCARD study, which has been ongoing for over 20 years with 354 normal subjects. The study's findings suggest that AI methods can predict patterns in cognitive attributes of normal subjects that might indicate their pre-dementia stage, something that may not be visible to neuropsychologists [18].

Another study based on Biocard data provides a significant advancement in the detection and prediction of Alzheimer's Disease, utilizing AI methods to identify early cognitive changes. Over 20 years, subjects were evaluated annually to determine their cognitive status—normal, mild cognitive impairment, or dementia. The study used the Clinical Dementia Rating Sum of Boxes (CDRSUM) as a quantitative index for assessing mild dementia and developed rough set rules (RSR) for classification. Researchers classified patients of AD, MCI, and normal, based on their CDRSUM scores. They discovered that some subjects showed signs of potential cognitive impairment or mild dementia that were not evident to neuropsychologists. These findings highlight the capacity of AI methods to detect subtle cognitive changes that might indicate a pre-dementia stage [19].

This approach is a critical step forward in the early detection of AD. By identifying patterns in cognitive attributes among normal subjects, AI methods can reveal early signs of dementia, offering a window for intervention before the condition becomes clinically apparent.

Another BIOCARD study utilizes multi-granular computing to refine the process of classifying cognitive data related to Alzheimer's Disease, aiming for early detection [20]. Researchers modified the number of attributes used in the BIOCARD study, increasing the variety of granules from five to seven attributes, compared to the constant fourteen attributes used previously. This allowed for a more nuanced comparison of classification results. The focus was also on the interpretability of the rules obtained from different granular levels. By creating rules with varying granularity and algorithms, the researchers aimed to identify classifications that are both complete and consistent across different rule sets. The goal is to develop a more accurate and reliable system for early diagnosis, which is critical for effective intervention. Researchers are testing various models to determine the most effective ones for identifying different stages of diseases like Alzheimer's and Parkinson's, and they seek classifications that remain consistent irrespective of the algorithms used [20]. Therefore, the overarching aim is to develop a more precise and reliable diagnostic system for early intervention.

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