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Increasing the Accuracy of Early Parkinson's Disease Diagnosis with Slow Saccadic Intrusions

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Abstract

Parkinson's Disease is a chronic neurodegenerative disorder that causes uncontrollable movements in the body, including tremors and impaired balance. As of today, there is no cure for Parkinson's Disease. While there are treatments such as Levodopa that can be used to slow the progression of the disease and control certain symptoms, it may not always be effective. Therefore, early detection of the disease is crucial. However, as the diagnosis of Parkinson's Disease heavily relies on subjective physician judgment and rarely on clinical tests, detecting Parkinson's Disease at an early stage is often challenging, inaccurate, and inconclusive. One possible way to detect Parkinson's Disease both early and accurately is through the detection of abnormal saccadic intrusions – in this case, slow saccades. This study used Dai and colleagues' algorithm based on the implicit piecewise polynomial approximation model, which includes the nonlinear denoising step and basic velocity-threshold step that helps detect slow saccades with high precision, to prove how it could be used to diagnose Parkinson's Disease early.

Keywords: Parkinson's disease, Neurodegenerative disorder, Saccadic intrusions, Implicit piecewise polynomial approximation

1. Introduction

Parkinson's Disease progresses as dopaminergic neurons located in the midbrain stop functioning properly (Alexander, 2004). As a result, this brain disorder can cause failures in the motor system, leading to bradykinesia, tremors, rigidity, postural instability, and more (Mazzoni et. al., 2012). Today, Parkinson's Disease is the second most prevalent neurodegenerative disease and does not have a cure available for use (Alexander, 2004). Therefore, the early diagnosis of Parkinson's Disease is crucial in slowing down and minimizing the disease progression. Moreover, detecting Parkinson's Disease early can increase the effectiveness of treatments and reduce symptoms like dyskinesia (Murman, 2012). However, Parkinson's Disease diagnosis is known to be very subjective and difficult as the symptoms can vary widely among individuals. In fact, a study has shown that the accuracy of the early detection of Parkinson's Disease is only 58%, with 3.6% to 19% of Parkinson's Disease subjects found to be scans without evidence of dopaminergic deficit (Beach and Adler, 2019). In other words, even patients that were clinically diagnosed with Parkinson's Disease have shown normal findings on dopaminergic imaging, indicating that they are not likely to have Parkinson's Disease. Inaccuracies like such present in the early detection of Parkinson's Disease reiterates the urgent need to develop more effective methods to increase the accuracy of diagnosis.

Saccadic intrusions are involuntary rapid eye movements that interrupt fixation on a target. Abnormalities of saccades are a common symptom in the early stages of many movement disorders, including Parkinson's Disease (Termsarasab et. al., 2015). In fact, a recent study reveals that Parkinson's Disease patients have slower saccades compared to healthy controls, which means that accurately detecting the number of slow saccades can be a viable

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method in detecting Parkinson's Disease early (Fooken et. al., 2022). Slow saccades are caused by abnormal bursting, a neural activity characterized by repetitive fast spiking. Abnormal busting of basal ganglia neurons is present among Parkinson's Disease patients, in which there is an evident increase in neuronal firing following the progression of the disease (Lobb, 2014). However, saccades are often overlooked in the clinical diagnosis of Parkinson's Disease and detecting them require technical expertise.

This study explores the function and accuracy of Dai and colleagues' algorithm based on the implicit piecewise polynomial model and investigates its potential to be used as a tool to diagnose Parkinson's Disease early. Although there were algorithms developed in the past with the ability to detect normal saccades, they have all faced limitations when detecting slow saccades. However, the proposed algorithm has demonstrated the ability to accurately track slow saccades, showing its strong potential in being used to detect symptoms of early-stage Parkinson's Disease. Therefore, this study's objective is to highlight how the proposed algorithm's denoising step and velocity-threshold step should be applied in the clinical setting to provide an affordable, accessible, and objective method to diagnose Parkinson's Disease.

2. Materials and Methods

Dai and colleagues have proposed an algorithm based on the implicit piecewise polynomial approximation model that contains two major steps: the nonlinear denoising step and basic velocity-threshold step. The denoising step is used to reduce the presence of noise and keep track of abrupt changes that occur with saccadic eye movement. This step that improves noise reduction is unique to this proposed algorithm and plays a significant role in increasing the accuracy in detecting slow saccades. Following that, the basic velocity-threshold step allowed the detection of saccades by applying the velocity-threshold step to the velocity of the estimated time series x. This step showed that the velocity is piecewise linear during saccadic intrusions and zero when fixed. The velocity must exceed 30 degrees/second to be considered a saccade (Dai et. al., 2021). While many accurate detection algorithms are already present, this algorithm is the only one that is designed to detect the movement of slow saccades, which makes it suitable as a method to increase the accuracy of early Parkinson's Disease diagnosis.

3. Results

Figure 1 reproduced below presented how the proposed denoising step successfully improved the reduction of noise in both the position and velocity of the saccades, ensuring a more reliable detection of saccades. Slow saccades are more easily influenced by noise compared to normal saccades with the same amplitude because of temporal differentiation in velocity-threshold step. While temporal differentiation is required to determine the velocity from the position data, it also amplifies noise, making reliable detection more difficult. (Dai et. al., 2021). Saccades are classified based on their velocity, in which it is considered a saccade when the velocity exceeds a threshold, and otherwise, it is a fixation. Moreover, lower velocity of slow saccades makes velocity thresholding less reliable due to the presence of noise hindering the detection process. Therefore, the denoising step in the proposed method is crucial.

The mean score of the proposed algorithm in detecting saccadic intrusions at different noise levels is 1.000 (Dai et. al., 2021). The perfect score revealed the extremely high accuracy rate of the algorithm when compared to previous algorithms for saccade detection. After the proposed denoising step, the root mean square error (RMSE) decreased, meaning there was a reduction in the average difference between the given model's predicted values and the actual values. This proves that the model's predicted values are highly accurate. Following the proposed algorithm, Zembly's algorithm demonstrated the second highest accuracy when detecting saccades under noise, outperforming other saccade detection algorithms. Yet, its mean score is 0.996, which is still lower than the proposed algorithm's perfect value of 1.00 (Dai et. al., 2021). Unlike the proposed method based on a velocity-threshold algorithm, Zemblys' is a machine-learning algorithm that uses various features extracted from the data, including Rayleigh test and i2mc, training a random forest model to classify saccades. Although machine-learning models are stronger in detecting saccades than hand-crafted algorithms like Nystrom's, it still struggles when it comes to slow saccades (Dai et. al., 2021). Moreover, while Zemblys' showed the ability to detect the normal saccades properly, it failed to precisely determine the end of

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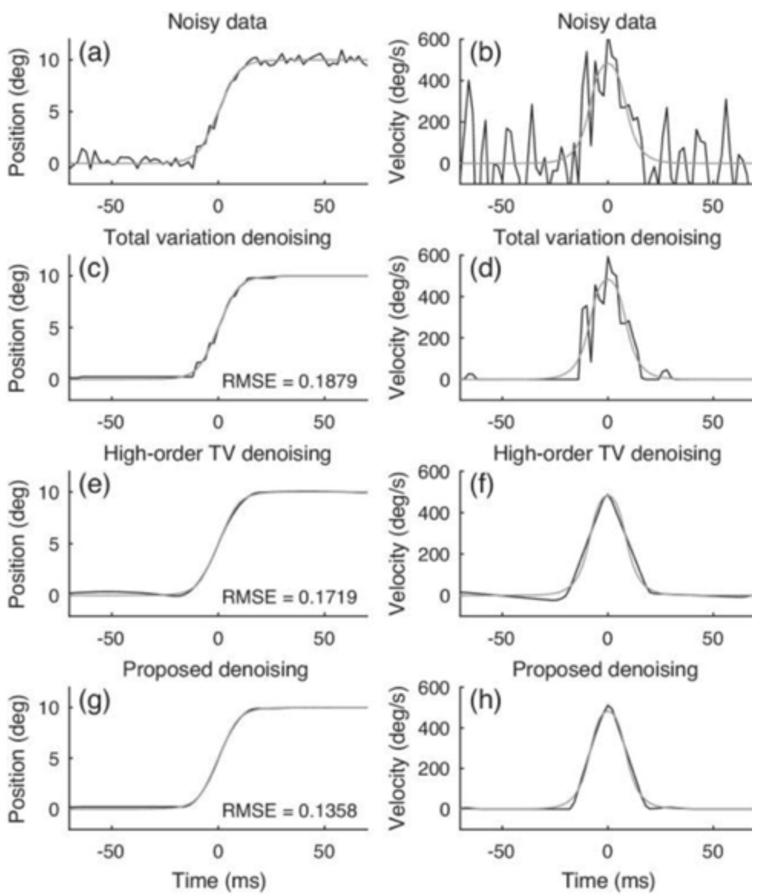

Figure 1: Noise signals after the proposed denoising step (Dai et. al., 2021).

slow saccades, falsely classifying large slow saccades as small normal saccades (Dai et. al., 2021). With a significantly improved denoising system, the proposed algorithm based on the implicit piecewise polynomial approximation model can more accurately detect the movement of saccades and find abnormalities, thus, can be used as a potential tool for aiding the early diagnosis of Parkinson's Disease.

When compared to other detection algorithms, Dai and colleague's proposed algorithm showed an overall higher accuracy in detecting true saccades. Figure 2 revealed that the proposed algorithm maintains a very stable false-negative rate of 0, proving that the algorithm is fully capable of handling slow saccades, even under high noise levels. Other algorithms such as Nystrom and Engbert's algorithm detect false saccades more often than the proposed, especially with increasing noise levels. As the proposed algorithm showed a significantly higher accuracy rate when compared to pre-existing algorithms, it can be used to detect Parkinson's Disease earlier with great precision.

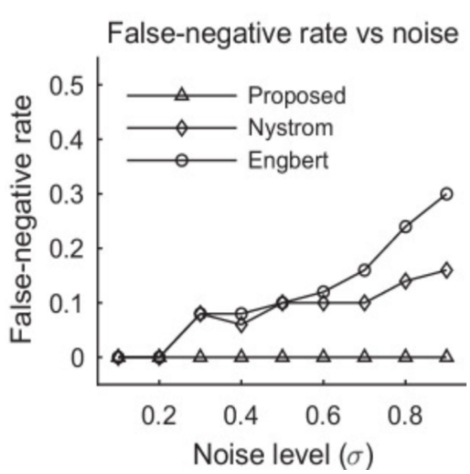

Figure 2: The rate of detecting false saccades among different algorithms (Dai et. al., 2021).

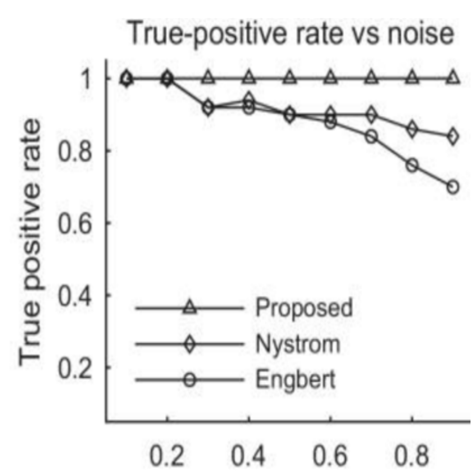

Figure 3: The rate of detecting true saccades among different algorithms (Dai et. al., 2021).

Not only does the proposed algorithm have a low false-negative rate, but it also shows a high true positive rate. As shown in figure 3, the proposed algorithm is the only one from the three that maintains a near perfect rate of 1

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throughout increasing noise levels. This means, while the proposed algorithm near perfectly avoids inaccurately detecting false saccades, it can also detect real saccades, even under the presence of more noise. Altogether, with the algorithm's ability to detect slow saccades with high precision and distinguish between true and false saccades, it has a strong potential to increase the accuracy of early Parkinson's Disease diagnosis.

Below, Table 1 presented the summary of the proposed algorithm's high accuracy rate of detecting slow saccades compared to 10 pre-existing algorithms. Despite the increasing amount of noise level, the proposed algorithm outperforms the other algorithms with its perfect accuracy. In comparison, the other algorithms' accuracy rate tends to fall as the noise levels increase.

Table 1: Accuracy in detecting slow saccades under different noise levels using simulated time-series (500 samples/second) (Dai et. al., 2021).

	Proposed	**Zemblys**	**Nystrom**	**Konig**	**Engbert**	**VT**	**DT**	**HMM**	**Friedman**	**MST**	**KF**
σ = 0.1	1.00	1.00	1.00	0.96	1.00	0.18	0.78	0.23	0.98	0.63	0.49
σ = 0.2	1.00	1.00	1.00	0.96	1.00	0.4	0.51	0.18	0.85	0.5	0.04
σ = 0.3	1.00	1.00	0.96	0.96	0.96	0.47	0.27	0.28	0.45	0.49	0.04
σ = 0.4	1.00	0.98	0.97	0.96	0.96	0.58	0.27	0.04	0.21	0.22	0.04
σ = 0.5	1.00	1.00	0.95	0.96	0.95	0.61	0.26	0.04	0.07	0.15	0.04
σ = 0.6	1.00	1.00	0.95	0.95	0.93	0.59	0.27	0.04	0.02	0.11	0.04
σ = 0.7	1.00	1.00	0.95	0.94	0.88	0.62	0.26	0.76	0.03	0.07	0.04
σ = 0.8	1.00	1.00	0.92	0.93	0.84	0.55	0.27	0.76	0.00	0.06	0.04
σ = 0.9	1.00	0.98	0.91	0.95	0.78	0.54	0.25	0.76	0.00	0.04	0.04
mean	1.000	0.996	0.956	0.950	0.921	0.504	0.348	0.342	0.289	0.252	0.089

4. Discussion

This study introduced an algorithm based on the implicit piecewise polynomial approximation model and explored the relationship between slow saccades and Parkinson's Disease. Although Dai's algorithm showed a high performance overall by detecting saccades perfectly under different noise levels through the denoising step and maintaining a low false-negative rate, it still has drawbacks that must be addressed. Currently, the proposed algorithm is not intended to track data with nystagmus or smooth pursuit eye movements. However, as smooth pursuit eye movements are a common abnormality seen in Parkinson's Disease patients (Dai et. al., 2021), it is crucial to modify the system in the future to reprocess the data and consider the presence of various abnormal eye movements that may be present among the patients. Apart from Parkinson's Disease, the algorithm can potentially be used for the early diagnosis of other neurodegenerative disorders, including Alzheimer's Disease, progressive supranuclear palsy, or spinocerebellar ataxia type 2 (Jensen, 2019). This is because reduced saccade velocity is a frequent phenomenology that is seen in cerebellar diseases.

5. Conclusion

Today, nearly 1 million Americans are estimated to have Parkinson's Disease. As no cure is available for Parkinson's Disease, it is important to detect symptoms of Parkinson's Disease as soon as possible to receive proper treatment. To do so, saccadic intrusions must not be overlooked. Abnormal saccades are one of the few symptoms of Parkinson's Disease that appear in the early stages, thus, they can act as a visuomotor warning that the body is experiencing a problem. As the proposed algorithm's denoising step and velocity-threshold step shows success in remaining highly accurate in its detection of slow saccades even under the presence of noise, the study solidifies its strong potential to increase the accuracy of the early diagnosis of Parkinson's Disease. Currently, the cost of getting scans like DAT scan can cost anywhere from $2,500 to $5,000, making it expensive to order for the general public, especially elders from disadvantaged and isolated backgrounds. Thus, this research can not only help simply and speed up the diagnosis process for the clinicians, but also make it accessible and affordable for all patients.

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