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Eye movement characterization during gait for Parkinson's Disease Recognition

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"Not enough to work, you must exhaust all day at work.'
Auguste Rodin

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Abstract

The Parkinson's disease (PD) is a neurodegenerative movement disorder that affect more than 30 million persons around the world. This disease is evidenced by control movement alterations such as rigidity, tremor, bradykinesia and balance impairments, that results of the deficit of dopamine neurotransmitter. Classically, the clinical PD diagnosis comes from the evaluation and quantification of motion pattern alterations that allows to establish different levels of the disease. Such evaluation is however focus in the analysis upper and lower limbs movements, which may be insensitive at the first stages of the disease. Currently, several studies have show that a strong correlation between the eye motion alterations and the dopamine deficiency, being these motion pattern highly sensitives to changes in concentration levels of this neurotransmitter, even in early stages of the disease. However, clinical eye motion studies use specific protocols and devices that restrict the analysis to static environments with strong controlled scenarios. Additionally, much of the devices used to register the eye motion patterns are invasive and they can alter the ocular dynamic. In this work is introduced a novel strategy to capture the ocular motion during gait by using a external camera that track the eye motions from a free displacement of the patient. Furthermore, two strategies were proposed to analyze the dynamic patterns: 1) a global strategy that follow the eye trajectory during the patient displacement and 2) a local strategy that codify the distribution of instantaneous motion orientations. Both strategies were evaluated in real scenarios with PD patients at different levels of the disease, showing important differences among them, even in patients in early stages of the disease.

Keywords: Parkison's Disease, Eye Movement, Gait analysis, Optical Flow, Flow orientation histograms.

Resumen

La Enfermedad de Parkinson (EP) es un trastorno de movimiento que afecta a más de 30 millones de personas alrededor del mundo. Esta enfermedad se evidencia en alteraciones de movimiento como rigidez, temblor, bradicinesia y deterioro del balance, como resultado del déficit del neurotransmisor dopamina. Tradicionalmente, el diagnóstico clínico de la PD proviene de la evaluación y cuantificación de los patrones de movimientos alterados que permiten establecer diferentes niveles o estadios de la enfermedad. Esta evaluación sin embargo se centra en el análisis de los movimientos de los miembros inferiores y superiores, los cuales pueden ser poco sensibles en los primeros estadios de la enfermedad. Actualmente, muchos estudios han mostrado una fuerte correlación entre las alteraciones del movimiento del ojo y la deficiencia de la dopamina, ya que este patrón de movimiento es altamente sensible a los cambios en los niveles de concentración de este neurotransmisor, aun en estadios tempranos de esta enfermedad. Sin embargo, el estudio clínico de los movimientos del ojo requiere protocolos específicos y dispositivos que restringen el análisis a entornos estáticos con escenarios fuertemente controlados. Adicionalmente, muchos de los dispositivos usados para registrar los patrones del movimiento del ojo son invasivos y pueden alterar la dinámica ocular. En este trabajo se introduce una novedosa estrategia para capturar el movimiento ocular durante la marcha por medio del uso de una cámara externa que sigue el movimiento de los ojos desde un libre desplazamiento del paciente. De igual forma, dos estrategias fueron propuestas para analizar la dinámica de estos patrones: 1) una estrategia global que sigue la trayectoria del ojo durante la marcha del paciente y 2) una estrategia que codifica la distribución de la orientación instantánea de las orientaciones de movimiento. Estas dos estrategias fueron evaluadas en escenarios reales con pacientes con EP con diferentes niveles de la enfermedad, mostrando importantes diferencias entre ellos, aun en pacientes en estadios tempranos de la enfermedad.

Palabras claves: Enfermedad de Parkinson, Movimiento del ojo, análisis de marcha, flujo optico e histogramas de orientación.

Contents

Acknowledgments v

Abstract vi

1 Theoretical Framework 2
1.1 Introduction . . . 2

2 Methodology 8

3 Characterizing the eye trajectory 13
3.1 Introduction . . . 14
3.2 Methods . . . 14
3.2.1 Tracking the Eyes . . . 14
3.2.2 Experimental setup . . . 15
3.2.3 Learning Eyes features . . . 15
3.3 Results . . . 16
3.4 Conclusions . . . 17

4 Description of visual field motion 20
4.1 Introduction . . . 21
4.2 Proposed approach . . . 22
4.2.1 Dense optical flow . . . 22
4.2.2 Orientation flow histograms . . . 23
4.2.3 Data Acquisition . . . 23
4.3 Results . . . 24
4.4 Conclusion . . . 25

5 Conclusions and Perspectives 27

1 Theoretical Framework

1.1 Introduction

The PD is one of the most prevalent neuro-degenerative diseases around the world [45], affecting around 30 million people [52], and with an expectation of the double of reported cases in the next 15 years [40, 35, 50, 34]. This disease is related with motor system disorders caused by the deficit of the dopamine neurotransmitter. Such deficit generates in long and mid term affections related with movement regulation and velocity [10, 46]. Specifically, the progressive loss of dopamine introduce several problems, as: a communication failure between the cortical area and the musculo-skeletal system, degeneration in general of the neural network and imbalance between inhibition/activation of neuronal commands [38, 46] (see in Figure **1-1**).
Those alterations, expressed as a set of movement disorders, progressively exacerbated in time, are currently used to coarsely quantify the disease. Such symptoms are mainly described as: (1) Bradykinesia (slow movement), (2) resting tremor, (3) rigidity and (4) impaired balance [13, 19]. In the clinical domain, the most commonly test used to diagnose the PD is the "UK Parkinson's Disease Society Brain Bank Clinical Diagnostic Criteria" (UKPDSBRC). This test is based on two main factors: 1) the evaluation and quantification of motor symptoms and 2) the evaluation of the patient response to dopaminergic medication [32, 17]. Complementary, the "Hoehn and Yahr scale" [25], classify the progression of the disease in five stages, following those motor descriptions, such as [25]:

Stage 1: associated to patients with early motor alterations such as mild unilateral rigidity, tremor or slowness of movement. At this stage, there exist a large number of false-positive reports caused by the poor occurrence and the small amplitude of motor alterations patterns, that can lead to wrong evaluations.

Stage 2: related with the "midline" or axial affectation, exposes the increasing of early symptoms, combined with trunk instability and the presence of motor symptoms in the non-affected body side. During this phase, there are not also evidence of impaired balance, whereby in most of cases there are not a PD diagnosis.

Stage 3: includes the first signs of impaired balance and retropulsion test failures that difficult to the patients to maintain an upright posture facing an external stimulus. Also, there exist a subtle loss of independence which may be imperceptible.

Stage 4: is characterized by the significantly impaired of the patients, with strong evidence of the disease w.r.t. the motor patterns. In this phase the patients report strong difficulty to maintain a bipedal position and to develop the locomotion without assistance.

Stage 5: described in patients with fully lost of mobility. In much of the cases the limitation of the patient independence is exacerbated to activities like eating by itself or turning in bed.

The description of such scale is very important to the proper following and intervention of the patient. However, despite of the efforts developed to quantify and classify the PD, this proposed scale result very coarse among the stages and there are not a precise description of the symptoms. Hence, in much of the PD cases, the diagnosis and following is fuzzy or even ambiguous to take clinical decisions [25]. Some researches have revealed the dramatic problem related with PD diagnosis, for instance, the accuracy in PD diagnosis has been evaluated in [47] with 5260 patients, obtaining 82.7% w.r.t the precision in the diagnosis by experts. Even worse, when the diagnosis was performed by physical doctor with no so much expertise in movement disorders, the results were 76.2% and 76.4% respectively. Other studies reported a specificity between 0.42% to 0.77% in PD diagnosis [27]. Those results have evidenced a salient misclassification and low accuracy in the diagnosis, which could be critical in early stages, where namely there are less clues and evidences to determine the disease progression. Additional technical tools have been introduced to support the diagnosis and reduce the high variability and low specificity intra experts. Among the most important, the gait analysis allows to compute several kinetic and kinematic patterns which are correlated with different stages of the disease [7, 59, 47].

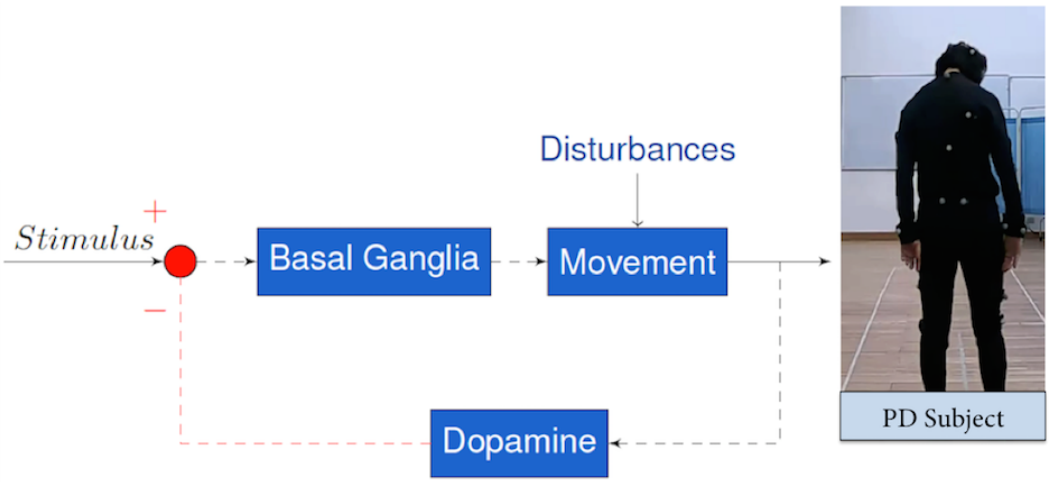

Figure 1-1: The regulation movement system could be represented as closed-loop control system. The input is the stimulus movement from upper zones of the brain. This signal is controlled by the basal ganglia, regulating the movement by a feedback component, the dopamine as the main neurotrasmitter. The loss regulation of these stimulus generated disturbances in movement typically in PD.

In general terms, the gait is an important marker of the PD diseases because such phenomenon, under normal conditions, requires the integrity and interaction of different control and movement subsystems to achieve an optimal energy consumption[49, 64]. Nevertheless, the parkinsonian gait is characterized by the velocity reduction, short stride length decreasing, abnormal postures to maintain the control, among others [48, 20].
The gait analysis is namely developed in a controlled conditions, where a set of devices allow to capture different kinematic and kinetic relationships which together with energy consumption indicator can be useful to support the progression of the disease. Also, this quantitative evaluation allows to reduce the subjectivity and identify differences among musculoskeletal or neuromuscular disorders. The advantage of these tools, as support in the diagnosis and following of the disease, has been widely tested in clinical scenarios by physicians with different levels of expertise. In spite of the advantages of the gait analysis, there exist main concerns with respect to the PD described as follows [53, 64]:

- The gait patterns are revealed in patients with advanced level of the disease (stages 3 and 4), being one of the main limitations the sensibility to recognize subtle changes in early stages.

- The controlled conditions and the invasive nature of some of the devices used limit the motor evaluation of the patients and many times alters the natural gesture of the motion.

- The clinical report of the gait analysis namely result from the correlation between the patient patterns with patterns computed from a control population. However, the alteration of PD patients have high variability in any of the stages, and the statistical comparison many times result insufficient [5, 48, 37].

- the "limb motor symptoms" or classical symptoms to diagnose PD appear after the loss of 50% of dopamine-producing cells, responsible to movement control [16], which result dramatic to propose a early treatment.

All of these limitations have motivated to the exploration of new biomarkers to improve the diagnosis and following [52], with special pay attention in early stages of the disease. Recently, some works have described that the eye movement alterations can be used as an alternative and powerful biomarker in PD and in other neurodegenerative disorders [3].In fact, the ocular movement requires a refined neural control which directly leads to high sensible to slight changes in dopamine levels [43, 26]. From these experiences have been shown that the eye movement alteration can suggest a "pre-motor" phase (before a significant neurodegeneration) of the disease[51, 65].
The reliable performance of eye movement as biomarker in PD, was described in the seminal work proposed by Gitchel, et al in 2012 [24], in which was found that the 100% of patients with PD in different stages presented eye alterations. In addition, the study found that visual alteration in a subject who has not yet been diagnosed with PD, and developing the disease eventually [24]. Many studies described [4], that the eye movement alterations are represented as changes in ocular control, specially in direction and velocity [28] (see in Figure **1-2**). Nonetheless, the proper computation of eye motion is challenge since many times the abnormal ocular behaviors can be wrapped with the head tremor that may be present in PD [33]. Therefore, a proper methodology to evaluate eye motion patterns evolution under isolated conditions in which the head motion can be filtered out remains as an open question [6].
Eye abnormalities are usually assess in passive or artificial tasks[33] that consist in the tracking of an object by the eye. In this case, the eye motion can be forced to follow normal patterns, leading to a wrong diagnosis. Additionally test are based on the electrooculography analysis, which is focus only in the plane of eye movements [22], losing the other visual field components. Moreover, this kind of device have some problems in the capture because the electrical signal of the eye muscle is weak [11, 54] and can be contaminated by noise.
Currently, there are some studies that try to capture eye motion patterns in free scenarios, under the assumption that eye abnormalities are amplified during a natural movement pattern, as the human gait [2], as is illustrated in Figure **1-3**. In this specific case, the eye has the main role of explore and sense the environment around during the gait, to establish the best dynamical configuration of limbs to develop an optimal movement [62, 55, 41]. Some seminal works show the relevance of capture the eye motion during the locomotion to detect

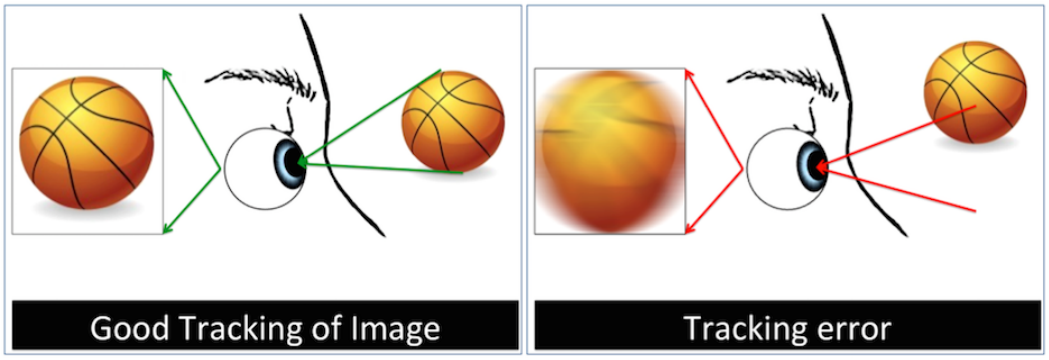

Figure 1-2: The comparison of ocular movement between control and PD patient. In the left panel (a) show the suitable perception of environment or an object when the eye movement control is appropriate. And in the right panel (b), show the ocular movement deficiency and the alteration of the image perception, affecting the movement performance in gait, commonly in PD

early patterns that can be related with the PD. Some of the limitations of such works is the use of invasive electrooculography devices [2, 41].

In this thesis is introduced a novel methodology to analyze the eye motion in free locomotion activities by characterizing ocular patterns registered in video sequences. Such patterns were evaluated under different conditions and with a population of PD patients, diagnoses at different levels of the disease. For doing so, the patient was equipped with a helmet camera that recorded high-speed sequences with the ocular motion, while the patient developed the locomotion. Then, a first proposal evaluates the global ocular dynamic trend by following the eye trajectory in time. For doing so, a adaptive boosting algorithm was trained with raw geometrical and appearance eye features. The computation of such eye trajectories show differences between control subject and PD patients, being a promising biomarker to detect patterns associated to early PD stages. A second proposed method was aimed to explore more local detailed patterns of the eye motion, present during the locomotion. To this end, a set of orientation histogram distributions were established from the computation of a dense optical flow computed in each video sequence of the recorded ocular motion. In this case, was found more descriptive eye motion patterns that can be useful to support the early diagnosis of PD, and also report a substantial difference in the different stages of the disease, even when the gait movements are close to control patterns.

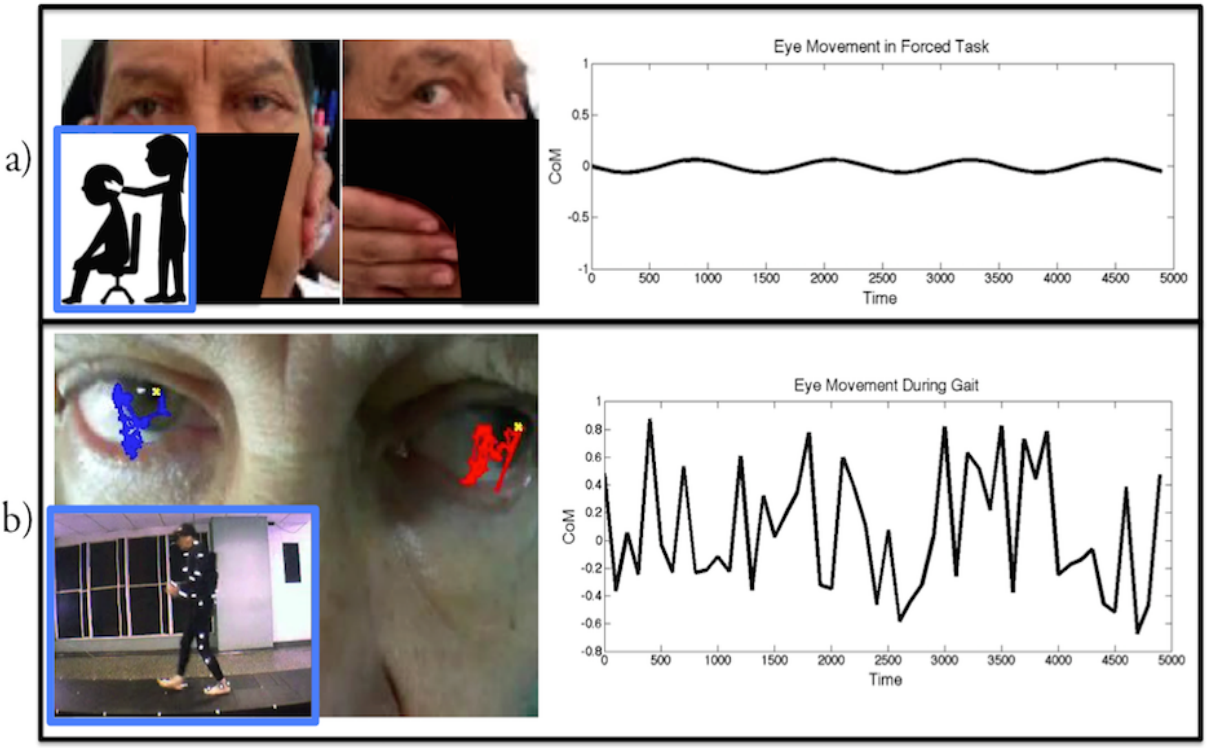

Figure 1-3: The comparison of two evaluation strategies for ocular movement in a subject with PD. In a), this method consist in moves the head's patient in a sitting position by the evaluator, observing any abnormality in the eye movement. However, in advanced levels of the pathology, the alterations are not easily noticeable. In contrast, b) this subject during gait pattern, the alterations are exposed with highly amplitude movement. In this condition, the ocular movement allows to characterize the level of PD.

2 Methodology

- Problem Identification

  - Research Problem:
    Parkinson's disease is not objectively evaluated.

  - Research Question:
    How to quantitatively support the diagnosis, the follow-up and the treatment of any stage of the disease?

- Objectives
  - Main Goal
    - To quantitatively characterize the eye motion during gait to support the PD diagnosis and classification.
  - Specific Objectives
    - To build a dataset of eye movement for PD and control patients during gait.
    - To develop a strategy that characterizes the eye movements during gait.
    - To classify subjects with PD by stages based on eye movement description during gait.
    - To validate the developed strategy.

- **Work package 1: To build a dataset of eye movement for PD and control patients during gait**
  - ***Methodology***
    - To perform a literature review to establish the better devices and conditions for the recording of eye movement during gait.
    - To perform some test recording and evaluate its results.
  - **Activities**
    1. To establish device for recording eye movement and conditions of capture during gait in a semi-controlled environment.
    2. To evaluate with test subjects to prove and design adequate condition of recording.
    3. To measure the quality of videos in order to determine if it is appropriate to perform eye movement analysis.
    4. To perform evaluations on control subjects and subjects with Parkinson's Disease.
  - **Analysis and strategies of risk mitigation**
    - Risk 1: Loss of dataset.
      - **Plan A**: Save the information in backup storage devices.
      - **Plan B**: Call back the patients for a new recording.
    - Risk 2: The video don't have optimal condition.
      - **Plan A**: Establish errors in test.
  - **Project Deliverables**
    - Data set of eye movement during gait.
- **Work package 2: To develop a strategy to characterize the eye movements during gait.**
  - ***Methodology***
    - To characterize the eye normal and abnormal movement during gait in PD for select moves to evaluate.
    - To design a strategy for eye movement description.
    - To validate strategy of characterization of the eye movement during gait.

- **Activities**
  1. To develop the background of eye movement characterization.
  2. To select and develop some strategies to characterize the eye movement during gait.
  3. To evaluate the performance of the selected strategies.
  4. To compare the output data of the selected method with ground truth of eyes movements during gait in PD and control subjects.
  5. To develop a strategy for eye movement description based on the results on the previous activity.
  6. To validate the developed strategy.
- **Analysis and strategies of risk mitigation**
  - Risk 1: The are not well known patterns to differentiate the eye movement during gait for control and PD patients in the literature.
    - **Plan A**: Analyze the eye movement during gait, in presence of visual cues whose response is well known, and establish the difference between normal and pathological subject.
    - **Plan B**: Analyze only the eye movements who are most commonly affected in PD.
  - Risk 2: The selected strategy performs poorly on the created dataset.
    - **Plan A**: Pre-process images in order to enhance relevant features on the dataset.
    - **Plan B**: Record once again the data set.
- **Project Deliverables**
  - Article of first approximation about strategies for eye movement description.
  - Implementations of strategies for eye movement description.
  - Validation of eye movement descriptor.

- **Work package 3: To classify subjects with PD by stages based on eye movement description during gait.**
  - ***Methodology***
    - To determinate a classical methods for diagnosis and classification of PD.
    - To develop a classification of subjects with PD.

  - **Activities**
    1. To establish the main methods for diagnosis and classification stage in PD .
    2. To develop and implement a strategy to relate eye characterization data and the stage of subjects with PD.
    3. To classify subjects of our dataset with PD.
  - **Analysis and strategies of risk mitigation**
    1. Risk 1: The strategy can not properly classify the stage of subjects with PD.
       * **Plan A**: Inspect the eye movement characterization.
       * **Plan B**: Search for mistakes in the developed strategy.
  - **Project Deliverables**
    * Classification of Subjects with Parkinson's Disease.

- **Work package 4: To validate the developed strategy.**
  - ***Methodology***
    * To determine accuracy of the proposed classification method.
    * To compare our strategy with others proposed in the literature.
  - **Activities**
    1. To apply the strategy selected classification on dataset.
    2. To evaluate the performance using precision and recall.
    3. To determinate statistical significance.
    4. To compare the strategy with state of the art.
  - **Analysis and strategies of risk mitigation**
    * Risk 1: Poor statistical significance, precision or recall.
      · **Plan A**: Adjust parameters of the method.
      · **Plan B**: Check the measurements.
    * Risk 2: The project is not completed within the time set.
      · **Plan A**: Planning a new schedule for activities to be performed.
      · **Plan B**: Perform multiple tasks simultaneously.
  - **Project Deliverables**
    * Validated method of Stage PD Recognition
    * Thesis Document

The main contribution of this thesis was characterization eye movement during gait that may be used to diagnose and classify PD. Were developed two strategies to characterize ocular movement. First, an automatic tracking strategy, that allow to know x and y eye position during gait. Second, based in the optical flow calculation, whit this information was created a histogram movement descriptor, to visualize and summarize to where subjects move the eye during a gait cycle. These strategies are described below.

3 Characterizing the eye trajectory during the gait towards Parkinson stage identification

Presented on the "10th International Symposium on Medical Information Processing and Analysis" SIPAIM 2014, October 2014

Parkinson's Disease characterization is commonly carried out by measuring a motor abnormality that may affect an optimal locomotion. However, such gait characterization is far from achieving accurate and sensible early detection of this disease, dealying between 6 *months to* 3 *years a first diagnosis. Current research has identified the eye movements (EM) as a powerful biomarker that may detect and identify PD, even in early stages. However, this eye analysis is now performed under fully controlled conditions and strict protocols, for which the patient must follow a set of routine movements in a static position. Such protocols however loss some natural eye movements during the gait that may help to promptly highlight the disease. This work presents preliminary results characterizing and analyzing the center of mass of the eye movement during the gait, captured using a high speed camera. An automatic tracking strategy was herein implemented to follow the eye during the locomotion. Promising results were obtained from a set of real patients diagnosed with Parkinson Diseases in stages of* 1 *y* 3*, which show strong differences among the computed signals.*

3.1 Introduction

Parkinson's Disease is the second most common neurodegenerative disease (around 6.3 million people are affected worldwide), that progressively alters the motor patterns [1]. PD is typically diagnosed and followed by using a standard gait motor characterization that mainly measures the level of rigidity, tremor at rest and postural instability [27]. However, such examination remains limited because of the diffuse border among normal and early PD stages. Eye movement characterization has demonstrated high sensitivity to PD classification and following up. Experimental evidence has demonstrated changes in the frequency and amplitude of the eye movement that correlates with neurotransmitter deficiency and abnormal motor movements [3, 8, 12]. The eye motion plays an important role during locomotion because visual exploration fully determined an optimal postural control. In early PD stages, the abnormal visual motion may cause global motor alterations, loss of balance and proprioceptive deficits [18, 24]. Such eye movement analysis has been carried out under many restrictions, for instance the evaluation is performed in static position, under controlled conditions and executing predetermined routines to the eye motion [65, 22]. These conditions result highly restrictive, losing the characterization of natural eye gestures during a daily exploration. Interestingly, the eye exploration motion correlates with the postural control w.r.t external perturbations. In addition, the signals obtained from electro-oculography are highly noisy, in particular those that correlate the eye movement with the corneo-retinal standing potential [54]. The main contribution of this work is a preliminary eye motion analysis of patients diagnosed with Parkinson in stages of 1.5, 3 and control patients. A set of videos of patients during the locomotion were captured using a high speed camera and an automatic tracking strategy was implemented to follow the eyes trajectory. Results demonstrate a high sensitivity to discriminate normal and pathological eye motion patterns.

3.2 Methods

The herein presented analysis of the eye motion uses an automatic tracking strategy to follow the eyes of patients during walking (An example of tracking is shown in Figure **3-1**) . In next subsections the methodology is presented. Then, images were mapped to a feature space using a set of Haar functions, thereby describing a set of rectangular features at the different scales that can be learned and used as rectangular detectors, in particular to characterize the eye. Finally an adapted adaboost learning algorithm allows to weight the features more representative in the eye identification task [60].

3.2.1 Tracking the Eyes

Given a new video-sequence, the eyes were identified at each frame by mapping the image to the Haar space and these features used by a cascade adaboost classifier. Such cascade

classifier allows a fast identification of the eyes, taking in average less than one millisecond to perform such task. Nevertheless, tracking errors were observed in some frames because of uncontrolled reference point. Every patient signed an informed consent according to the Helsinki declaration.

3.2.2 Experimental setup

The proposed approach was tested using a real dataset of patients recorded with a custom constructed tracking system (see in Figure **3-1**(b)). A total of 8 participants were recorded distributed as: 4 parkinson disease patients (stages of 1.5 and 3) and 4 controls. A light high speed camera Gopro+3 on helmet (840 x 480, 240 fps) was used to capture the eye movements while the patient was walking along of a platform of 4.50m.

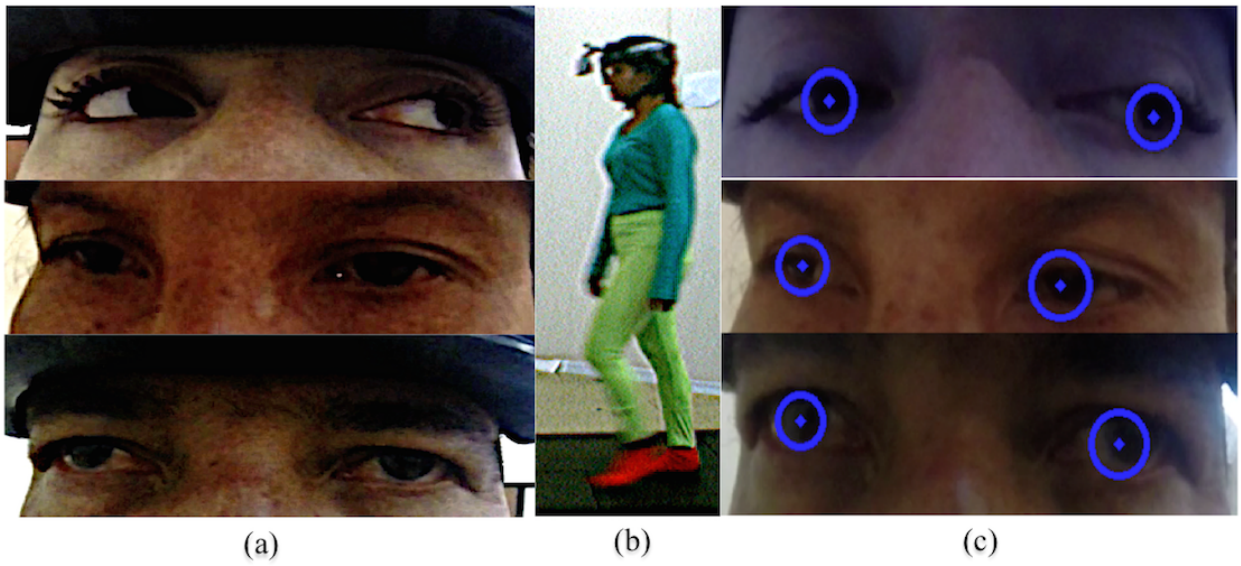

Figure 3-1: Left panels (a) show different captured videos. Panel (b) displays a patient walking with the custom tracking system. Right panels (c) exhibit the eyes tracked during a typical sequence.

3.2.3 Learning Eyes features

A Viola and Jones tracking strategy was herein implemented to follow the eyes of patients during locomotion [61]. For doing so, a training step was firstly performed from a bank of positive (images with eyes) and negative images. Each image was then represented as an integral image to rapidly calculate rectangular characteristics of the image at multiple scales, filtering out some noise high frequencies and allowing a rapid identification of the interest zone. For each video the proposed strategy computed the global CoM trajectory of the eyes during a free walking (without fixation point), allowing to capture the natural

eye movement when exploring the scene. Figure **3-2** shows a typical trajectory obtained by control patients. A relative constant motion is observed in these participants. The notorious amplitude change on eye trajectories is may be attributed with specific gait torques such as the heel-strike, which alter the body dynamic, producing many times jumps that modify the motion .

3.3 Results

For each video the proposed strategy computed the global CoM trajectory of the eyes during a free walking (without fixation point), allowing to capture the natural eye movement when exploring the scene. Figure **3-2** shows a typical trajectory obtained by control patients. A relative constant motion is observed in these participants. The notorious amplitude change on eye trajectories is fully correlated with specific gait torques such as the heel-strike.

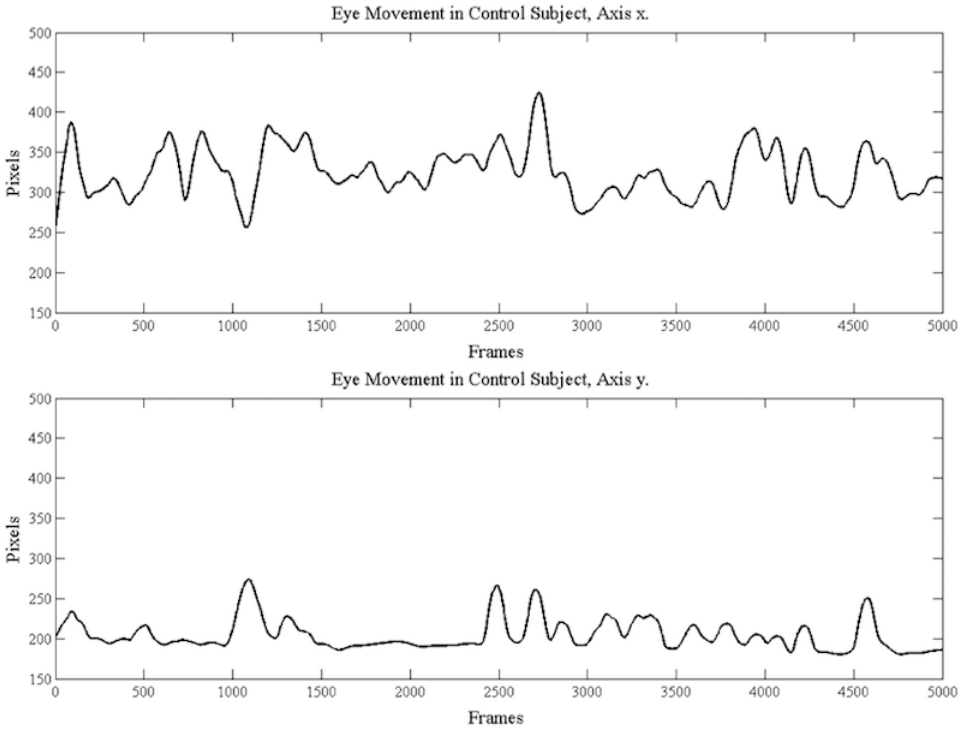

Figure 3-2: Eye movements in axis x to the left and y to the right of control subject

In Figure **3-3**, a typical PD trajectory is presented, a patient diagnosed in stage 1.5. In spite of the low change in terms of the global motion, the eye trajectory evidences strong changes regarding the visual exploration. The x, y-axes totally lost the amplitude change that suggests low exploration of the eye and motion rigidity.
In Figure **3-4**, a pattern, observed in a patient with PD in stage 3, is plotted. A total abnormal eye pattern is reported. While in $y-$axis a very smooth motion was reported,

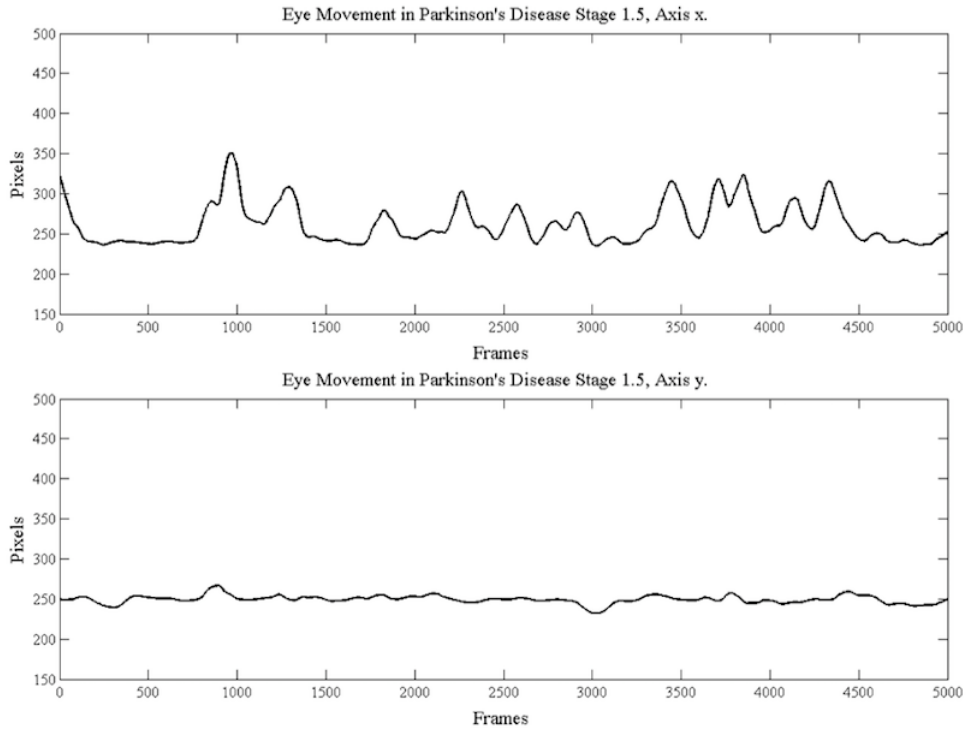

Figure 3-3: Eye movements in axis x to the left and y to the right of PD stage 1.5

without any exploration. In the $x-$axis an altered motion is reported that is associated to the response of gait torques with poor stabilization and therefore postural alterations.
This behaviour contrasts with control subjects (Figure **3-2**.) who keep a constant motion this have a relationship with normal visual scanning that is done when walk, this exploration or EM is necessary for appropriate postural control, being that in free walking (without fixation point), visual system scans the body and compare with environment for do postural adjustments during gait, this ability will be affected in PD because, low scanning or EM generating postural alterations and abnormal movement when the subject walking.
Finally in Figure **3-5**, it was summarized the trajectory of the center of mass for each each patient in x and y axis (left and right panel respectively). As is illustrated in each box-plot, the CoM displacement is discriminant enough among the different patients being a powerful biomarker for parkinson disease. Large variability is shown in boxplot corresponding to a patient diagnosed with parkinson in level three. Such large variability is associated to the deficiency on eye motion control.

3.4 Conclusions

In this paper an eye motion analysis of parkinsonian and control patients during walking was presented. Preliminary results show important changes in frequency and amplitude of

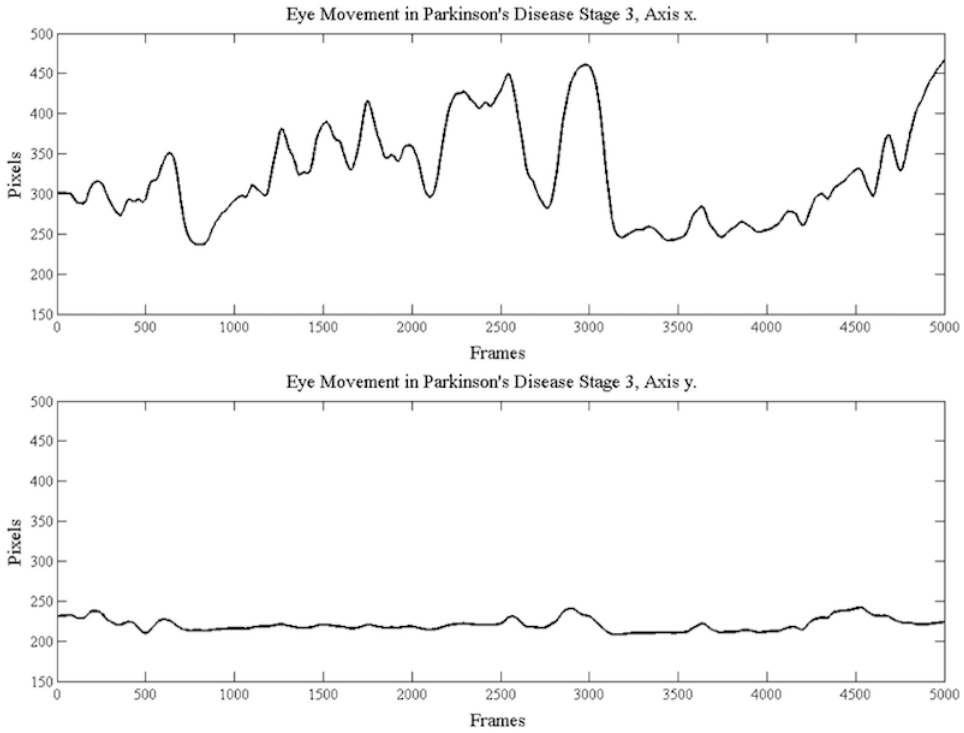

Figure 3-4: Eye movements in axis x to the left and y to the right of PD stage 3

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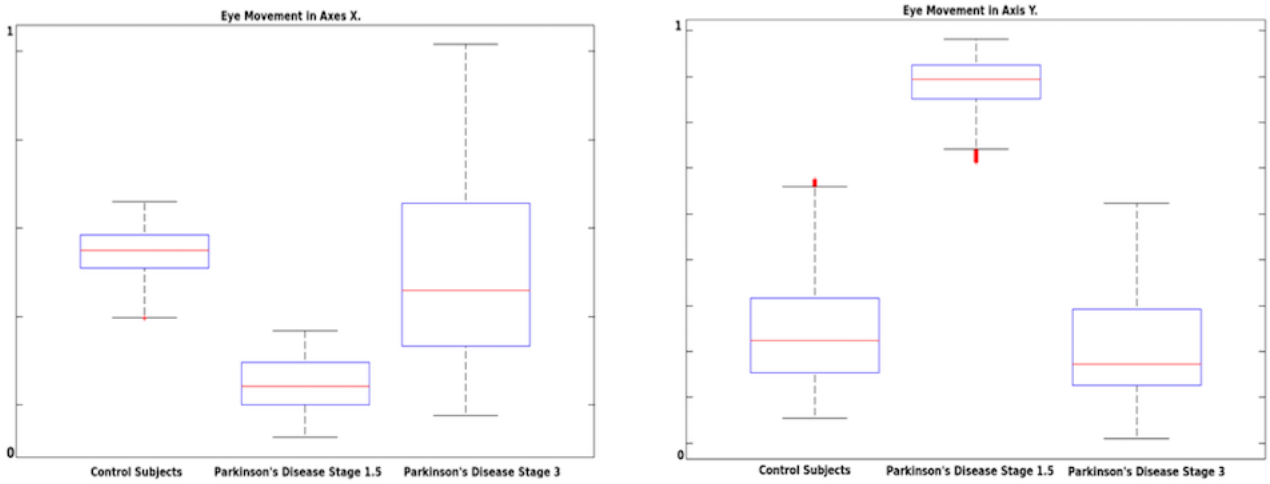

Figure 3-5: Statistical box-plot representation of three different displacement for control and parkinson diseases. The right and left panel represent the x and y axis respectively. The right boxplot summarizes the movement for 5 control patients while the middle boxplot represent a displacement for a 1.5 parkinson disease patient. Finally in the left boxplot is illustrated the statistical boxplot for a parkinson patient diagnosed with stage of 3.

CoM eye trajectory in PD patients. The more advanced the stage of the disease, the more important the observed alterations, suggesting this analysis is a potential tool to support the PD diagnosis. Future works include the evaluation of the proposed approach in larger datasets.

4 A Characterization of the Parkinson's Disease by describing the Visual Field motion During Gait

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An early diagnosis of Parkinson's Disease (PD) is crucial towards devising successful rehabilitation programs. Typically, the PD diagnosis is performed by characterizing typical symptoms, namely bradykinesia, rigidity, tremor, postural instability or freezing gait. However, traditional examination tests are usually incapable of detecting slight motor changes, specially for early stages of the pathology. Recently, eye movement abnormalities have correlated with early onset of some neurodegenerative disorders. This work introduces an new characterization of the Parkinson disease by describing the ocular motion during a common daily activity as the gait. This paper proposes a fully automatic eye motion analysis using a dense optical flow that tracks the ocular direction. The eye motion is then summarized using orientation histograms constructed during a whole gait cycle. The proposed approach was evaluated by measuring the χ^2 distance between the orientation histograms, showing substantial differences between control and PD patients.

4.1 Introduction

Among the neuro-degenerative disorders, PD is a major public health concern, with about 10 million people worldwide in 2005 and the expectation that this figure will be doubled for 2030, according to the World Health Organization (WHO) [40]. Typically, this pathology is associated to symptoms such as bradykinesia, rigidity, tremor, postural instability, freezing gait (FOG) and other gait disorders [56, 9]. However, traditional tests are not sensitive enough and may delay the diagnosis between 6 months to 3 years [27, 44], among others because of the high inter and intra-examiner variability. Some investigations have then focused in other more unspecific symptoms, such as depression, dementia or smell and sleep disorders[15], aiming to improve the disease characterization by examining upper brain functions that might be affected. Lately, eye movement abnormalities have been studied and characterized as strong biomarkers of Parkinson's Disease [3], following the hypothesis that this disease affects the dopamine neural systems [36].
The oculo-motor control centers are highly sensitive to dopamine deficiency, a condition reflected in the eye motion dysfunction that seriously impairs the eye response to the target spatial location, even for early stages of the PD [18, 57]. It has been demonstrated that eye motor function correlates with the disease stage [46, 24]. However, the detection of some degree of motion abnormality is still insufficient and any characterization of the PD demands in addition a precise quantification. Usually, customized devices track the eye movement by measuring potential differences when the eye targets a particular object, but these measures are noisy and usually confuse the eye with other salient face regions. Overall, these tests under controlled conditions hide the natural eye motion control. Consequently, any motion evaluation should be performed in conditions that respect the natural eye movement [54]. The gait particularly constitutes a state in which all systems connect together for the interaction with the environment is optimal. During gait, the eye constantly explores the world to feedback every system about the surrounding conditions. The idea of measuring the eye movement during different gait tasks becomes then appealing in terms of registering the ocular activity in natural conditions [66].
A main contribution of this work is the characterization of the Parkinson Disease by determining the ocular motion patterns during gait. The proposed approach performs a classical dense optical flow description that captures the instantaneous eye motion, upon which a velocity orientation histogram is built. The relative occurrence of the flow vectors is computed for a pre-defined set of orientations. Significant differences were thus found between control and PD patients, and also among the different stages of the disease. The rest of the paper is structured as follows, the dataset and video recording conditions are described in section 4.2.3, the eye motion tracking and the histogram construction are explained in sections 4.2.1 and 4.2.2 respectively. Section 4.3 shows the results by comparing eye movement description in control and PD subjects.

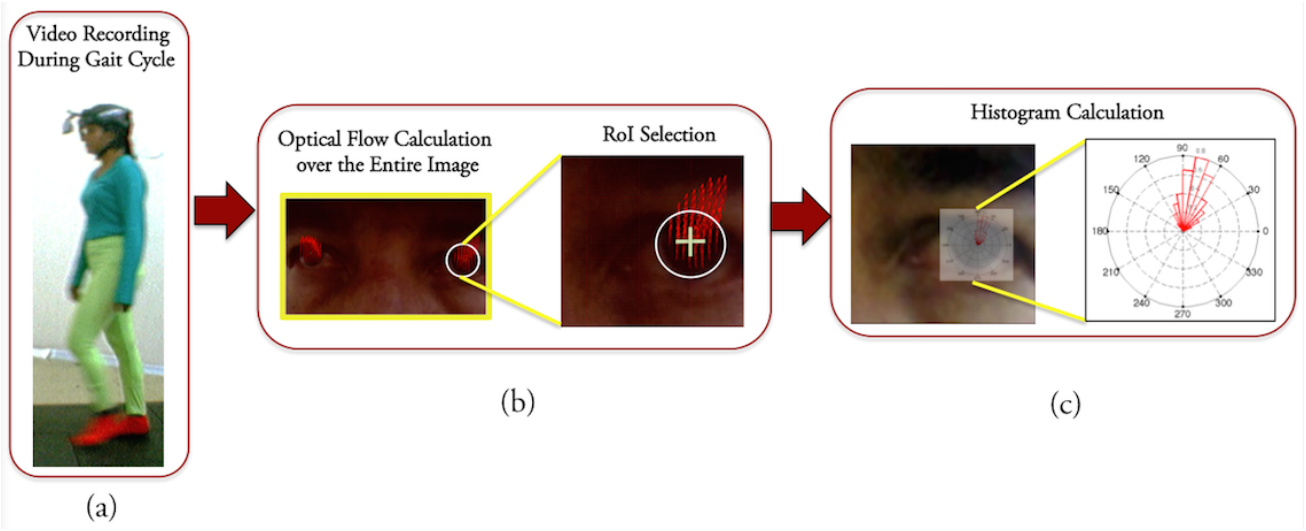


Figure 4-1: Panel *a* shows the patient and the capture system. Panel *b* displays the optical flow calculation over the entire image and the RoI selection. Panel *c* depicts the velocity orientation histogram.

4.2 Proposed approach

Dopaminergic brain systems play a crucial role in motor and cognitive mechanisms as well as a number of basic lower-level functions including lactation, sexual gratification, and nausea. Under the assumption that control eye abnormalities are related with dopamine deficiency, a motion eye descriptor during gait is herein introduced to characterize the Parkinson disease. The proposed approach starts by characterizing the instantaneous eye movement using a dense optical flow field from a local appearance matching between consecutive frames. Afterwards, the eye movement is coded for a complete gait cycle as a histogram of orientations previously selected. A further description of each step is presented hereafter.

4.2.1 Dense optical flow

The eye motion was captured with a camera attached to a helm placed on the forehead (see Figure **4-1**(a)). The presence of particular salients in the face like the zygomatic arch may hamper proper tracking and eye detection [54], a common problem for traditional eye detection methods like the electrooculography or some video processing techniques like the background subtraction. An appropriate characterization of this eye movement was then herein performed by capturing apparent motion patterns of objects representing local pixel motion between two consecutive frames. The dense optical flow approach proposed by Horn and Schunck [23, 63, 31] was then implemented and computed for consecutive frames and the obtained apparent motion ends up by following an oriented pixel-to-pixel and neighbor

variation, case in which flow distortions are minimal and the smoothest solutions can be selected. This process is of course iterative. One of the main advantages of this method is that it produces a high density of flow vectors, i.e. the missing information in the inner parts of homogeneous objects is completed by the motion boundaries and the tracking results very robust to a many types of noised [39]. For the proposed approach, the Parkinson Disease characterization was achieved by this classical algorithm, describing directional changes for each pixel along the time and thereby determining how eyes move when the subject is walking, as illustrated in **4-1**(b).

4.2.2 Orientation flow histograms

Exploration eye movements are essential part of the human foveated visual system that pursuits and gazes objects of interest by integrating information from many sources. The whole visual task must afford the eye reaches both an angular velocity that minimizes the retinal slip and a gentle movement that effectively reduces the targeted offset of the image. This pursuit system is forced if the subject is walking and the background is variable, as proposed in the present investigation but then the descriptor should obtain information about the velocity and the targeted position. Yet this is nearly impossible with no information about the background, it is possible however an estimate if the two experimental groups are evaluated under the same conditions. In consequence, a representative descriptor per class is constructed as an orientation flow histogram for the whole gait cycle, thereby correlating the directional eye movements computed from the optical flow. This orientation flow histogram summarizes the eye patterns from multiple directions by computing the instantaneous eye motion during a gait cycle [14]. The histogram in this work was computed from the optical flow information inside a region of interest (RoI), where the left eye was used to define the RoI, since the camera recording was focused on this eye. Specifically, this histogram $H_t(i) = [h_t(i_1), h_t(i_2)...., h_t(i_{n)}]$ is composed of 36 bins homogeneously distributed (see **4-1**(c)). Finally, the Chi-squared distance χ^2 was calculated between histograms to evaluate the discrimination capability of the proposed approach.

4.2.3 Data Acquisition

Twelve control subject and seven subject with Parkinson's Disease participated in this study in the gait laboratory of Universidad Nacional de Colombia. The experimental group of PD patients are distributed as: 1 PD subject in stage 1, 3 PD subjects in stage 2 and 3 PD subjects in stage 3, according to Hoehn and Yahr scale (1 corresponds to the earliest PD stage and 5 stands for the most advanced stage of the pathology)[30]. The data set was acquired by a high speed camera GoPro HERO3$^+$, attached to a helmet (840×480, $240\,fps$)

placed at the forehead. Eye movement was acquired while the subjects were walking along a customized walkway of 4.50m, with no specific request of the experimenter for fixating at any point, this experimental setup is shown in **4-1**. Each patient agreed to be recorded and a written informed consent was provided and signed, following the Helsinki declaration.

4.3 Results

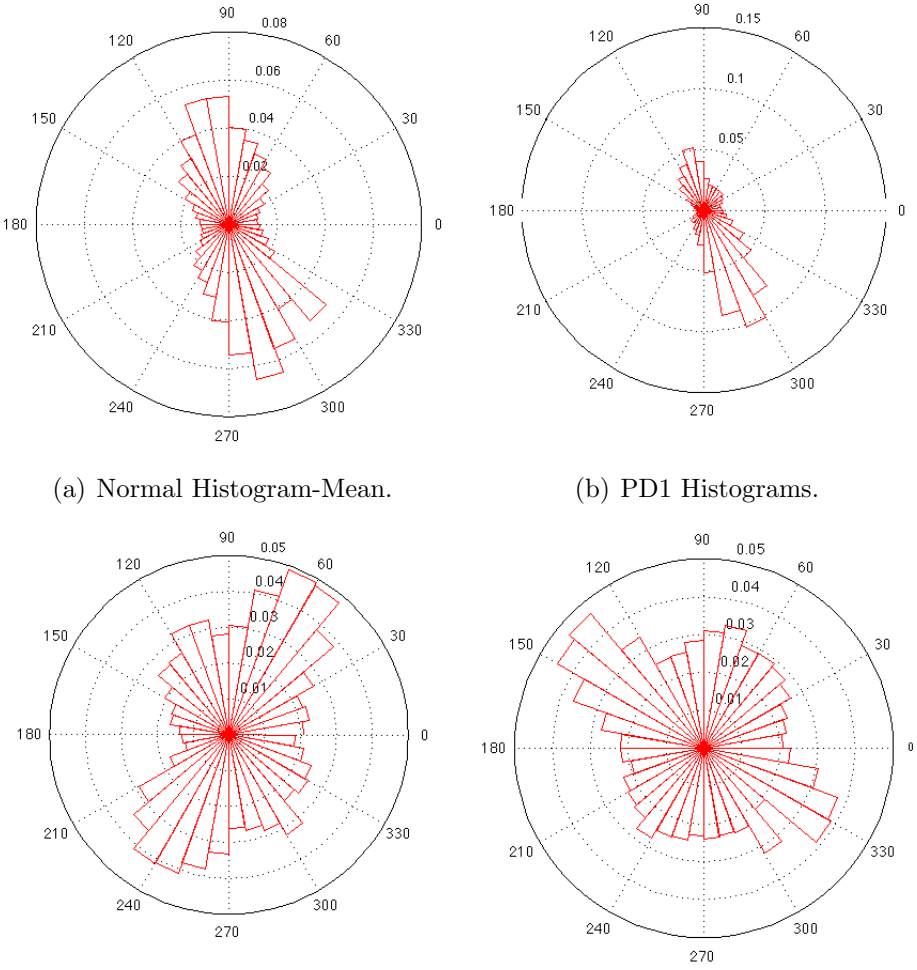
In this work, it was analyzed the ocular motion during gait, a common daily activity. Constant changes in the environment forces the organ to scan and re-configure the whole motor system[42]. This analysis allows a proper PD characterization. The set of motion histograms was computed per subject and during a single gait cycle. Additionally, a mean histogram for each available class estimates the eye pattern per class (see Figure **4-2**) and allows the comparisons between classes.
Figure **4-2**(a) displays the expected ocular movement for control patients, a dominant direction while the patient is exploring the visual space during gait. This sensing is required to measure and planning the movement, provided that a suitable visual feedback during gait. In this case, subjects walk the motion lab pathway [42, 29, 21].
The orientation histogram for the single patient with a Parkinson's disease stage 1, is shown in Figure **4-2**(b). This histogram illustrates the early impairment by the motion amplitude and symmetry patterns.
On the other hand, Figures **4-2**(c) and **4-2**(d) show in general, that as long as the Parkinson's disease advances, the patient movement requires more effort to select the correct gazing, and the system then evidences an eye sweeping almost every direction. Specifically, Figure **4-2**(c) illustrates the imprecise gaze with the consequent increment in the number of directions that a patient explores. Furthermore, in Figure **4-2**(d), eye motion changes are notorious, the exploration direction is modified.
The Chi-squared distance quantifies the level of similarity between histograms. The present study has determined differences between control and PD subjects and along the different PD stages. Furthermore, this metric provides a discriminating measurement and description of the ocular motion. Table 1 shows the compared Histogram Mean per class or stage (in the column) for each subject of the class, while also the mean of this comparison is shown.
Results in Table 1 evidences differences between control subjects and PD patients. Moreover, these measurements show how the distance between histograms increases with respect to normal subjects as long as the the PD stage advances, i.e. these results demonstrate this approach is capable of distinguishing between normal subjects and PD stages and the presented describer characterizes the early stages of the PD [58].

Table 4-1: Chi-Square, Perfect match is 0 and total mismatch is unbounded. HM is Histogram Mean. Only in one case a single histogram is used because this class has only one patient. N is Control. PD_1 is Parkinson's Disease Stage 1. PD_2 is Parkinson's Disease Stage 2. PD_3 is Parkinson's Disease Stage 3.

	N-M	**PD1**	**PD2-M**	**PD3-M**
HM-N	0.09	0.06	0.19	0.21
H-PD1	0.15	0	0.3	0.3
HM-PD2	0.19	0.23	0.09	0.12
HM-PD3	0.24	0.25	0.15	0.08

4.4 Conclusion

In this paper has introduced a novel ocular motion feature characterizes PD, even in early stages. Orientation flow histograms are used as representative descriptors per class. This characterization is performed in natural conditions using a robust eye movement descriptor. This approach detects different stages of the disease. Future work includes a more exhaustive experimentation, the method will be performed with a larger data set.



(a) Normal Histogram-Mean.

(b) PD1 Histograms.

(c) PD2 Histograms-Mean.

(d) PD3 Histograms-Mean.

Figure 4-2: The histogram (a) shows the typical movement directions in control subjects. The histogram (b) illustrates the eye movement performance in Parkinson's disease stage 1 (PD1). The histogram (c) displays eye movement in Parkinson's disease stage 2 (PD2) and finally, in (d) it is illustrated the histogram that shows the impairment in Parkinson's disease stage 3 (PD3)

5 Conclusions and Perspectives

This thesis presented two different methodological proposals to characterize the main eye motion patterns during the gait pattern. These approaches are based on the automatic characterization of video-sequences by registering the ocular movement. The proposed approaches were evaluated for different population of patients that include control and PD subjects at different levels of the disease. The descriptors computed from the proposed approaches, evidenced significant differences among the group of patients. The results shown that the increasing dispersion of eye movements or loss of orientation are determinant to establish the disease progression. Subsequently, the proposed strategy is useful to support the diagnosis of the PD.

In a future work, include an exhaustive evaluation with larger population of patients. As well as, the proposition of new markerless approach to better understand the complex ocular motion patterns.

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