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Gait analysis for early Parkinson's disease detection based on deep learning

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Abstract: Better handling of neurological or neurodegenerative disorders such as Parkinson's Disease (PD) is only possible with an early identification of relevant symptoms. Although the entire disease can't be treated but the effects of the disease can be delayed with proper care and treatment. Due to this fact, early identification of symptoms for the PD plays a key role. Recent studies state that gait abnormalities are clearly evident while performing dual cognitive tasks by people suffering with PD. Researches also proved that the early identification of the abnormal gaits leads to the identification of PD in advance. Novel technologies provide many options for the identification and analysis of human gait. These technologies can be broadly classified as wearable and non-wearable technologies. As PD is more prominent in elderly people, wearable sensors may hinder the natural persons movement and is considered out of scope of this paper. Non-wearable technologies especially Image Processing (IP) approaches captures data of the person's gait through optic sensors Existing IP approaches which perform gait analysis is restricted with the parameters such as angle of view, background and occlusions due to objects or due to own body movements. Till date there exists no researcher in terms of analyzing gait through 3D pose estimation. As deep leaning has proven efficient in 2D pose estimation, we propose an 3D pose estimation along with proper dataset. This paper outlines the advantages and disadvantages of the state-of-the-art methods in application of gait analysis for early PD identification. Furthermore, the importance of extracting the gait parameters from 3D pose estimation using deep learning is outlined.

Keywords: Gait analysis, deep learning, Parkinson's disease 3D pose estimation

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1 Introduction

Parkinson's disease (PD) is considered to be the second most common age-related neurodegenerative disorder after Alzheimer's disease. It is estimated that 7 to 10 million people worldwide have PD [1]. Scientifically, it is well known that abnormalities of gait are seen in people with PD [2]. This is due to the result from varying combinations of hypokinesia, rigidity as well as from the defects of posture and equilibrium that includes the characteristics of shuffling gait with small steps and poverty of movements in the trunk. Due to this fact, it was identified that the early identification of this abnormal gait leads to the identification of PD in advance. This leads our research to identify different possible gait analysis mechanism which can subsequently be used for the early identification of PD.

In medical research, changes in gait reveal key information about the person's quality of life [3]. There is a specific interest when searching for reliable information on the evolutions of different diseases: (a) neurological diseases such as multiple sclerosis or Parkinson's; (b) systemic diseases such as cardiopathies (in which gait is clearly affected); (c) alterations in deambulation dynamic due to sequelae from stroke and (d) diseases caused by ageing, which effect a large percentage of the population. Accurate and reliable knowledge of gait characteristics, monitoring and evaluating them at a given instance of time are key aspects. This enables early diagnosis of diseases and their complications to guarantee the best possible treatment.

With the advancements in technologies, many techniques are available for the identification and analysis of human gait that can be broadly classified as wearable and non-wearable technologies. Wearable technologies are considered to be out of scope of this paper because they will obstruct the natural movement of the elderly person. Non wearable technology such as IP systems captures data of the subject's gait through optic sensors and take objective measurements of the different parameters through digital image processing.

In this paper, only IP are considered for reviewing. The recent advancements in deep learning techniques make it applicable for many domains and present implementations who perform

pose estimation almost use only deep learning-based approaches. In order to limit the review, only techniques which use deep learning for pose estimation, gait analysis and their combination for early identification of PD were discussed.

2 Gait abnormalities and PD

Studies show that changes in gait characteristics leads to gait deficiency [4]. The first symptoms of neurological disorders are poor balance, a significantly slower pace with a stage showing support on both feet [5]. Some patients also show gait alternations such as shorter steps, lower free speed when walking and higher cadence than healthy persons. Several other symptoms can be identified for different types of health disorders such as osteoporosis [6], multiple sclerosis [7] or PD. Gait disorders are commonly observed by people with PD and probably occur as a result of progressive loss of dopamine-producing cells in the substantia nigra compacta of the central nervous system. The absence of dopamine in the basal ganglia circuit ultimately results in the loss of gait automaticity. Clinically, people with PD usually have the hallmark features of slowness (bradykinesia) [8], cessation of movement (akinesia) [9] or freezing of gait. As the disease advances, these gait disorders become more prominent, disabling the patients and severely limiting their quality of life [6]. The reduction of stride length is considered the most prominent feature of PD gait and is often accompanied by lower walking speed and the tendency towards a longer duration in the double support phase [10].

Apart from spatio-temporal variables such as stride length, cadence or walking velocity, focusing on kinematic parameters as features for PD gait analysis is advantageous. Kinematic parameters of gait can be pelvis tilt/rotation, hip extension/rotation or knee extension/flexion. There are studies which used spatio-temporal [5], kinematic parameters [11] and their combinations to identify the abnormal gait patterns in patients with PD. [2] indicates that the observation and analysis is a key parameter in the early detection of PD.

Hence, an accurate and reliable knowledge of gait characteristics for certain movements of a person are more important. The early diagnosis of disease and its complications enable the medical facilities to handle the situation appropriately in the near future.

3 Literature review

An early research from [12] and [13] gives an overview of the initial methods used for human pose estimation. More recent surveys from [14], [15] covers a more detailed and in-depth survey on vision-based approaches. They provide a good overview on the latest techniques related to 3D pose estimation. Especially [15] has covered the important aspects such as data acquisition, feature representation, data reduction and classification of gait parameters. In recent years, several other technologies are implemented using deep learning techniques which are out of scope of [15]. But there doesn't exist a literature overview, where the combination of human pose estimation for gait analysis is used and a review on most recent methodologies. This paper gives a detailed overview on the uncovered topics.

[16] a dual-source approach for 3D pose estimation from monocular images was proposed. They used the MoCap dataset with 3D poses and other source of images with annotated 2D poses as data sources. A combination of Convolutional Pose Machines (CPM) [17] for 2D pose estimation with 3D pose estimation is performed. 2D joint estimation from a single raw RGB image and 3D pose reconstruction was used for an efficient 3D pose estimation. [18] used SIMPLify method as the base method and extended it in different directions. They fit a 3D human body model based on 2D features detected in multiple view images. [19] proposes a two-stage depth ranking based method (DRPose3D) to improve the 3D pose estimation. The depth ranking is used as an additional geometric feature which can be identified by humans intuitively and contains rich 3D information.

[20] proposes an efficient and effective direct prediction based on ConvNets. An incorporation of a parametric statistical body shape model (SMPL) within an end-to-end framework is the key part. This allows to generate a very detailed 3D mesh, which results from 2D key points and masks.

In the above-mentioned review, none of them are involved in gait analysis from the estimated poses. A hierarchical representation of the human body is proposed by [21] and showed that this sort of representation is well suited for human gait analysis. Hierarchical graphical models were developed by splitting the human body into parts. This may lead the algorithms to identify the arms and legs similar as they share the same visual primitives.

[22] proposed an incremental Gaussian Mixture Model with Hidden Markov Model (GMM-HMM) for 2D structure-based gait recognition in video. In order to make the pose estimation simple and efficient, the experiments were performed in fixed regions with specific gait rules. This algorithm cannot identify

multiple peoples pose in the single video frame as they assume only one person will be in frame.

Joint Gait Pose Manifold (JGPM) based Visual Gait Generative Model (VGGM) is proposed by [23]. Initially, JGPM was used to represent gait kinematics by coupling the two nonlinear variables pose and gait in a unified latent space. Subsequently, the Gaussian Process Latent Variable Model (GPLVM) for JGPM learning.

DeepPose method that estimates human pose is applied in [24] to extract 2D joint locations of 18 different body parts. A cascade convolutional deep neural networks-based pose predictor is used to increase precision of joint localization. Despite promising results, two major drawbacks are the use of two cameras for frontal and side view and the use of markers on human body for pose estimation. This makes this approach only usable in a controlled indoor environment.

The initial review on the parkinsonian gait date backs to 1972 [10]. Gait patterns of free speed walking in 21 parkinsonian patients was analysed by means of intermittent-light photography and filming. The speed of the forward progression in these patients was reduced due to diminished stride length and increased cycle duration. Moreover, it is observed that the time ratio between swing and stance phases was either increased or decreased. Their research is a base for further research in the direction of identifying the relation between PD and human gait.

[2] proposed a quantitative gait analysis in PD in comparison with a healthy control group. This study did a detailed analysis on the impact and spatiotemporal, kinematics and kinetics of gait parameters in patients with PD. Consequently, this study contributed in identifying which gait parameters help in therapy phase for the recovery of gait. Finally, they concluded that ankle plantar flexors are mostly affected in PD gait.

A relationship between clinical features and freezing of gait with respect to the gait abnormalities was outlined in [25]. 30 patients with PD divided into two subgroups: (i) tremor-dominant (TD) group and postural instability and gait disturbance (PIGD) group (ii) freezing of gait and non-freezing of gait group were taken for these studies using a computerised video motion analysis system. The comparison between these subgroups results in the identification of significant reduction in walking velocity and stride length in PIGD group compared to the TD group.

A similar study from [26] found that dysfunctional kinematics and abnormal kinetic parameters play an important role in the characterization of gait in PD patients off therapy. They proposed that these parameters can be used to document treatment effects of parkinsonian gait disorders.

[6] mentioned that a quantitative analysis of gait parameters is necessary for successful management of an individual patient with PD.

A bigger study on the effects of quantitative parameters of gait using 218 healthy people and 168 PD patients was performed by [27]. They used force plates for extracting gait parameters, their study highlights the tight coupling and importance of abnormalities in gait to PD.

Deep learning techniques were used for pose estimation algorithms for vision-based assessment of parkinsonism and levodopa-induced dyskinesia (LID) [28].

4 Proposed approach

The literature review shows that there exists research in the direction of gait analysis through pose estimation and gait analysis for early PD identification is necessary. But no research in the direction of using pose estimation on elderly subjects to extract gait information and identify the possibilities or symptoms related to PD was performed. This led us to combine these techniques together to develop a framework with which the patterns related to early detection PD must be extracted.

In the scope of our project, the data from elderly subjects starting from 80+ years is acquired. The data from the subjects include cognitive dual tasks and regular gait data through RGB-D cameras. Deep learning algorithms such as Convolutional Neural Networks (CNN) will be used for estimating the 2D poses through obtained RGB images. These 2D poses are projected into an 3D environment based on the obtained depth data by mapping the depth information with the estimated 2D poses. Later these estimated 3D poses are used to extract gait parameters. The gait parameters such as stride length, cadence, step width, step angle, step length etc are considered to be in differentiating the gait deviations. Based on the requirements, additional gait parameters can also be extracted from the estimated 3D pose. The data from the subjects are acquired and the gait parameters are extracted periodically in 6 months interval. This will continue for 3 years and the extracted gait parameters are used to identify the gait abnormalities and the symptoms of PD. This research is compared with the MoCA (Montreal Cognitive Assessment) data of the patients for evaluation.

5 Conclusion and future work

In this paper, we first introduced the importance of PD identification followed by its relation to the abnormalities in gait of the subjects with PD. Subsequently, a discussion on the relation between the efficient human pose estimation and extraction of gait parameters was carried out. A brief introduction to gait abnormalities and its relation to PD was deliberated by mentioning the relevant literature.

An initial discussion was carried out on the most recent technologies related to human pose estimation. Subsequently, the review on different gait analysis techniques and the effects of human pose to gait parameters assessment was discussed. The relevant literature related to the abnormalities in gait to the PD was presented. This discussion involves several technological implementations as well as clinical proofs.

From the review, we found that this area of research still needs a lot of improvement in estimation of the accurate 3D poses as well as quantitative gait parameter estimation. In future, we aim to estimate the maximum number of gait parameters such as cadence, step length, step width etc. efficiently and accurately from the estimated human pose, which can consequently be used for the PD detection in advance.

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