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RESEARCH ARTICLE

GAIT KINEMATICS - A REVIEW

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ABSTRACT

Gait analysis is used in clinical evaluation of musculoskeletal system, design and assessment of prosthesis (especially for lower limbs), in the process of rehabilitation after injury and in biometrics. This paper reviews the general methodologies involved in kinematic gait analysis right from acquisition of data to processing and interpretation of meaningful results. The major components of kinematic gait analysis are: acquisition of data by cameras or instruments like accelerometer, electrogoniometer followed by processing and examination, measurement of general gait parameters, and electromyography (EMG).

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INTRODUCTION

Gait analysis is the study of locomotion (walking pattern) of a human or an animal from data recorded through instruments like accelerometers, goniometers, cameras, pressure sensors etc. [2]. Gait analysis includes both kinetic and kinematic analysis. Kinetic analysis involves the study of forces which causes the movement or locomotion with the help of pressure sensors and force plates. Physicians may prefer their patients to undergo clinical gait analysis instead of radiographic imaging as gait analysis can be used to study the progression of neuromuscular diseases. Pathological conditions can be classified and differentiated from the information drawn from gait analysis. Kinematic analysis involves the measurement of geometry of movement without considering the force that causes the movements. Cameras, accelerometers, goniometers are used for acquiring data for kinematic analysis. Majority of kinematic evaluations are performed using video graphic or optoelectronic systems consisting of integrated hardware and software components [3]. Several techniques have been developed over the years for gait analysis. They differ in the methodologies used for data acquisition. Some of them are large, expensive, time consuming (for acquiring and processing of data), requires trained personnel to operate and interpret the results, some other techniques are applicable in routine clinical practice, are inexpensive, and do not require technically trained personnel to use operate and maintain it. This paper reviews the techniques developed for gait analysis, their merits and demerits and future uses.

Direct Measurement Techniques

Direct measurement technique deals with sensors that are attached to the dynamic portion of the body. Devices like goniometers (mechanical and electrical), accelerometers are used.

Electrogoniometer

Electrogoniometer is one of the important instruments used in the gait research. It is used to measure the joint angles and its movement [9].

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It consists of a mechanical part and an electronic part. The mechanical part consists of the transducer probe, the stationary and movable arm, the grayscale sheet and the protractor. The electronic part consists of the microcontroller circuit, the analog to digital converter, LCD display, the power supply board. It has a transducer probe which contains a source (Light emitting diode) and a detector (Light dependent resistor). There is a gap between the source and the detector through which the gray scale sheet runs which acts as a light attenuator. The probe is attached to the movable arm of the electrogoniometer and so when the patient flexes his arm, the probe is moved. The stationary arm is attached to the biceps and the movable arm is attached to the forearm with the help of Velcro bands. The grayscale sheet is a semicircular sheet in which the right end is completely dark and the left end is faded. The grayscale sheet acts as a light attenuator as it prevents large amount of light falling on the LDR. It also helps in giving us a decreasing voltage of the LDR. The protractor is present below the grayscale and the pointer moves over it. The LCD display is used to display the angle that is measured [10].

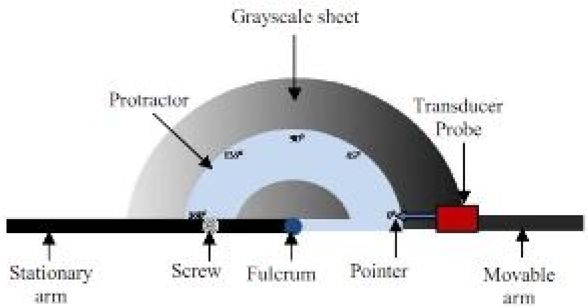

Fig. 1. Electrogoniometer

Electrogoniometers in gait analysis

The advantages of this instrument are low cost and low complexity. These instruments are mainly used in gait analysis on lean patients than on muscular patients as there will be an angular change due to skin and muscle movement [11]. The first type of electrogoniometers was first developed by Johnson and smidt (1969). The first light electrogoniometer was first devised by Mitchelson (1977) which is used to measure the limb angle using light sensing devices. Gore (1980) conducted a series of experiments to monitor movement of hip joint during gait. He used tri-axial electrogoniometers to measure the hip movement in both left and right legs [12]. Attaching electrogoniometers to the subject is a time killing process as the potentiometer should be attached properly to the limb segments and the center of rotation precisely over the joints [13].

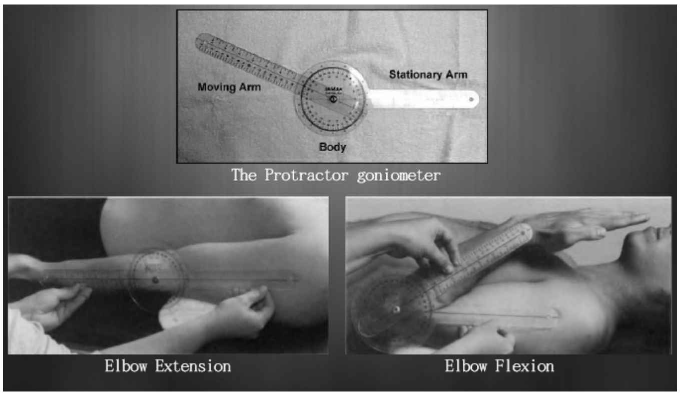

Fig. 2. Measurement of Elbow Angle Using Electrogoniometer

Electromyography

Electromyography is the technique used mainly for measuring the levels of muscle activity. The EMG is acquired when the muscle contracts and the electrical activity is generated as action potentials. The surface EMG signals are picked up using the surface electrodes and interfaced with a PC system via Biometrics EMG acquisition system. The acquired signals are processed and analyzed and then the variation in the RMS amplitude levels and median frequency of EMG in the patient's walking pace is studied [14]. Other type of electrode is the wire electrode which is used to obtain the EMG signals in deep muscles. The most commonly used wire electrode in gait analysis is the intramuscular wire electrode with a 25-gauge hypodermic needle inserted in the muscle of the subject. An EMG – driven model (Buchanan *et al.*, 2004) was used to estimate the muscle forces of the right leg. Nissan *et al.*, 2009 analyzed various EMG patterns of gastrocnemius and soleus muscles with the help of surface EMG [15, 16]. EMG data acquisition systems are done in both cable and wireless methods. Wireless systems are either radio telemetry or data loggers. In cable systems, the power is obtained from the cable and signals are free from any radio frequency (RF) interference or dropout. The disadvantage is the need for a cable connecting the wearer to the instrumentation. Telemetry systems eliminate the cable, but suffer from problems with signal dropout and RF interference. They also require the use of a body-worn battery. Data loggers eliminate the cable and RF problems, but require a body-worn battery and are limited in the amount of data that can be acquired before being downloaded to the computer [11].

Accelerometer

Accelerometers are electromechanical devices for measuring acceleration forces and are a good choice for evaluating the human body movement and balance. It is a non-invasive and portable method that can accurately measure simple parameters of gait such as stride time, stride symmetry and speed. The accelerometers are comprised of a mechanical sensing element and so the obtained mechanical signal is converted to electrical domain. The accelerometer sensors are also used in biometric gait authentication. It is done in two methods: visual-based gait recognition and sensor-based gait recognition. The accelerometer sensors are placed in hip, waist, chest regions or in hands [16]. G. Currie *et al.*, performs a new technique for the evaluation of temporal and spatial parameters of gait using accelerometers. He used three accelerometers in orthogonal directions as an instrument which records the acceleration of the centre of gravity in the three directions as the subject walks [17].

Indirect Measurement Techniques

Indirect measurement technique (also known as non- contact or imaging technique) involves video recording of the walking subject. CCD cameras are used for indirect measurement techniques. Apart from the information about the patient walking pattern the recorded video has additional redundant information about the background, noise etc. Markers were used to track the movement of the subject [18]. Markers were placed on well defined anatomical landmarks to trace the image of the dynamic portion effectively. The markers used in the marker based system can be again classified into active markers and passive markers. An active marker emits light on its own. Light emitting diode (LED) comes under active markers. Passive markers cannot produce light on their own. They are coated with reflective material to reflect the light produced by light source placed near the camera used for recording. The light is reflected directly along its line of incidence [19, 20]. For both active and passive marker system to acquire the required data from the video certain software techniques have been developed. It involves 2D and 3D reconstruction of images. Presently experts are working with markerless gait analysis systems. The subjects need not wear markers on their body. Specialized image processing tools have been created and utilized for obtaining the required information from the image without using markers. Marker less systems were developed in order to reduce the discomfort caused in patients while using markers. Markers also increase the complexity and cost of the recording system. The features acquired during gait analysis can be divided into static features and dynamic features. Static features do not change with the variation of mental state. Features like height of the person, length of leg comes under static features. Dynamic features describe the motion of human. Trajectories of positions of knee joints and ankle joints are extracted as dynamic features [21].

Gait analysis using active markers

Nissan Kunju *et al* used Labview for processing the image obtained using active markers. The LEDs (Light Emitting Diodes) are placed on the corresponding anatomical positions. The subject is made to walk in a complete dark environment and video recording is done. A template for the marker used in the recording is created. Labview uses template matching algorithm to find the locations of markers in a given image slice or video. Then the corresponding angles are calculated using the co-ordinates of markers. Nissan Kunju *et al* also measured the angles using electro-goniometers. The results obtained in both the methods were comparable. This method can be used for full body kinematics study or study of a specific limb with a little or no change. The parameters like frame rates and number of frames to be captured should be modified depending upon the dynamics of the joint under study [20].

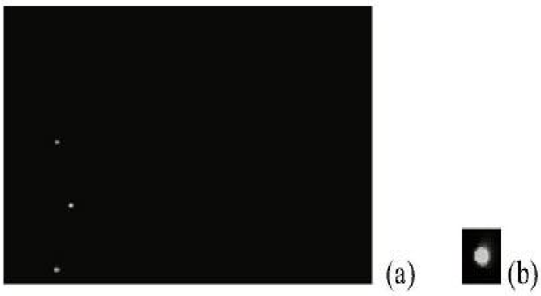

Fig. 3. (a)Image acquired by camera. (b) Marker template

Marker-less Techniques

Markers attached to anatomical locations can change the gait patterns and also cause pain (intra cortical bone pins). To solve these problems markerless systems are being used in modern gait analysis. Acquiring details from the video in markerless techniques can be done manually or by specialized software. David H. Sutherland and John L. Hagy used manual method of gait analysis. In this method the video of the walking subject is acquired from cameras placed orthogonal (at the sides and front). A special projector is then used to determine the measurements required. The instrument projects the film image of the subject onto a viewer and it has superimposed horizontal and vertical wires which can be adjusted for determining the co-ordinates of anatomical landmarks. The parameters like knee angle, hip angle can be calculated using triangulation [36]. J. Saboune and F. Charpillet used a marker-less technique which involves simulation of a model and comparing it with the video of a walking human [37].

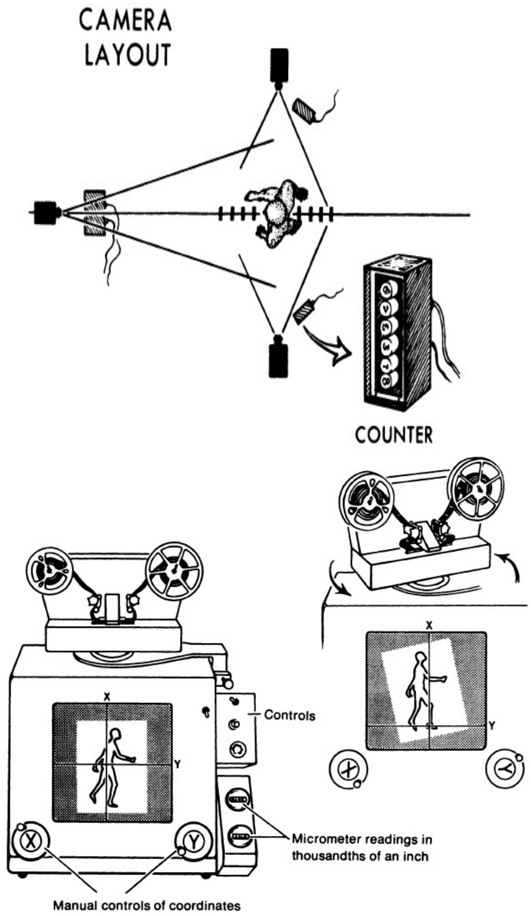

Fig. 4. Arrangement of cameras (left) and Vanguard motion analyzer used by David H. Sutherland and John L. Hagy

2D and 3D methods

Gait analysis can be done by acquiring data using instruments like goniometers, accelerometers and by data acquisition using cameras. The video acquired using cameras can be processed using 2D and 3D approaches. The majority of available methods use 2D methods. 2D methods analyses the video sequences captured by a single camera. These methods can be divided into feature/appearance based [38-44] and model based methods. Images of low quality can be used for appearance based methods. They are simple to implement but often sensitive to variations of viewpoints, shoes and lighting. Model based methods require images of high quality. The main problems in 2D methods used in gait analysis are occlusion and limitation of single camera view. In practice, a 2D analysis will be easily affected by varying viewpoints, surface variations and cannot provide correct and accurate results [43]. In gait analysis by 3D methods videos are captured by more than two cameras. The walking persons are tracked with the help of 3D human models. Then the 3D human structure is reconstructed and features are extracted.

Gait analysis in bio-metrics

Human gait is an identifying feature of a person. It is determined by the height, weight, limb length, and habitual posture. Hence gait can be used as a biometric measure for identifying person and classifying unknown subjects. Gait can be detected and measured at low resolutions. Face or iris recognition requires images or videos with high resolution. Gait can be used for human identification in situations when information with high resolution is not available [42]. While using gait as a bio-metric tool data acquisition is done mostly through cameras. These techniques are known as vision based gait recognition techniques. Instruments like accelerometer, goniometers are not used as they may increase the complexity of the recording system. Also the time taken for getting useful results is high. Recently, instead of camera a physical device (such as accelerometers) is connected to the subject for the purpose of collecting gait patterns. These techniques are known as sensor based gait recognition techniques [40-32]. Johansson attached lights to joints of a human body and shown motion sequences of light to observe the gait patterns. The observers were able to identify the person and their sex from the movement of light sequences alone. Cutting, *et.al* also used similar techniques and obtained person identification and gender classification results.

Cutler and Davis distinguished walking humans from other moving objects like cars using self correlation of moving foreground objects Polana and nelson recognized activities like frog jumping and human walking by detecting the periodicity in optical flow. Bobick classified activities using a time delayed motion template. Little and Boyd identified walker on the basis of moment features, periodicity of foreground silhouettes and optical flow. Nixon *et al.*, identified walkers by gait using principal component analysis of images of the walking person. Shutler *et al.*, identified person from their gait using higher order moments summed over successive images of a walking sequence as a feature. The efficiency of the biometric system can be increased when combined with other types of biometrics (for example face recognition).For instance in the recognition rates of gait and face profiles separately were 85.7% and 64.3%. When both the techniques are combined, performance increased upto 100%.

Other Methods Used in Gait Analysis

Roetenberg used magnetic fields to track ferromagnetic markers that caused distortions within the magnetic field. The metal content of the area in which the field is created should also be considered. Even earth's magnetic field may distort the generated field just like the markers [33, 34]. Patel V V *et al*. used MRI and CT to evaluate static positioning and movement of the limbs [35].

Future of Gait Analysis

The following ideas can be implemented to take the gait analysis to the next level.

1. Real time gait analysis systems should be made to reduce the time involved in processing of information into a meaningful result.
2. Different types of locomotion tasks should be developed and used instead of regular tasks in order to analyze different pathologies. For example knee pathologies can be studied better using tasks like stair ascent or descent than normal walking alone.
3. The link between the scientific investigations of gait and the clinical application of results should be strengthened in order to increase the usage of gait analysis in rehabilitation medicine.
4. The gait analysis tools or methodologies which provide appropriate/sensitive measures for clinical population should be identified and used widely.
5. Gait analysis laboratories should be problem driven coupled with technology driven. Problems setting needs to be clinically based.

6. International standards for techniques involved in gait analysis should be made common and followed in all gait analysis laboratories.
7. Each of the existing approaches has undesirable constraints that limit its applicability for real-time modeling of full body motion with the prerequisite for accuracy, scan rate, number of sensors, and range, and without impingement of the limited function of disabled individuals. The emerging techniques in this field should focus on minimizing these constraints.

Conclusion

Gait analysis useful in clinical applications for diagnosis of neuromuscular and musculoskeletal diseases involves creation of model for comparing with real time images and data. The development of appropriate models facilitates a deeper understanding of the behavior of the musculoskeletal system and allows predictions to be made regarding its response to various perturbations without the need for live animal experiments.

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