GAIT Analysis and Rehabilitation: A survey

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Abstract— ***This paper is focused on gait analysis methodologies for clinical use. For the purpose of explanation instrumented measurement of the movement patterns that make up walking and the associated interpretation of the same are considered. In this paper, Brand's four reasons for clinical tests, gait cycle and analysis of the varying characteristics are considered as a basis for determining what methodologies are required for gait analysis in a clinical rehabilitation context. It gives overall comparative study of various techniques used for gait analysis and rehabilitation along with the suggested improvements.***

Keywords— *Gait, **Gait cycle, Clinical gait analysis, Rehabilitation***

I. Introduction

Gait analysis is the systematic study of animal locomotion more specific as a study of human motion, using the eye and the brain of observers [1]. Locomotion is the process by which we move from one position to another. This process is a continuum from standing to walking to running and involves starting, stopping, changing directions, and altering speed. Gait analysis is augmented by instrumentation for measuring body movements, body mechanics, and the activity of the muscles. Gait analysis is used to assess, plan, and treat individuals with conditions affecting their ability to walk. The study is based on quantification which includes introduction and analysis of measurable parameters of gait, as well as interpretation.

A systematic physical examination of the patient is required to be conducted as part of a gait analysis. The core of most modern gait analysis is the measurement of joint kinematics and kinetics [3]. Other measurements regularly made are electromyography (EMG), oxygen consumption and foot pressures

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A single sequence of functions of one limb is called a gait cycle. It is essentially the functional unit of gait. The gait cycle has two basic components, the swing phase and the stance phase [2]. Stance is the phase in which the limb is in contact with the ground. Swing is the phase in which the foot is in the air for limb advancement. A gait cycle is also referred to as a stride. Gait cycle analysis is vital in the sense that it includes a study of identifying various causes of the impairments for individual patients, like ankle and hip joint impairments in the case of stiff legs [3]. Shock absorption and energy conservation are important aspects of efficient gait. In some cases the gait analysis has suggested that multiple impairments, not just about the knee, but also about the hip and ankle, lead to disabilities like stiff legs. Individual subjects are likely to have individual reasons for their impairments.

Rehabilitation is a clinical gait analysis. Richard Brand [1] proposed four reasons for performing any clinical test viz.

1. To distinguish diagnosis between disease entities
2. To determine severity of disease or injury
3. To select among treatment options
4. To predict prognosis

The third point regarding selecting one of the best suitable treatment options can be taken as a definition of *clinical gait. A clinical test is* conducted in order to select from among different management options for a patient. Much contemporary gait analysis is done for the purpose of clinical research. In planning the rehabilitation of patients, it is important to know all the factors that contribute to their disability.

The paper is organized in total V sections as follows. Section I includes overview of gait analysis. Section II details about methods of gait cycle, Different method for gait analysis are discussed in section III along with their limitations. Section IV focuses on Measurement Methods in Clinical Gait Analysis i.e. rehabilitation. Finally, section V concludes the paper.

II. Gait Cycle

Walking is the most convenient way commonly used to travel short distances. Walking efficiency totally depends upon free joint mobility and appropriate muscle force. As the body moves forward, one limb typically provides support while the other limb is advanced in preparation for its role as the support limb. The gait cycle (GC) in its simplest form consists of two phases namely, stance phase and swing phase. As mentioned in [2], the stance phase further is subdivided into 3 segments, (1) initial double stance, (2) single limb stance, and (3) terminal double limb stance.

Each double stance period accounts for 10% of the GC, while single stance typically represents 40%. The two limbs typically do not share the load equally during double stance periods. The swing phase for this same limb is the remaining 40% of the GC. Ipsilateral swing temporally corresponds to single stance by the contra-lateral limb [2]. Slight variations occur in the percentage of stance and swing related to gait velocity. Duration of each aspect of stance decreases as walking velocity increases. Two steps make up each GC, which is roughly symmetric in normal individuals. The transition from walking to running is marked by elimination of double support period.

A. Gait Cycle Phasing

A consistent sequence of motions is performed at each of the lower extremity joints during locomotion. As shown in Fig.1, each stride contains of 8 relevant phases. Stance is comprised of 5 gait phases namely, initial contact, loading response, mid stance, terminal stance, pre-swing with the remaining 3 phases occurring during swing.

The first two gait phases which comprises 0-10% of GC, occur during initial double support. These phases include initial contact and the loading response. Initial contact is usually referred to as heel strike. The joint motion during this phase allows the transfer of weight onto the new stance phase leg while attenuating shock, preserving gait velocity, and maintaining stability.

The second phase, swing phase, by the contra-lateral limb corresponds with single support by the ipsilateral limb to support body weight in the sagittal and coronal planes. The first half of single support is

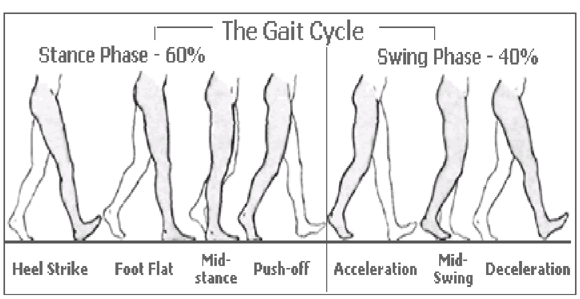

Figure1. A Single Gait Cycle or Stride

termed mid stance which covers 10-30% of GC, is involved with progression of the body center of mass over the support foot. This trend continues through terminal stance for next 30-50% of GC. This phase includes heel rise of the support foot and terminates with contra lateral foot contact.

III. Methods of Gait Analysis

Gait analysis provides with information that is useful to the clinician and this is generally required that results are reported in terms analogous to accepted clinical concepts [2]. It is always advisable that gait analysis must be cost-effective. This process does not, therefore, make further demands on the measurement systems but does require an understanding of how the patient's condition is likely to be affected by an intervention to a level sufficient to determine which options are preferable. Prediction of outcomes about the patient’s condition after intervention, takes this one stage further.

Gait Analysis is different from clinical testing in the sense that, in gait analysis, the reason is not to make clinical decisions for the individual patient, but to learn about a condition affecting a group of patients or the effect of an intervention [1]. The criteria which are valid for clinical research may not be valid for clinical testing [2]. For example, a measurement made on a single patient cannot be relied upon because of random errors and hence it will not be useful for clinical purposes. Instead, by increasing the number of patients in a sample, measurements even with quite large random errors can result in meaningful conclusions in clinical research.

There are some necessary conditions for any clinical measurement. The very first condition is that it should characterize the patient. If the patient attends on two separate occasions, between which his or her condition might be considered as stable, the measurements taken should be similar. This requires that the measurement technique itself is repeatable. Secondly, the quantity being measured is required to be stable and independent of factors such as mood, motivation or pain. Third, the diagnosis mechanism should be such that the estimated measurements are sufficiently precise to reveal clinically important differences between patients with the same diagnosis, to determine whether a patient's condition is stable, improving or deteriorating. If all the above conditions are satisfied then such tests can be clinically useful and will be much easier to interpret because of their accuracy.

In accordance with these necessary condition, Masaki Sekine [4] has proposed a method to distinguish walking patterns using wavelet-based fractal analysis. In this study, wavelet-based fractal analysis was chosen because the wavelet transform is an appropriate method for the analysis of both stationary and non-stationary biological signals. They have developed a mechanism based on accelerometer, in which even the effect of aging is taken care. Previous systems classified walking along a corridor and on stairs by using wavelet transform. These studies demonstrated that the method was effective for classifying walking types for young subjects but not for elderly subjects, since gait changes with age. It is observed that, locomotion is slower for elderly people than for young people. The amplitude of impact acceleration at heel-strike decreases with age. Elderly people also shuffle along the corridor, and complexity of acceleration increases. To catch these minute details in the speed acceleration signal is used. This signal is able to represent both, the complex pattern and the non-stationary property. Fractal dimension reveals the complexity of the signal.

From the experimental results it is vital that, the advantage of using the wavelet-based fractal analysis is indeed twofold [4]. First, analysis of the non-stationary acceleration signal using the wavelet transform is very much possible. Secondly, the time-frequency information contents obtained with the wavelet transform are effectively used to estimate the fractal value as detailed in the method section to characterize the acceleration signal during walking along the corridor and on the stairs. The estimation of the fractal dimension is nothing more than a representation of the variances of the wavelet coefficients at each scale, which provides valuable information about the variance progression over the wavelet scales. Additionally, it was applied to evaluate the acceleration signals in elderly subjects and subjects with Parkinson’s disease.

In order to perform a diagnostic function it is necessary for measurements to be able to distinguish normal from abnormal patterns of movement and also between the characteristics of one disease from another. There are two aspects to this. The first is having measurement systems should be capable of working to adequate precision. The second is knowledge of what characterizes normal walking or a particular disease pattern.

To recognize the changes of gait pattern due to aging, Rezaul [5] has proposed to apply Support Vector Machine (SVM) technique. As Minimum foot clearance (MFC) heights are more likely to be associated with tripping during walking and these values tend to decrease with ageing [10], features derived from MFC distributions and plots were used to develop young-old classification models. This type of classification capability could potentially lead to many SVM applications particularly as gait diagnostics: For example, SVM can be trained in a similar way to detect elderly fallers from their gait characteristics so that necessary measures can be undertaken to prevent injurious falls. As SVM has the ability to build improved predictive models; using which, SVMs find an optimal separating hyper-plane that provides superior generalization ability especially when the dimension of input data is high and the number of observations available for developing or training the model is limited. From experimental results it is observed that SVM classifiers are more suitable than traditional NN with back propagation learning algorithm.

Brand [1] suggested a very important aspect for the measurement systems. According to him the measurement technique should not affect the function it is measuring. The walking performed in a gait analysis laboratory is a demonstration of ideal conditions in which the patient concentrate on what they are supposed to carry out the walking exercise. But it may not necessarily represent their normal walking. Hence while developing the efficient measurement system real circumstances should be considered instead of the ideal one.

Kyoungchul Kong, [11] suggested a system Based on Air Pressure Sensors Embedded in a Shoe using Fuzzy logic. They propose a method which uses fuzzy logic for detecting the gait phases continuously and smoothly. The smooth and continuous detection of the gait phases enables a full use of information obtained from ground contact forces (GCF) sensors. Their work also aims at developing advanced rehabilitation systems, in which by using a higher level algorithm which quantitatively monitors the amount of abnormalities in a human gait.

IV. Measurement Methods In Clinical Gait Analysis (Rehabilitation)

Modern clinical gait analysis has its origins back to the early 1980s with the opening of the laboratory developed by the United Technologies Corporation at Newington, Connecticut and those provided with equipment by Oxford Dynamics (later to become Oxford Metrics) in Boston, Glasgow and Dundee [1]. Retro-reflective markers were placed on the skin in relation to bony landmarks. These were illuminated by stroboscopic method and detected by modified video cameras. If two or more cameras detect a marker and the position and orientation of these cameras are known then it is possible to detect the three-dimensional position of that marker [12]. Almost all commercially available clinical systems use some variant of the Conventional Gait Model [13] which has been referred to as the Vicon Clinical Manager (VCM) model. This was developed using the minimum number of markers possible to determine 3-dimensional kinematics and kinetics [9] of the lower limb.

The accuracy of any such gait system is completely dependent and limited by the accuracy of any alternative means to determine marker position and can be taken to be of the order of 1 mm. This is probably an order of magnitude smaller than other sources of error in determining joint kinematics and kinetics. This particular measurement technology has thus reached a mature state of development that, at the same time as advances will almost certainly continue, already probably delivers all that is required by conventional gait analysis [5].

But the same is not true for the computer models used to derive joint kinematics and kinetics from the marker position data supplied by the measurement hardware [3]. It assumes three degree of freedom joints for the hip and knee and a two degree of freedom joint at the ankle. The model follows hierarchical approach, requiring the proximal segments to have been detected in order to define distal segments. It incorporates regression equations to determine the position of the hip joint center with respect to pelvic markers. Kinetics is determined using an inverse dynamics approach which generally requires considerable filtering to give any useful signals.

In [9] a model with 6-DOF gait rehabilitation robot that allows patients to update their walking velocity on various terrain types and navigate in virtual environments (VEs) through upper and lower limb connections is proposed. This robot is composed of an upper limb device, a sliding device, two footpad devices, and a body support system. The footpad device on the sliding device generates 3-DOF spatial motions on the sagittal plane for each foot. This allows the generation of various terrain types for diverse walking training. The upper limb device allows users to swing their arms naturally through the use of a simple pendulum link with a passive prismatic joint. Synchronized gait patterns for this robot are designed to represent a normal gait with upper and lower limb connections. To permit patients to walk at will, this robot allows walking velocity updates for various terrain types by estimating the interaction torques between the human and the upper limb device, and synchronizing the lower limb device with the upper limb device. Experimental results show that through the interaction between the human and robot arms, the patient is able to successfully update his walking velocity. Also he will be able to accomplish a certain task. The result shows that the walking velocity profile can be updated during the navigation in virtual environments. Through this development, training modes of gait rehabilitation can be more effectively combined to VEs and allow more choices for upper limb coordination.

The Problem of Measurement Technology

Need of routine clinical use is the primary problem of current measurement. In order to verify the dependability of clinical use, several studies have been conducted in which a single subject has been analyzed in a number of different laboratories [14]. These studies have shown a degree of variation among different sites. These variations are observed to be sufficient enough to destabilize clinical applications. The relative measures of reliability are specifically making the interpretations of finding difficult and approximate. Almost all reliability studies have been done on subjects without pathology where marker placement is reasonably straightforward and no variations were considered [4]. Reliability for clinical populations is rarely reported in the literature and is almost certainly inferior. Most of the time these set measured marker positions is used to fit to the body moves. In order to determine that axis of the knee joint, as to have a simple hinge joint, least Mean Square like approaches is applied.

The second source of error is the degree of movement of the skin, muscle and other soft tissues in relation to the bones that occurs during walking [8]. This is perhaps most marked in relation to the rotational profile of the hip. This problem of skin and other soft tissue movement is proved to be more problematic than that of model calibration. This problem of skin movement can be satisfactorily addressed by making direct measurements of bone position and by using 3-dimensional images of bones.

There has been some work done on marker-less optical methods as well. In [8] a system is designed as a telemedicine tool to monitor remotely the progress of patients through treatment. The system requires minimal user input and simple single-camera filming making it very accessible to nontechnical, nonclinical personnel. The spatiotemporal segmentation and model-based tracking allows the design to use a novel motion capture method using simple cameras. This system allows gait studies to acquire a larger data set and also allows trained gait analysts to focus their skills on the interpretation phase of gait analysis. Results are observed to be comparable with manual measurements and other equivalent systems. The biggest advantage is that, this system will never require a trained therapist to be present in the gait recording process and will allow patients' gait to be recorded in a relaxed and convenient environment.

V. Conclusion

In this paper, Gait analysis methods with different variations with regards to walking patterns are discussed. Also the significance of gait cycle is explained. It is observed that aging has a major impact on the gait characteristics and which is a major reason for many good systems to fail and not been able to produce outstanding results. Also the marker positions and skin movement affects the measurement hence, marker-less systems are more powerfully used for rehabilitation.

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