Computer Vision Methods for Parkinsonian Gait Analysis: A Review on Patents

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Abstract: Gait disturbance is an important symptom of Parkinson's disease (PD). This paper presents a review of patents reported in the area of computerized gait disorder analysis. The feasibility of marker-less vision based systems has been examined for 'at-home' self-evaluation of gait taking into account the physical restrictions of patients arising due to PD. A three tier review methodology has been utilized to synthesize gait applications to investigate PD related gait features and to explore methods for gait classification based on symptom severities. A comparison between invasive and non-invasive methods for gait analysis revealed that marker-free approach can provide resource efficient, convenient and accurate gait measurements through the use of image processing methods. Image segmentation of human silhouette is the major challenge in the marker-free systems which can possibly be comprehended through the use of Microsoft Kinect application and motion estimation algorithms. Our synthesis further suggests that biorhythmic features in gait patterns have potential to discriminate gait anomalies based on the clinical scales.

INTRODUCTION

Parkinson's disease (PD) is characterized by the loss of neurons in brain. The loss results in dysfunction of circuitries that mediate motor and cognitive functions. As a result of this loss there can be a number of motor symptoms such as rigidity, akinesia, bradykinesia, rest tremor, and postural abnormalities, most of them affecting walking ability [1]. Current standard for assessment of symptoms is subjective rating using clinical scales such as the Unified Parkinson Disease Rating scale (UPDRS) [2], to evaluate treatments and to follow the disease progression. Unfortunately, the need for real world PD treatment remains unmet for many patients. Since PD is progressive, there is a need for follow up of treatments over time. Medicine dosing may need to be adjusted with respect to physical exercise, food intake and mood [3].

Parkinsonian Gait (PG) develops with the passage of time as a result of PD features i.e. bradykinesia, postural reflexes and rigidity in muscular tone [4]. A typical PD patient stands with a stooped posture with the spine bent forward with flexed knees and hip. He stands rigidly with a masked face. His hands, wrists and fingers may shake with slow tremor frequency. His arms may fail to swing. The trunk rotation is restricted as he starts walking. He walks with short angular movement at all the joints. The swing phase is reduced with the lengthened step cycle. The feet may shuffle due to reduced stride length and step height. The trunk is bent forward as the body weight is carried out on his toes. As a result the centre of gravity of the body is pushed ahead of the foot support which creates a risk of falling [5]. He also finds trouble in gait initiation and because of psychological stress; he may become 'frozen' [4]. Levodopa helps to reduce bradykinesia and rigidity during PG [6]. However with longer treatment, the duration of Levodopa effects become shorter. There may be fluctuations in drug response resulting in ON-OFF phenomenon [7]. Different types of medication adjustments are required depending upon different abnormal movements such as chorea and dystonia. Drug response fluctuations are corrected with smaller and more frequent dose adjustments which demands accurate and timely diagnosis.

In order to quantify the normal and pathological locomotion patterns, quantitative gait analysis is a very important clinical tool. Quantitative gait analysis has been proved useful for treatment prescription and evaluation of post-treatment conditions. In an observational gait analysis by a clinician, the approximations are made based on the deviation of gait parameters with the normal gait symmetry. A precise and quantifiable measurement of these variables can be produced using computerized gait analysis methods. The easiest parameter to be measured quantitatively among temporal and spatial gait parameters is the walking speed (meters/sec) because the motion and alignment of body joints are strongly influenced due to walking velocity throughout the gait cycle [8]. Other measurements used in gait characterization are the step length, stride length and the cadence. The distance between the heels of the person during the double support phase of gait is known as the step length. The distance covered by the heel from the initial contact of one foot to the subsequent contact of the same foot is called stride length. Two step lengths are equal to one stride length. Ca-

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dence is the number of steps within a given period of time which can be multiplied by stride length to determine the walking velocity. The rhythmic alternating movements of feet which results in the forward movement (i.e. one stride) of human body is called a gait cycle. The gait cycle is further divided into two periods known as swing and stance. The limb is moved forward during the swing phase while in the stance phase, the limb supports the body weight (Fig. **1**).

An important application of neurological diagnosis and management is computer-vision (CV) based gait analysis since it is able to provide quantitative data on postural and locomotive abnormalities using image processing techniques [9]. The CV based gait analysis systems are characterized in two types; the holistic-based gait analysis and the model-based gait analysis. In the holistic-based gait analysis (HGA), diagnosis is performed with a marker-free system. In this approach posture and motion cues are extracted from the segmented silhouette of the test subject in video frames. Statistical information is derived using the image and then correlated with the biometric features of gait [10].

The model-based gait analysis (MGA) approach fits the model e.g. a human model to the image data [11]. This approach uses markers on the human body to calculate temporal characteristics of gait. Stride frequency, cadence and velocity can be measured using MGA [12]. For example, Cunado *et al.* [11] used Fourier series to elaborate leg motions. They correlated between the leg motions in sequence of images to determine a dynamic human model for gait evaluation.
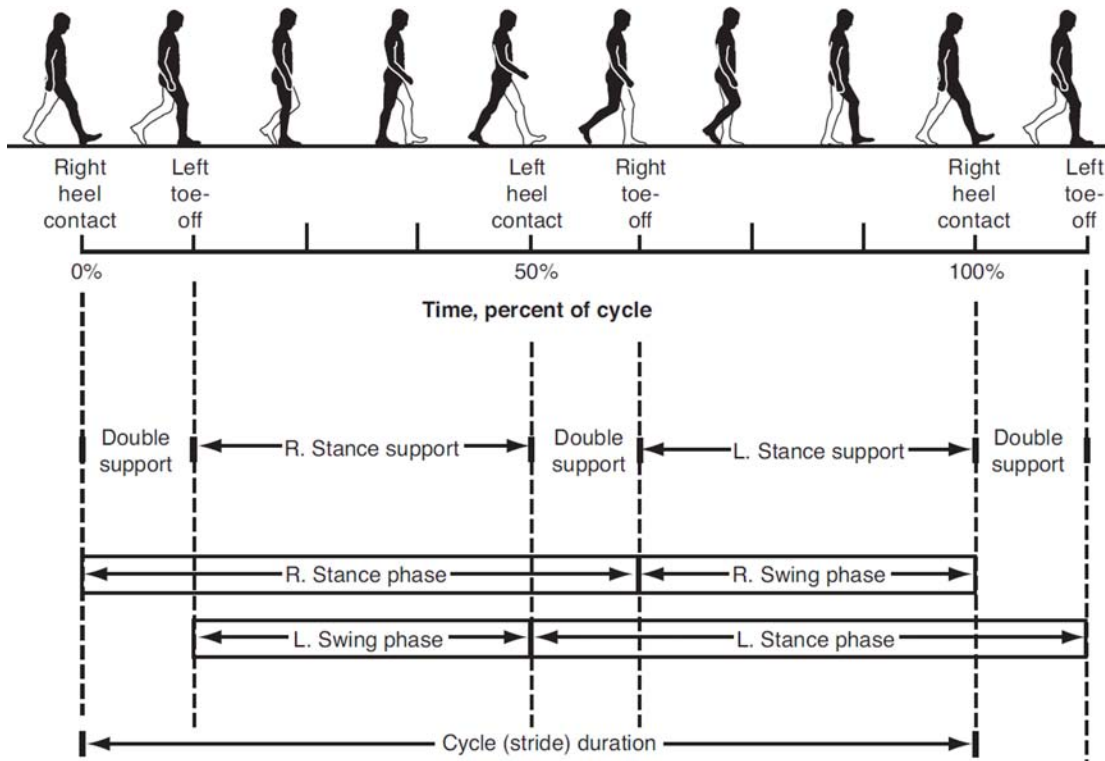
Wearable accelerometers and sensors were used in traditional gait analysis methods. Later the MGA systems consisted of Electrogoniometers (EGM) and Moving Light Displays (MLD). Subjects were asked to wear joint markers which caused discomfort [13] and used to consume significant setup time. These problems were tackled using HGA systems as these systems do not require physical contact. Especially in biomedical applications (like rehabilitation monitoring after orthopedic surgeries and neurological disorder assessment) the hardware setup can be effectively reduced through marker-free gait analysis giving the patient maximum possible comfort during examination.

REVIEW METHODOLOGY

The aim of the study is to evaluate applications of computer-vision (CV) based gait disorder assessment methods. The possible use of these systems in the self-treatment of a Parkinson's patient using a single web camera attached to a personal computer has been investigated. To achieve this objective, patents have been reviewed to find methods for a marker free (i.e. holistic-based) gait analysis system that rid lab constraints and extensive setup procedures in gait diagnosis. The target is to find a cost efficient and more realistic method for assessing PG which may be useful for gait analysis in the home environment. The focus of study is laid on image processing techniques to assess gait through video frames. The study of efficient image segmentation algorithms, gait feature extraction methods and gait feature classification techniques to distinguish between the symptom severity levels are the primary concerns.

Previous work in CV based gait analysis methods had constraints due to the need for structured lab environment and extensive setup procedures. The reason of using a complex system was that the image segmentation of the test human body has been the most challenging aspect. Even in the

Fig. (1). Time Dimensions of a Gait Cycle [8].

holistic-based gait diagnosis, researchers used lab settings such as the subjects were worn specifically designed colored dresses so that the human body pixels could be identified in video frames using color segmentation algorithms. Illumination in the test area has been another big problem. Bad illumination disrupts the pixel values which lead to incorrect foreground segmentation. The high illumination creates light reflection on the foreground which effects segmentation process. Modeling of an appropriate skeletonization method to extract gait features and body joints details from the segmented human silhouette is difficult. Bad modeling may reduce gait classification accuracy.

A three tier review methodology (Fig. **2**) has been applied to synthesize patents reported in the area of CV based gait analysis systems. Keywords such as 'Gait Disorder', 'Gait Video Analysis', 'Gait recognition' and 'Vision based Gait analysis' were used in the Google Patent search engine.

The patents in the area of gait analysis are characterized into 'CV based gait analysis systems' and 'Sensor based gait analysis systems'. In the sensor based gait analysis, gait features are readily extracted using the sensor data. There is only a need to statistically analyze these features to examine the gait disorder. In the first tier of review methodology, a review of these statistical methods has been done for their possible use in the HGA systems.

Patents on the CV based gait analysis systems are further characterized between marker (i.e. MGA) and non-marker based (i.e. HGA) methods. In the MGA methods, the gait features like the step length, stride length and the cadence are readily calculated from the position of illuminated (or colored) markers placed on the subject's body. In the second tier of review methodology, a review of classification methods used in MGA systems to categorize between pathological and normal gait patterns has been done for their possible use in the HGA systems.

In the third tier of review methodology, an emphasis has been laid upon the patents reported in the area of the non-marker (i.e. HGA) based gait analysis. Different image segmentation techniques to segment the human silhouette from the background have been evaluated. Different models for skeletonising the human silhouette are investigated for gait feature extraction. Feature extraction and classification methods are reviewed for their possible use in classifying the gait disorder on a clinical rating scale. The patents which have been found related to the gait disorder assessment methods are listed (chronologically) in Table **1**. Till date, no such invention has been reported which is non-invasive and could classify the gait disorder between symptom severities using a single web-camera. A patent (US20040228503) though reported to have described a non-invasive biometric tool consisted of a web-camera attached to a computer and was used to identify a person based on his gait characteristics. The patent directs a possibility towards the development of CV based PG classification tools to be used in home environment for the self-treatment of PD patients.

REVIEW OF PATENTS

The first patent on video-based gait analysis was reported by Boyd *et al.* [14] in 1986. In this method, subjects were asked to stride over an elongated transparent platform. A moveable camera was placed on a trolley below the platform to record plantar movement of subject's feet during strides as shown in (Fig. **3**). The moveable camera was driven by a pulley whose cable was connected to a belt worn by the subject so that the camera moves in synchronization with the subject's strides. Electrical heating elements were used to heat the platform surface to preclude the condensation formation as the subject strides over the platform. Gait features like stride frequency, cadence and velocity were calculated using the contact areas of feet during subject's motion for gait disorder assessment. Although the aim of gait disorder diagnosis was met by this system the type of extensive setup mechanism used was costly, time consuming and caused discomfort to the subjects.
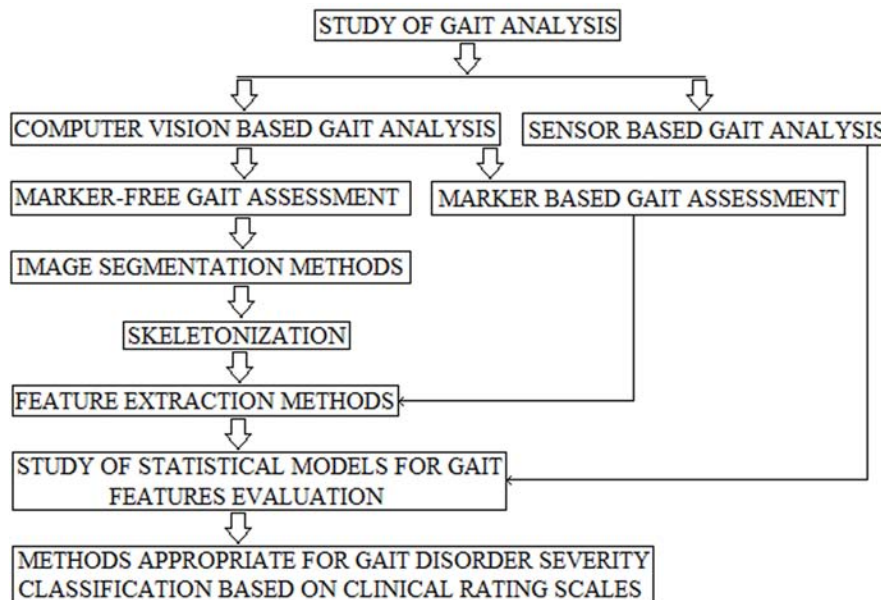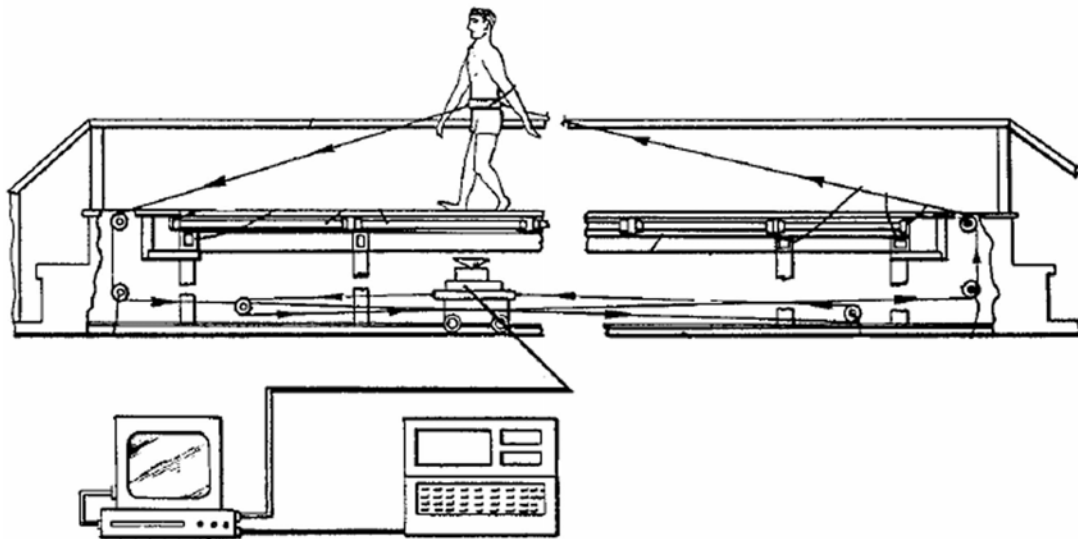

Fig. (2). Review methodology.

Table 1.   The Retrieved Patents and their Brief Description.

Patent No.	Year	Brief Description	Instrument Type
US4600016	1986	A moveable camera placed on a trolley below the platform was used to record plantar movement for gait analysis.	Invasive
US4631676	1986	Sony Motion Analyzers were used to analyze the patterns of leg motility during the gait.	Invasive
US4813436	1989	Foot pressure was measured using invasive markers and insole sensors for gait analysis.	Invasive
US5072294	1991	The centroids of reflective markers attached to the leg joints were computed using pixel segmentation for gait analysis.	Invasive
US6231527	2001	Insole sensors were used to assess weight bearing forces on feet during the gait over a treadmill.	Invasive
US20040228503	2004	A single camera attached to a personal computer was used for human identification through CV based gait analysis.	Non-Invasive
US20050234309	2005	Wearable sensors coupled with a computer interface were used to analyze PG for dosage titration.	Invasive
US20070275830	2007	Piezoelectric sensors were used in a treadmill for gait analysis.	Invasive
US20070021689	2007	Neuromuscular status is classified through gait analysis using wearable sensors.	Invasive

Fig. (3). An elongated platform for video-based gait analysis by Boyd *et al.* [14].

In the same year, Pugh [15] came up with a MGA approach using video cameras. He used reflective markers which were attached to the joints of the subject for gait analysis. Subjects were asked to walk along a pathway having a marked centerline. Gait was recorded using a pair of Sony Video Motion Analyzers positioned at the front and sideways of the pathway as shown in (Fig. **4a**). The video frames were digitized to locate x, y and z coordinates of each marker's centroid (Fig. **4b**) using a CAT-100 video analysis board. These coordinates were joined in a computer to form stick and line figures shown in (Fig. **4c**) representing the leg movements of subject to form a gait cycle. The stick figures of a gait cycle were used to assess hip and knee flexions using an angular plot called cyclogram (A cyclogram depicts the angular relationship of two joints during a motion cycle) as shown in (Fig. **4d**). Orthopedic conditions were quantized using the cyclogram by a comparative analysis between pathological gait and the similar data of a normal gait.

A similar idea had been presented in a patent by Engle [16]. His setup was simpler than the system presented by Pugh [15] and consisted of a computer, a VCR and a camera for gait recording. In his work, the stress was laid upon pixel segmentation of reflective markers based on the threshold level of brightness. Marker centroids were calculated in real-time video processing to form stick figures for gait analysis.

A marker based gait video recognition system was reported by Jan C. Au [17] in 1989. The difference of this MGA system from the previously discussed MGA systems is that it consisted of markers secured at various joints of the subject's body as well as in the shoe insoles to calculate foot pressure. These markers produced signals which were digitized to find angular positions of various joints and gait features as well as the foot pressure to calculate stride length as shown in (Fig. **5a**). Using the stick figures, a time series analysis was done based on the flexion of knee and hips dur-
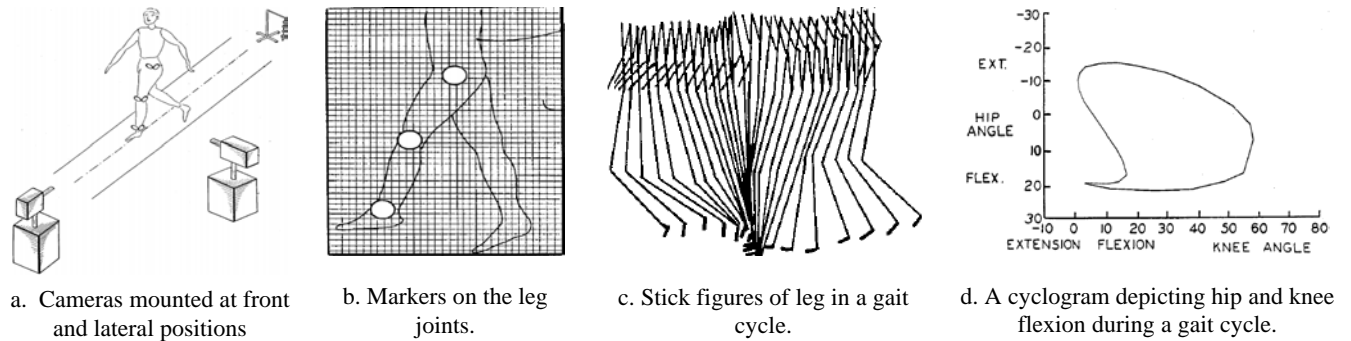
a. Cameras mounted at front and lateral positions   b. Markers on the leg joints.   c. Stick figures of leg in a gait cycle.   d. A cyclogram depicting hip and knee flexion during a gait cycle.

Fig. (4). A model-based gait analysis system by Pugh [15].

i. Hip Flexion.   ii. Knee Flexion.

a. Gait cycle represented by stick figures.   b. Comparative Analysis between Pathological and Normal Gait.
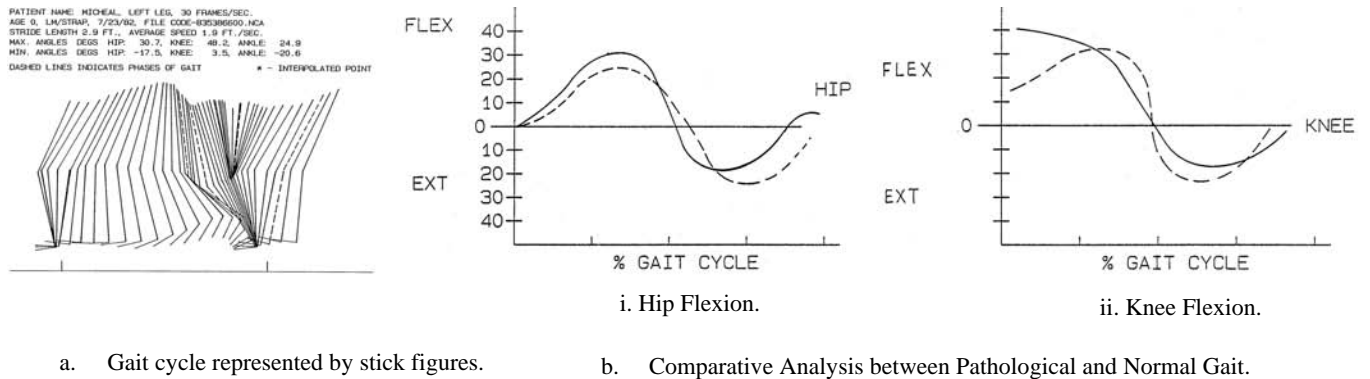
Fig. (5). A marker-based gait analysis tool by Jan C. Au [17].

ing the gait. A comparative analysis is made between the pathological gait pattern and the normal gait pattern to quantify gait disorder (Fig. **5b**).

In order to reduce the testing space, treadmills have been utilized so that motion analysis can be performed within the photographing area of camera and less walking space would be required for gait analysis. A MGA system for diagnosing abnormal conditions in posture and gait using a treadmill was reported by Sol [18] in 2001. The patients were asked to stride on a walking platform. Full-length mirrors were attached at the rear vertical wall behind the treadmill and at lateral vertical wall. Gait was recorded using cameras attached at the front, lower rear, lateral and on the overhead (Fig. **6**). Weight-bearing and ground reactive forces on the feet were assessed using insole-sensors in the shoes. Gait disorder was diagnosed manually by a clinician based on the information from the sensor signals.

Another system for gait disorder assessment using a treadmill has been reported by Lee *et al.* [19] in 2007. This treadmill included a rotatable belt whose rotation was adjusted with the walker's speed as shown in (Fig. **7a**). Markers were placed at the hip, knee and ankle of the subject which were processed to determine the angle and position of the joints. Piezoelectric sensors were attached on the conveyer belt to control the belt rotation. Using this information, the control unit analyzed the walking speed and other gait features. A comparative analysis was made between the normal and abnormal values of knee joint positions using a

time series acquired from this system as shown in (Fig. **7b**). The results were displayed on the treadmill screen to the subject as a feedback to help him in improving his gait.
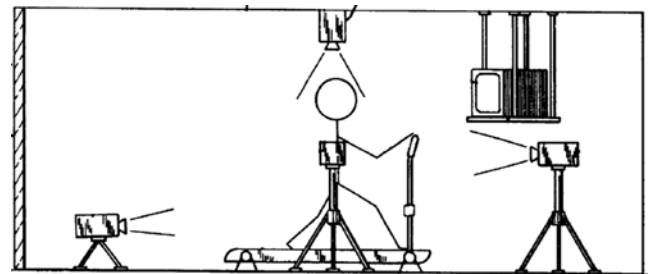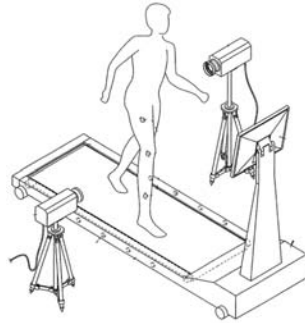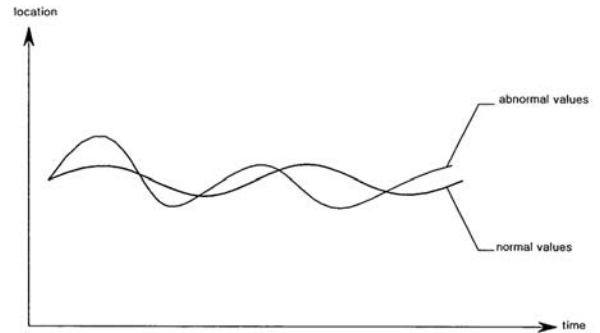

Fig. (6). The placement of mirrors and cameras by Sol [18].

Apart from the MGA systems for gait feature extraction, a gait classification system is reported by N. Stergious [20]. The system could detect foot contact events using the insole pressure sensors. Gait patterns were obtained from a series of foot contacts and were processed to extract stride data. Gait stability was quantified in terms of stride-to-stride fluctuations by the application of Fourier spectral analysis over the gait time-series. Autocorrelation decay in the gait time series was utilized in conjunction with Fourier analysis to estimate the extent to which a time-series is self-correlated over different time lags. The two gait features (representing the Gait rhythm) were utilized to classify between neuromuscular symptoms using Fuzzy c-means clustering algorithm.

a. Treadmill with a screen and mounted cameras at the lateral positions.

b. Comparative gait analysis between the normal and abnormal gait using knee joint position.

Fig. (7). Model Based Gait Analysis using treadmill by Lee *et al.* [19].

The discussed patents [14-20] reported invasive methods for gait analysis which required either sensors or markers to be placed on the subject's body. A major drawback was that the gait analysis required complex setup mechanisms which were expensive in terms of cost as well as in terms of resources. Test facilities were required to conduct gait analysis. An expert was needed to evaluate the digitized results produced by the MGA systems. Also a patient needed to have a prior knowledge about the test procedures. Wearing of markers caused discomfort for patients during gait analysis. For gait disorder evaluation through MGA systems, a comparative analysis had to be done between pathological and normal gait features which would result in coarse information. Although a classification method to distinguish between the neuromuscular symptoms has been described in a sensor-based system [20], no vision-based system has been found to have categorized gait disorder between the symptom levels.

Irrespective to the drawbacks, it is noticeable that the notion of vision-based gait analysis has advanced with the passage of time. From the 'condensed foot marks' [14] to the extraction of 'biological rhythm' in gait [20], the aim has been to improve the quality of gait diagnosis in terms of cost and accuracy as well as to enhance the comfort level in conducting the procedures. Neuromuscular gait characteristics have been of particular interest in the review of such systems. An optimistic approach would be to treat marker-based systems as benchmarks to be compared with the gait features extracted from the marker-less systems. One such comparison is presented by F. Wang *et al.* [21] in which an 'in-home' automatic HGA tool has been compared with a GAI-TRite mat. A GAITRite mat is an electronic walkway equipped with pressure sensors to detect footfalls and shuffling in gait. The HGA system on the other hand consisted of two inexpensive web cameras connected to a computer to record gait videos. The cameras were placed orthogonal to each other and a GAITRite mat was placed in between the cameras. Four subjects were recruited to participate in the validation study of this HGA system. The participants were asked to walk on the GAITRite mat and were video-recorded. In the first processing step, the HGA system used a color segmentation algorithm to separate human silhouette
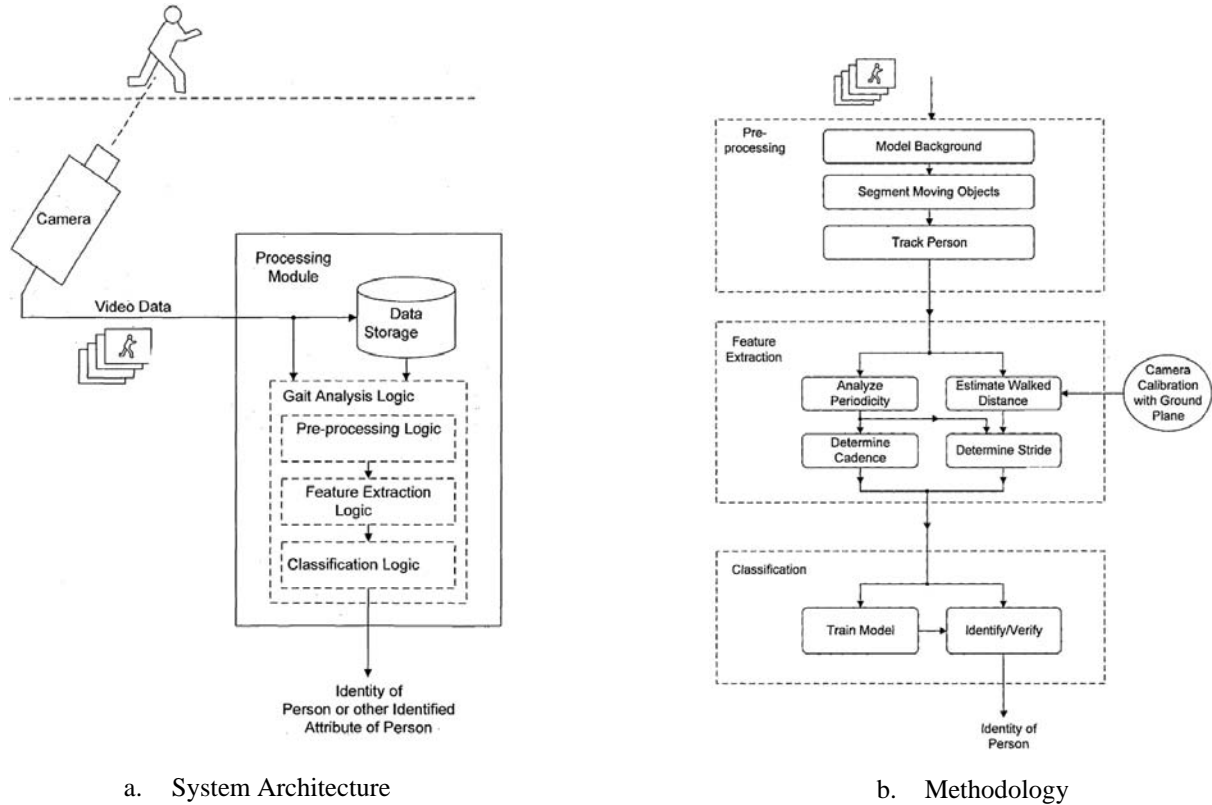
from the scene. Black and white human silhouettes were extracted from raw videos to maintain the privacy of individuals. A 3d-human model was created from back projecting the two silhouettes obtained from the two cameras. Gait features such as walking speed, step-time and step-length were computed from the human model. Experiments conducted over 16 recordings (4 recordings per subject) showed close results of gait feature values produced by the GAI-TRite and the HGA system (Table **2**). The work proves that the HGA systems can perform gait analysis equally well comparatively to the sensor-based systems. A drawback associated with both the systems was that the important gait features such as the joint angles (hip and knee flexions) as well as the posture lean cannot be estimated to carry out a detailed gait examination.

In a patent, Cutler [22] reported a state of the art HGA system in which the human gait was used as a biometric feature to recognize subject's identity. This system used a single camera which was connected to a processor to assess gait (Fig. **8a**). The method was free of markers and complex setup procedures. This system could assess gait in an open environment. Hence there was no special requirement of a test facility for gait analysis. The block diagram depicting the methodology is shown in (Fig. **8b**).

A holistic approach had been used for identification of subjects using linearly-related gait parameters i.e. stride and cadence. A three step general procedure was followed for identification of a person i.e. pre-processing, feature extraction and classification. Each step was further divided into sub steps as listed in the block diagram (Fig. **8b**). First, the subject's gait video was acquired using a camera which was mounted at an elevated position from the ground. Pre processing of video included the first sub step that models background details such as buildings, stagnant objects, pavements and grass in the video data. The second sub step included segmentation of the moving subject through which the foreground information in the scene was extracted from the background. The segmentation required a technique that was robust to illumination and camera jitter. Cutler used a non-parametric technique as described by A. Elgammal *et al.* [23] through which a binary silhouette was produced to distinguish between the foreground and the background. The fore-

Table 2.   **Holistic-based Gait Analysis Tool vs. GAITRite [21]. Values of Gait Features Obtained from the Holistic-based Tool and the GAITRite were Approximately the Same.**

	Participant 1		Participant 2		Participant 3		Participant 3	
	HGA	GAITRite	HGA	GAITRite	HGA	GAITRite	HGA	GAITRite
Walk Speed (cm/s)	79.8	80.5	77.3	77.1	74.6	76.9	63.6	63.4
Step Time (s)	0.66	0.68	0.58	0.57	0.67	0.65	0.7	0.7
Step Length (cm)	52.5	54.3	45	44.1	49.7	49.6	44.5	44.2

a.   System Architecture   b.   Methodology

Fig. (8). Holistic Based Gait Recognition System by Cutler [22].

ground and the background were represented by white and black pixels respectively. In the third sub step, subject was tracked all along the video frames by simply linking the overlapping binary silhouettes in each frame of the video. The approach given by Haritaoglu *et al.* [24] was used to eliminate non moving elements by discriminating the specific locomotion of human gait which forms the foreground. A bounding box was used to isolate foreground pixels. The span of the binary silhouette in x and y coordinates were used to form maximum and minimum x and y coordinates of the bounding box respectively as shown in the (Fig. **9a**). Gait related features of stride and cadence were extracted from the binary silhouettes in the bounding box (Fig. **9b**).
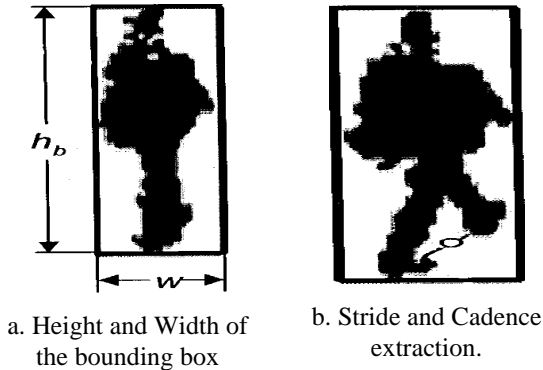
The silhouette of a normally walking subject exhibits a periodic behavior. This periodic behavior was plotted by calculating the width of bounding box in each video frame with the function of time to extract stride and cadence infor-

mation (Fig. **10**). The maximum width of the bounding box during a gait cycle represents the stride length (Fig. **9b**). The classification of subjects based on cadence and stride length was done using Bayesian decision approach. Two approaches had been applied to classify the densities in the Bayesian approach. In the first approach, the stride length and cadence were related using linear regression. In the second approach, the stride length and cadence were assumed to vary as a bi-variate Gaussian. In this way a subject could be identified based on gait analysis.
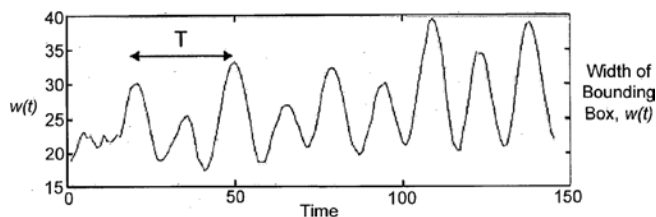
Although the system does not classify the human gait based on pathological measures, it provides a direction for gait analysis in an open or home environment using a web camera attached to a personal computer. Stride Length and Cadence are the gait features which may be utilized for PG recognition [25]. A drawback associated with this system is that a human skeleton (or a stick figure) cannot be extracted

from bounding rectangles which could be helpful to acquire joint and flexion angles as well as postural information for the detailed diagnosis of pathological symptoms. Other un-patented methods which were previously utilized to classify between pathological and normal gait in different holistic-based diagnostic systems for PG recognition have been further investigated.

a. Height and Width of the bounding box

b. Stride and Cadence extraction.

Fig. (9). Silhouette in the bounding box [22].

Fig. (10). Periodic behavior of the width of bounding box [22].

Howard Lee *et al.* [26] utilized digital image processing methods to detect neurological disorders. The gait cycles of 90 people were recorded using a video camera (Fig. **11a**). 50 people were from the normal group and 40 belonged to the patients group. The image was segmented using RGB color space (Fig. **11c**). The segmented image was skeletonized by calculating the medial axis of pixel values of segmented body parts (Fig. **11d**). Gait features i.e. swing distances and joint angles (Fig. **11e**) were calculated from selected frames of gait video. General Regression Neural Networks (GRNN) was used as a classification tool. Based on gait features, the system classified between the normal and pathological test subjects with a classification rate of 88.4%. The constraint in this work was the setup procedure in which a novel colored dress (Fig. **11b**) had been specifically designed for subjects for image segmentation.

R.D. Green *et al.* [9] extended the work by applying a Kalman filter to track human body in the gait videos. Kalman filter filters out the moving human silhouette from the static background scene which enhances the accuracy in silhouette detection. The environment settings as used by Howard Lee *et al.* [26] were set to identify gait abnormalities in video images. Joint angles and swing distances were used as gait features for disorder assessment. The gait of ten Levodopa responsive PD patients and eight people with normal gait were recorded using a video camera. Using the cross correlation between the pathological and the normal

gait cycle waveforms (Fig. **12**), the system correctly classified between the normal and pathological subjects with an improved accuracy of 94% as compared to the previous 88.4% [26].

In another approach, Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) methods were applied on still images for gait disorder classification [13]. During the gait analysis, subjects were asked to wear white clothes. Dark curtains were put behind the gait platform (Fig. **13a**). Subjects were asked to walk on a platform in parallel to the camera. The gait was recorded using a video camera. The video frames were segmented into binary images (Fig. **13b** and **13c**) based on pixel brightness values using grey-level thresholding method. These binary images were used for classification using PCA and LDA algorithms. The gait of seven patients with PD and seven normal people were inspected using this method. LDA achieved 95% classification accuracy for 1529 test cases. The classification results are shown in (Fig. **13d** and **13e**).

The reviewed systems [9, 13, 21, 22 and 26] described methods which were purely based on marker-less gait analysis. These systems were able to classify between normal and abnormal gait conditions. Yet there is a need for a classification method which may classify the pathological gait based on extremities of disorder. A HGA system with an extended gait classification algorithm may also support clinicians in making an accurate diagnosis of patients on timely basis since an accurate picture of patient's conditions can be delivered through the internet to the clinicians. The main loophole found in the current HGA systems is the low accuracy in segmenting the human silhouette which further leads to coarse estimation of gait features and possible inaccuracies in classification between symptom classes. The low accuracy in segmentation is because of the limitations associated with color segmentation i.e. lighting conditions, occlusion of the body color with the background etc.

A recent solution to image segmentation problems is the development of Microsoft Kinect [27] that can accurately predict the human silhouette and associated positions of body joints in successive video frames. Kinect is based upon an image processing technique called 'Depth Imaging' (Fig. **14a**). Pixels in a depth image indicate calibrated depth in the frame rather than measures of color or intensity which offers several advantages over the traditional intensity sensors. A depth image is invariant of color and texture, can work in low brightness and gives a calibrated scale estimate which resolves silhouette ambiguities in different poses and simplifies the task of background subtraction. Joint positions are accumulated by computing the 3D centre of mass of each probable body parts having a similar calibrated pixel depth. Body parts are joined by connected components labeling to form a complete human body and a skeleton can be derived based on the joint positions to estimate pathological gait characteristics.

The Kinect sensor can be an option for silhouette estimation in HGA systems but there are few limitations associated with it. The application is restricted to process frontal images of human body to extract body joints whereas the gait analysis demands sideways recordings to extract biorhythmic features such as stride fluctuations in gait cycles. Moreover, the
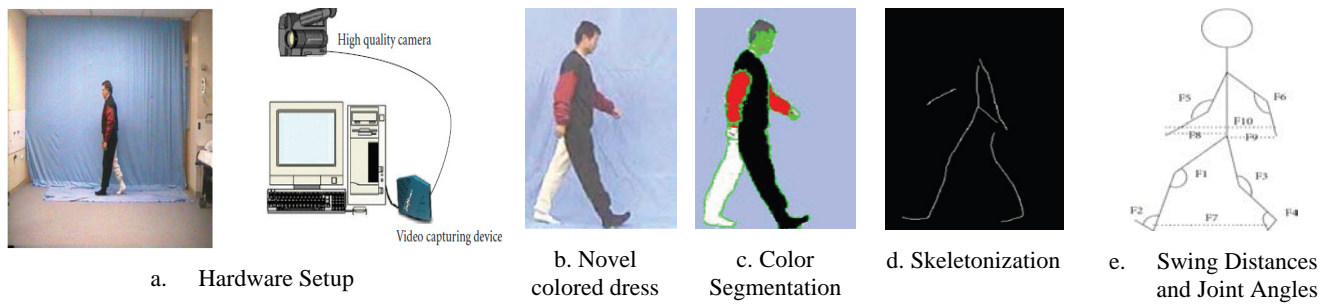
a.   Hardware Setup

b. Novel colored dress

c. Color Segmentation

d. Skeletonization

e.   Swing Distances and Joint Angles

Fig. (11). Gait analysis using Swing Distances and Joint Angles by Howard Lee *et al.* [26].

a.   PD Gait

b.   Normal Gait

Fig. (12). Cross Correlation between the Parkinsonian and the Normal Gait by R.D. Green *et al.* [9].

a.   Environment Setting.

b.   Binary Images of Normal Gait.

c.   Binary Images of Parkinsonian Gait.

d.   Distribution of first two PCA components of training binary images.

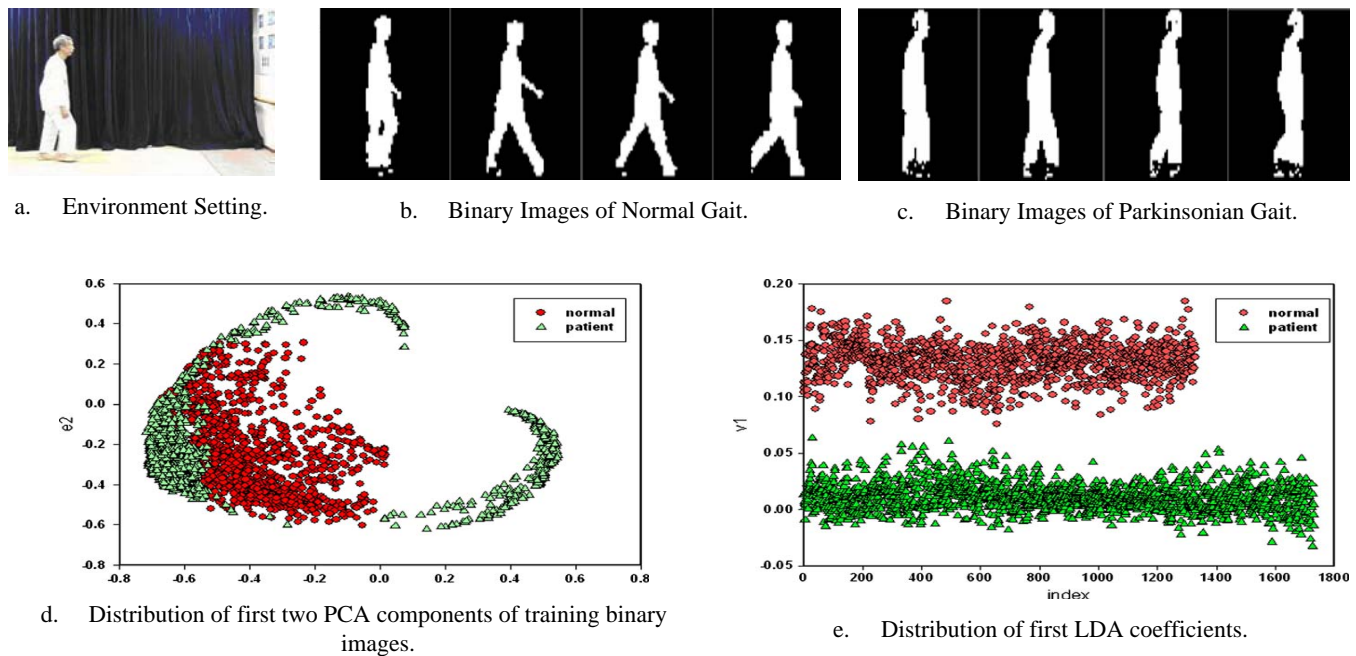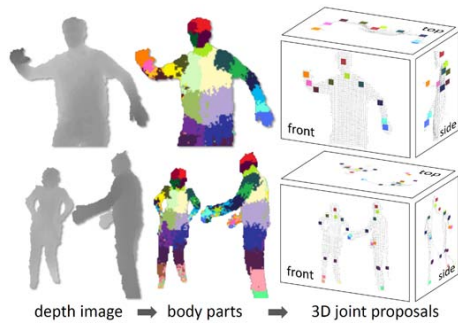e.   Distribution of first LDA coefficients.

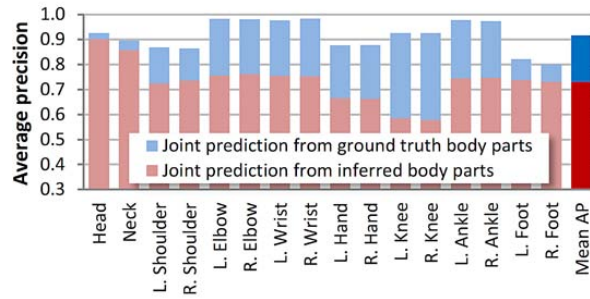**Fig. (13).** Linear Discriminant Analysis for Parkinsonian Gait analysis [13].

precision of detecting joints in left and right feet is the lowest comparatively to the other body parts (Fig. **14b**) due to the fact that leg joints (knees, heels, toes etc.) cannot be distinguished from the frontal images of human silhouette. There is a need to modify the Kinect application to deal with the sideways movements of body so that the feet joints specifically the movement of toes, knees and hips can be tracked to identify biorhythmic gait symptoms.

An important issue in Parkinsonian gait analysis is to utilize the diagnosed symptom level to accommodate re-

quired medicine. Medicine dose adjustments have to be made for the patients based on symptom fluctuations throughout the day. An overview of PG analysis for dosage titration based on the fluctuation of body movements (bradykinesia, hypokinesia and dyskinesia) has been given by Klapper [28]. In this study, the statistical methods classified the patient's movement status using sensor data. Although this invention used wearable sensors coupled with a computer interface, the statistical analysis methods that were used in this work may be utilized in the HGA system for
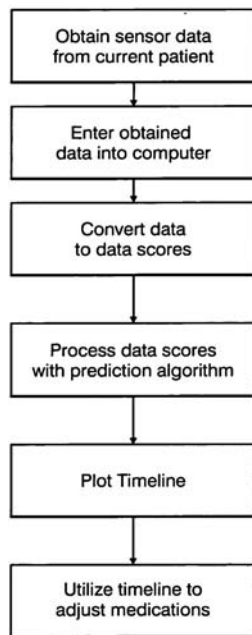
a.   3D joints predicted from an input depth image to infer body parts. Colors indicate most similar calibrated pixel depths.
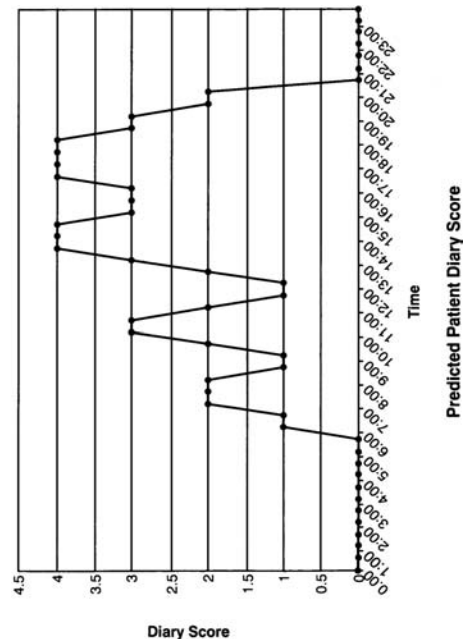
b.   Joint Prediction Accuracy

Fig. (14). Silhouette estimation of human body using Microsoft KINECT application [27].

a. Flowchart of the dose adjustment method.

b. Timeline of the patients' status throughout the day

Fig. (15). Automatic Dose Adjustments using the Sensor data [28].

automatic gait classification. The flowchart of this method-ology is shown in (Fig. **15a**). A timeline is produced (shown in Fig. **15b**) based on the classification results of patients' fluctuations throughout the day. Using this timeline, an accurate dose (e.g. Levodopa) level for the patient can be titrated.

CURRENT AND FUTURE WORK

The review was aimed to investigate patents in the area of CV based gait analysis. The purpose was to find suitable methods adoptable by the patients for the self-treatment of Parkinson's at home. The 'in-home' gait classification tools would also support clinicians to observe patients from re-mote locations through internet. Other targets of the review were to evaluate cost and resource efficiency in gait analysis, portability of system and comfort in carrying out the experi-ments taking into account that the PD patients are physically restricted due to disease symptoms.

Currently, no such method has been patented which al-lows non-invasive computerized gait disorder analysis. A three tier review methodology was utilized to explore exist-ing patents in the area of gait disorder assessment to deline-ate the reasons why the marker-less systems are unfeasible in their current form. The main challenge found in the marker less HGA is the process of image segmentation. Previous research showed that color or grey level segmentation meth-ods for discriminating the human silhouette in video frames are flawed from the artifacts such as bad illumination or ob-ject occlusion. The inaccuracy in segmentation leads to coarser details in obtained gait features which may further lead to incorrect gait classification. Microsoft Kinect is the latest technology which provides an alternative solution to the segmentation problem but the sensor cannot perform sideway analysis of body movements which is essential to locate the leg bendings specifically the flexions in the knees and hip.

Another alternative solution to image segmentation problems in HGA is to utilize motion estimation algorithms to separate the moving human silhouette from the stagnant background. Currently the motion estimates [29-31] are used as biometric features to identify a person based on his locomotion patterns. A motion estimation method can particularly be very useful for human silhouette detection in gait videos if it is applied in conjunction with the 'depth-images' derived from the Kinect sensor. In this way, the artifacts of illumination and occlusion as well as camera calibration problems can be avoided.

An important aspect in the review methodology was to explore gait features which can possibly be extracted by the HGA. Several patents reported previously on the sensor-based and MGA methods have been looked upon. Among the gait features, biorhythmic features (such as autocorrelation decay in the gait time series) were successful in classifying the gait disorder between neuromuscular symptoms. Other features relevant to PG analysis are the stride details, cadence and the angular movements of joints during locomotion. In one study [21], walking speed, step-length and step-time have been extracted from a HGA tool and a GAITRite (sensor-based) mat simultaneously. The comparison showed that HGA systems can perform equally well to the sensor-based systems in analyzing the gait in home environment.

In the reported patents on marker-based systems, a comparative analysis between the pathological and normal gait features was made for gait disorder classification. None of the patents on CV based gait analysis methods were able to use a clinical rating scale for gait disorder classification. It is due to the fact that not enough details could be accumulated from the human skeleton and stick figures. The additional information like body's centre of gravity or lean in the posture could be useful to detect anomalies in gait and to analyze the risk of falling. This suggests that a skeleton alone is not sufficient to distinguish pathological gait conditions. For the same reason, the illuminated markers were used along with the foot pressure sensors to estimate the gravitational artifacts. Some patents have reported to have used pressure sensors attached with the conveyer belt of treadmill. All these requirements make the marker-based gait analysis expensive, non-portable, uncomfortable and time consuming to be operated. Also a testee is required to have prior knowledge about the gait analysis procedures. For these reasons, marker-based systems are not favorable to be used by the Parkinson's patients in home environment.

In conclusion, an accurate pathological gait analysis is possible through the non-invasive CV based systems. In contrary to the invasive gait analysis tools, marker-less systems provide a comfortable and user-friendly setup which can be employed at home as these systems may require just a single web-cam or a Kinect sensor attached to a computer. There is a need for a robust image segmentation algorithm which can be achieved possibly by modifications in Kinect application or by using motion estimates in videos. An accurate segmentation of human model would support in a detailed gait feature analysis which would further help in an accurate gait classification between the symptom severities on a clinical rating scale. LDA seems to be a promising tool to classify gait disorders using gait cycle time-series analysis. It is concluded that home assessment of pathological gait disorder is possible in the near future through the use of a maker free gait analysis system equipped with an efficient image processing algorithm.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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