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Review

A Review of the Implementation of Computer-Based Systems to Detect and Monitor Parkinson's Disease

Diego Machado Reyes[1*] and Ana Lilia Reyes-Herrera[2]

Parkinson's disease is the second most common neurodegenerative disorder, affecting nearly 1 million people in the US and is predicted to keep increasing. Parkinson's disease is difficult to diagnose due to the similarity with other diseases that share the parkinsonian symptoms, thus increasing the probabilities of misdiagnosis. Therefore, it is relevant to develop diagnostic tools that are quantitatively based and monitoring tools that will improve the patient's quality of life. Computer-based assessment systems have shown to be successful in this field through diverse approaches that can be classified in two main categories: sensor-based and computer vision-based systems. In this article a comprehensive review is performed to analyze the different approaches taken; moreover, their challenges and future perspectives are discussed.

INTRODUCTION

In the last decade, medicine has evolved exponentially; multiple treatments and diagnostic tools have been developed for many areas. However, the early diagnosis and treatment of degenerative diseases has eluded this rapid evolution in medicine . The complexity and roots of these diseases play an important role in the difficulty to diagnose and treat them. One disease in particular, Parkinson's disease has a vast impact on patients' quality of life. Parkinson's disease affects more than 10 million people worldwide, nearly 1 million people in the US and it is expected that the number will keep growing (Marras et al. 2018). The treatment of Parkinson's disease in early stages with cabergoline has shown a lower risk and delay of onset motor complications (Rinne et al. 1998); thus, highlighting the importance of being able to recognize motor problems as early as possible in the development of the disease. However, it is estimated that when motor symptoms appear, already 50% of all dopamine receptors have disappeared (Marsden 1990; Ross et al. 2004). Several premotor symptoms have been proposed for the early diagnosis of Parkinson's disease (Tolosa et al. 2007, 2009; Iranzo 2011; Lang 2011); however, the most studied premotor symptoms like olfactory loss, REM sleeping disorder, constipation and mood changes are not specific enough to be used as stand-alone biomarkers to diagnose Parkinson's disease (Tinelli et al. 2016). As the motor symptoms are better indicators of the development of Parkinson's disease, and concurrently a powerful revolution in computer science has taken place in the last decades, the implementation of computer systems as diagnostic tools has become a growing research area . Significant research has been conducted to analyze the effectiveness of implementing computer systems to detect gait patterns in patients with Parkinson's disease.

Moreover, an important advantage of the computer-based systems compared to the traditional scales for Parkinson's disease diagnosis is their objectivity, as the analysis performed is purely quantitative contrasted to the qualitative assessment of traditional scales that could be confounded by observer bias. As beforementioned, while nonmotor symptoms are present in all patients, these symptoms are mainly used as supportive criteria for the diagnosis, as they are not definitive indicators of Parkinson's disease. Therefore, it is relevant to focus on the motor symptoms for the implementation of computer-based systems in the diagnosis and monitoring of Parkinson's disease.

Address correspondance to:
[1]University of Mississippi, Brevard Hall, University, MI 38677, United States
[2]Monterrey Institute of Technology and Higher Education, Atlixcáyotl 5718, Reserva Territorial Atlixcáyotl, 72453 Puebla, Pue., Mexico
*diego_machado_reyes@outlook.com

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PATHOLOGY AND EPIDEMIOLOGY OF PARKINSON'S DISEASE

Parkinson's disease is the second most common neurodegenerative disorder (Reich and Savitt 2018) as it affects more than 10 million people worldwide and nearly 1 million people in the US (Marras et al. 2018). It is important to recognize the difference between parkinsonism and Parkinson's disease as they have different recommend treatments and disease courses. Parkinsonism refers to a clinical syndrome of bradykinesia, resting tremor, rigidity, postural reflex impairment, shuffling gait and imbalance, while Parkinson's disease refers to a progressive parkinsonism due to the loss of dopaminergic neurons in the substantia nigra of the midbrain without an identifiable cause (Jellinger 1991). The most common cause of parkinsonism is Parkinson's disease; however, a differential diagnosis is required as there might be different causes for parkinsonism (Reich and Savitt 2018). The Movement Disorder Society (MDS) proposes clinical diagnostic criteria for Parkinson's disease, based on four main steps (Goldman and Postuma 2014). The first one is to establish the presence of parkinsonism through visual analysis to recognize bradykinesia and either rest tremor or rigidity. The second step is to establish the absence of absolute exclusion criteria, to ensure that the parkinsonism is not caused by another disease. The third step is to identify supportive criteria that are characteristic of Parkinson's disease and not usually found in other unrelated courses of parkinsonism; the most important is a "clear and dramatic beneficial response to dopaminergic therapy" (Postuma et al. 2015). The fourth and last step is to search for red flags that might throw uncertainty on the diagnosis; for example, the rapid progression of gait impairment that would require the use of a wheelchair in the first five years of symptoms onset (Goldman and Postuma 2014). Degeneration of the dopaminergic neurons in the substantia nigra results in striatal dopamine-deficiency syndrome, that in turn is responsible for the classical motor symptoms in Parkinson's disease (Jellinger 1991). While there is no specific cause for the degeneration of said dopaminergic neurons in the substantia nigra, there are several risk factors that have been associated with Parkinson's disease. These risk factors include increasing age, male gender, white race, drinking well water, diet rich in animal fat, milk and iron, obesity, midlife constipation, rapid-eye-movement sleep disorder, physical and emotional stress, family history, rural residence, pesticides, farming, teaching, health care work, and exposure to metals like iron and manganese (Kasten et al. 2007). It is also important to mention that the estimated prevalence in Europe is between 100 and 200 cases per 100,000 population (Kasten et al. 2007) and in North America 572 per 100,000 (Marras et al. 2018). Moreover, comparison of prevalence studies worldwide indicate that Parkinson's disease might be more common in the developed world (Kasten et al. 2007); however, due to the methodological differences, such as age distribution, the results might be confounded. Nevertheless, it is clear that the prevalence rises exponentially after the age of 50 (Kasten et al. 2007).

SENSOR-BASED ASSESSMENTS

An approach taken to develop computer-based systems to aid in the diagnosis and monitoring of Parkinson's disease is the sensor-based assessment. Several systems have been developed with successful results. Earlier versions involve more invasive wearable sensors strapped to upper or lower extremities (Keijsers et al. 2006; Bächlin et al. 2009; Pansera et al. 2009; Patel et al. 2009; Cancela et al. 2010). Contrastingly, more recent developments have diminished the invasiveness of the sensors and implemented a pair of sensors attached to the ankles or shoes (Moore et al. 2008; Barth et al. 2011; Raccagni et al. 2018). Moreover, some have focused on the detection of gait freezing, which is a common cause of falls in advanced Parkinson's, in order to monitor the patient and prevent falls that can later lead to lethal diseases (Moore et al. 2008; Bächlin et al. 2009). Most of the sensor-based approaches use accelerometers, gyroscopes, EKG measurements or a combination of these in order to track and analyze a variety of movement-related features and find recognizable differences in the patterns. The tracking of movement patterns other than gait has also shown promising results (Keijsers et al. 2006; Rissanen et al. 2008; LeMoyne et al. 2010; Eskofier et al. 2016). Furthermore, the implementation of deep learning in sensor-based movement assessment has shown improved results compared to machine learning algorithms previously used (Eskofier et al. 2016). It is important to highlight that while many of the systems cited are specialized in detecting or monitoring Parkinson's disease movement abnormalities, research has also been performed to analyze the differences between gait patterns of other causes of parkinsonism that can be misidentified as Parkinson's disease (Raccagni et al. 2018), such as multiple system atrophy (MSA) and progressive supranuclear palsy (PSP). This is relevant as Parkinson's disease has been shown to be misdiagnosed in approximately 18% of the cases (Schrag et al. 2002; Wermuth et al. 2012).

COMPUTER-BASED VISION SYSTEMS ASSESSMENTS

The implementation of computer vision systems to track gait patterns is a field that has grown significantly in the last decade as gait is unique for every person. In addition, computer vision analysis is a non-invasive, non-intrusive measurement since the subject does not need to behave in a certain way (Lee et al. 2014). Moreover, cameras and video processing software have improved enough to track and analyze biomechanical data. For these reasons, the implementation of computer vision systems as a diagnostic and treatment supportive tool has gained interest in the scientific and medical community. Since gait is a coordinated action between the nervous system and the musculoskeletal system, it makes a reliable indicator of neurodegenerative diseases (Ortells et al. 2018). Some systems tend to need specialized environments and computationally expensive processes (Green et al. 2000; Lee et al. 2008; Cho et al. 2009), while less sophisticated vision devices, such as Microsoft Kinect, have shown accurate measurements on a variety of gait parameters (Rocha et al. 2015; Xu et al. 2015) and some other devices have used computationally inexpensive calculations (Khan et al. 2013).

Most computer-based vision assessments use consumer standard cameras to record the movements of Parkinson's disease patients. The main differences appear in the image analysis methods and algorithm to determine if the subject has Parkinson's disease. Dr. Kahn and his team in Motion Cue Analysis for Parkinsonian Gait Recognition (Khan et al. 2013) provide a clear vision-based algorithm for parkinsonian gait recognition. First, a recording of the subject is made, then a background subtraction is applied to differentiate the pixels from the subject and the background. Posteriorly, a noise-filtering technique is applied and then the silhouette is isolated. Afterward, a skeleton is made by applying a model fitting to distinguish the head, torso and leg segments. Finally, motion cues are extracted and compared to an imaginary perfect gait to determine if the subject presents normal or parkinsonian gait.

Gait Analysis Methods

Different analysis techniques are used for the gait parameters. The most prevalent are Linear Discriminant analysis (Green et al. 2000; Cho et al. 2009) and Support-Vector Machine (SVM) (Bauckhage et al. 2009; Khan et al. 2013). Moreover, a more recent approach used a cloud platform-based web service to perform a classification between normal and abnormal gait (Nieto-Hidalgo et al. 2018).

Frontal Versus Sagittal

Another relevant difference within the published research is the use of frontal versus sagittal image analysis. The frontal analysis is advantageous due to the reduction of space for the patient to walk. However, as shown by Nieto-Hidalgo and his team, the sagittal approach proved to be more accurate (Nieto-Hidalgo et al. 2018).

Kinetic Implementation

In the case of Microsoft's Kinect implementation in the Parkinson's disease assessment, Rocha and her team were able to develop a system based on Kinect v2 for Parkinson's Disease Assessment (Rocha et al. 2015). The data evaluated showed that 96% of gait parameters were statistically significant to make a distinction between controls and Parkinson's subjects. Therefore, they concluded that the gait analysis provided by Kinect v2 was valuable as a supportive method for assessing Parkinson's disease in a clinical setting. It is important to recognize the advantages provided by the implementation of the Kinect, which are the computational inexpensive processing and the reduction of the constraints in the environment while reducing noise in the image processing at the same time.).

DISCUSSION

As Parkinson's disease is the second most common neurodegenerative disorder (Reich and Savitt 2018) and has no identifiable cause, it is in the interest of public health to find more effective methods to diagnose and monitor the disease. As presented in this article, several different approaches have been taken in order to develop systems that can aid doctors in their diagnosis and monitor the disease progression.

While in more recent developments the size of the sensors has been reduced and the placement has been in less uncomfortable areas, the sensor-based assessments remain invasive. Computer vision systems show a significant advantage over the sensor-based assessment, as these are not invasive and have similar effectiveness in detecting parkinsonian gait patterns. However, the sensor-based assessment still has an advantage over the computer vision systems for in-home monitoring, as the sensors attached to the shoes do not require the same spacious and unobstructed areas as their counterpart needs. Furthermore, some patients could feel uncomfortable if a camera is constantly recording in their home.

In light of these conditions, one could recommend using the sensor-based assessment for in-home monitoring of patients with Parkinson's disease, as they have shown to be effective in the detection of gait freezing and prevention of falls. Likewise, with further research and integration with data science, they could prove to be useful in long term monitoring of the patients that in turn could lead to a better understanding of the disease's course. On the other hand, computer vision systems could be useful for medical practitioners in their diagnosis in clinical settings, as these systems require larger areas to operate and a more controlled environment. These systems could prove useful in a clinical setting as they could provide a supportive quantitative analysis for Parkinson's disease diagnosis to the current qualitative scales used.

Challenges

Despite the promising results from sensor-based assessments and computer vision system assessments, challenges are present for both. As beforementioned, some patients might feel uncomfortable with a camera constantly recording them. Moreover, sensors could be easily damaged due to weather conditions and users not taking appropriate care; battery life could be also a concern for these devices. Furthermore, most of the systems analyzed in current literature are efficient at detecting the parkinsonian gait; however, less research has been performed in order to differentiate between the diverse causes of parkinsonian gait, as it can not only be caused by idiopathic Parkinson's disease but atypical parkinsonism disorders such as MSA and PSP.

Future Perspectives

These challenges should be encouraging to the scientific and medical community to continue developing systems that aid medical practitioners in their diagnosis and understanding of the disease course, as well as improve life quality for patients. Further research needs to be performed to develop less invasive sensors with high usage, long battery life and environmental conditions resistance that could be easily implemented in the footwear of patients. This type of future device could be very helpful in the analysis of the disease's course and the prevention of gait-freeze related falls. Furthermore, the implementation of computer vision systems in the clinical setting could be incredibly helpful as a supportive tool in the early diagnosis of Parkinson's disease. Future research could develop systems that detect subtle movements imperceptible to some medical practitioners; this could lead to opportune treatments to delay the onset of motor symptoms.

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