Gait Analysis of the Inferior Articulations of Healthy People and with Locomotion Problems

Sergio Rodolfo Cruz Gómez and Manuel Martín Ortiz

Autonomous University of Puebla
Faculty of Computer Science
14 Sur y Av. San Claudio, C.P. 72570 Puebla, Mexico
sergio.cruz.g@hotmail.com, mmartin@cs.buap.mx

Abstract. Gait analysis is the study of the animal locomotion, more precisely for this paper, the human locomotion. Several studies have been made by many researchers, however, there is limited information about the unique characteristics of the direction change in the gait. In this paper we present a different approach to get the information we need to do this analysis, by being non invasive, because most of the ways researchers do have complicated procedures and often require the patience to be static for long periods of time. The objective of this work is to give an alternative non invasive help to medics and physiotherapists when evaluating a patience state.

Key words: Kinect, computer vision, gait analysis.

1 Introduction

The knowledge of the human locomotion is the base of the systematic treatment and of the manage of the pathological gait, specially when prosthesis and orthosis are used. The normal human locomotion is being described as a series of alternating and rhythmic movements of the extremities and the chest which determine a movement forwards from the center of gravity. More specifically, the normal human locomotion can be described enumerating some of it's characteristics. Even thou there are small differences in the gait from an individual to another, these differences are between small limits. The gait's cycle starts when the foot touches the ground and ends when with the next touch of the ground from the same foot. The two greatest components of the gait's cycle are: the stand phase and the swing phase. A leg is in stand phase when it's in touch with the ground and it's in the swing phase when it does not touch the ground. The length of the full step is the lineal distance of the sequential points of contact of the heel of the same foot. [1]

2 Gait's cycle

In it's study, the gait's cycle starts when a foot makes contact with the ground and ends with the same contact of the same foot, to the distance between those points we are going to call a full step. The gaits cycle is divided in two different components: the stand phase, and the swing phase. These two phases are alternating from one leg to another during the gait. In a full step, the simple stand refers to the period when there is only one leg touching the ground. The period of double stand occurs when both feet are in touch with the ground simultaneously. The difference between walking and running is the absence of a period of double stand. For this project is important to know the time that each of the gait's phases take, this way we can have a general idea to corroborate with the prototype. The relative quantity of time spent during each phase of the gait's cycle is as follows [1]:

- Stand Phase: 60% of the cycle
- Swing Phase: 40% of the cycle

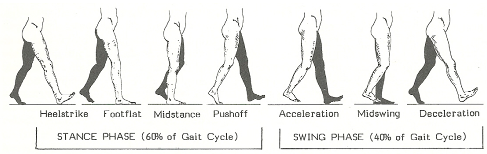

Fig. 1. Gait Phases

3 Cinematic analysis of the human gait on the sagittal plane

For this project is necessary to know what happens in each of the segments of the leg when walking. The analysis is divided in three intervals, in which are described how the ankle, knee and hip act in the sagittal plane for each one of the phases.

3.1 Interval I

Movement of the articulations in the sagittal plane between the contact of the ankle with the ground and the stand point. [1]

- The ankle

Moment with the contact of the ankle with the ground	The articulation of the ankle is in neutral position (0 degrees)
Simultaneously in contact with the ground	The articulation of the ankle starts to move in direction of the plantar flexion
Moment in which the foot's sole makes contact with the ground	The ankle's articulation moves 15% from the neutral position to the plantar flexion.
In the middle phase	The ankles articulation goes fast to approximately 5 degrees

– The knee

Immediately after the contact of the ankle with the ground	The articulation of the knee is in complete extension
Simultaneously the ankle in contact with the ground	The articulation of the knee starts to flex and does so until the foot's sole completely touches the ground
Immediately after reaching flat position of the foot	The knee has approximately a 20 degrees flexion and starts to stretch
In the middle stand	The knee articulation has approximately a 20 degrees angle of flexion and continues stretching

– The hip

Simultaneously the ankle in contact with the ground	The hip is approximately in 30 degrees of flexion
Immediately after the contact of the ankle with the ground	The articulation of the hip starts to stretch
Flat position of the foot	The angle of flexion decreases around 20 degrees
Between flat position and middle stand	The articulation of the hip goes to it's neutral position (0 degrees)

3.2 Interval II

Movement of the articulations in the sagittal plane between the middle stand and the takeoff of the foot from the ground. [1]

– The ankle

In the middle stand	The ankles articulation goes fast to approximately 5 degrees
The moment the ankle takes off the ground	The ankle's articulation is approximately 15 degrees
In the interval of the ankles elevation and the foot's takeoff	The ankle's angle moves fast to 35 degrees, and when taking off the foot the articulation is approximately at 20 degrees from the plantar flexion

– The knee

In the middle stand	The knee has approximately a 10 degrees flexion and continues stretching
immediately after the ankle looses touch with the ground	The knee is at 4 degrees from full extension
Between ankle's takeoff and toes takeoff	The articulation of the knee moves from almost full extension to a 40 degrees flexion

– The hip

In the middle stand	The articulation of the hip is at neutral position (0 degrees) and starts to stretch
Immediately after the ankle looses touch with the ground	The hip reaches the maximum stretch of 20 degrees
The moment the toes takeoff	The hip is almost at neutral position and moves towards flexion

3.3 Interval III

Describes the movement of the articulations in the sagittal plane in the swing phase. [1]

- The ankle

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During swing phase	The foot moves from it's initial plantar flexion to an essentially neutral position (0 degrees) and stays like that during all the phase

- The knee

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Between the foot's takeoff and the middle part of the swing phase	The knee flexes from an initial position of approximately 40 degrees to a maximum angle of approximately 64 degrees
Between the middle part of the swing phase and the touch of the ankle with the ground	The knee stretches almost fully until the last instant of the swing phase.

- The hip

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During swing phase	Starting from a neutral position, the hip's articulation flexes approximately 30 degrees and keeps that position

With this information we can know the correct gait that a healthy person should have. [1]

4 Diseases of the lower limbs in walking

To define the diseases in this paper we contacted Doctor Jaime Rebollo Vázquez, from the medical clinic of the Medicine Faculty of the Meritorious Autonomous University of Puebla, so he could advise us. Dr Rebollo did a statistic of the patiences that go to the clinic and gave us a list of the most common diseases:

- Ankle sprain
- Chondromalacia patella
- Gonarthrosis

4.1 Ankle sprain

The ankle sprain is the most frequent traumatic lesion of the lower limbs. This lesion changes the posture, which is why the treatment is a important to the normalization of the posture. The ankle sprain is the forced inversion of the ankle. It is a lesion that occurs more frequently between the age of 21 and 30 years old, possibly due to the increase of sport activities in that age. When this disease occurs in younger or older persons, the lesion tends to be worse. Up to 44% of the people that suffered an ankle sprain present some kind of sequel.

Depending of the damage of the lesion we can classify it in three types:

- Grade 1: A stretch is produced, the patient can walk, there is low pain and in general there are a few symptoms. The swelling is minimum and the patient can start a sport activity in two to three weeks.

- Grade 2: There is medium pain with a minor articular instability. There is swelling. The patient walks with a pain position and the symptoms are more evident.
- Grade 3: There is severe pain, deformity and swelling. The patient can't walk nor rest the foot in the ground.

From the three types we are going to be able to study only one, the second one, because the grade 1 does not have enough symptoms and the grade 3 does not allow the patient walk. [14]

4.2 Chondromalacia patella

The Chondromalacia patella presents in the body when there is cartilage wear. The cartilage is the best shock absorber we have in our articulations. We have Chondromalacia patella when the cartilage stops being smooth and white, and changes to a wrinkled surface, even being able to disappear, leaving the bone exposed. The Chondromalacia patella presents the following symptoms:

- Patients frequently complain about pain in the back of the knee, in some cases the knee can be stiff and is difficult to stretch.
- The Q angle is usually increased (angle formed by Ankle-knee-Hip).

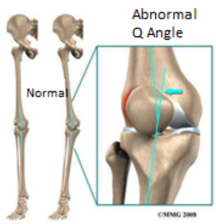

Fig. 2. Q Angle

- The ankle is slipped towards the inside.

In this case we will approach the disease by noticing if the knee moves towards the inside of the legs, as seen in figure 2. [15]

4.3 Gonarthrosis

The Gonarthrosis is a disease that affects normally the adult population, characterized by the pain, claudication, deformity and functional incapacity. Affects mainly women. The symptoms of the Gonarthrosis are:

- Pain: Is the most frequent symptom, can be located in the back, front and medial part of the knee .

- Stiffness: The duration of this symptom is less than 30 minutes, which makes this disease different from the other swelling diseases.
- Swelling incapacity: The affected articulation presents difficulty to move.

Fig. 3. Displacement of the knee towards outside

In the Gonarthrosis, exists an external ligament decomposition, which makes the knee to slip towards the external part of the leg, this movement is the most common of the Gonarthrosis as seen in figure 3. [16]

5 Motion Capture (MoCap)

Motion Capture or MoCap is a technique of digitalization recording the movements of the entities, persons or animals. Traditionally the computer animation techniques are used to create movements of the entity. There are three types of techniques of motion capture (MoCap). The first technique is called optical motion capture where the photogrammetry is used to establish the position of an object in the 3D space based in it's observed place in the fields in 2D from a certain number of cameras. [4][5] The second technique is called magnetic motion capture, where the positions and orientations of magnetic sensors are calculated with a transmitter.[8][9] The last technique is called electro mechanic motion capture, and involves motion modeling using a suit with glued sensors. [1][2][3][6][10]

Another form of motion capture is the kinect, which is a combination of motion captures. The kinect sensor is an horizontal bar connected to a small base with a motorized pivot. The device has an RGB camera, depth sensor and a multi array of microphones. The depth sensor is made by the PrimeSense company.[12]

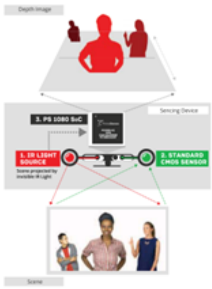

Fig. 4. Use of the kinect's depth

The technology that PrimeSense uses gives the ability to digital devices to observe a scene in three dimensions. Translates it's observations in a synchronized stream of images to information, such as people identifier, it's body properties, movement and gestures, and objects classifier, as seen in figure 4.

This is due to the infrared light, which is invisible to the naked eye. This solution uses a standard images sensor CMOS to read the codified light from the scene. This process allows the depth acquisition and is what makes the PrimeSense solutions so accurate. [13]

This solution can be coupled to the customer needs, because it can change it's preferences, such as range, field vision, depth resolution and frames per second.

5.1 Software development

The first part of the software is focused in data capture, so we can define if a person has any disease of the previously mentioned. We are going to use the kinect device because it has many advantages, like no being invasive, it does not need specialized devices as sensors and external transmitters and it is also a very known device, which gives us access to the device support and wide information.

When it comes to the articulations needed for this project we only need the ankle, toe tip, knee and hip, because the diseases that we are focusing into are concentrated in these articulations, and their symptoms are presented in the same articulations.

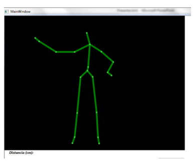

Fig. 5. Human skeleton given by the kinect device

We capture the articulations using the kinect, which can give us a full body point map as seen in figure 5 . Now the following question is if the kinect device can be used to capture the human body accurately. Given that it is an non invasive system it does have errors when it comes to accuracy. The error changes depending on how far the object is.

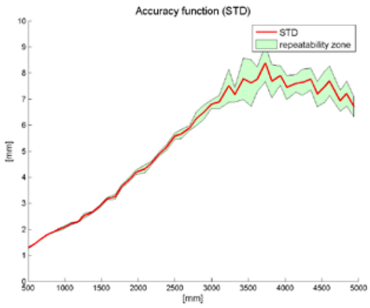

Fig. 6. Kinect error

As we can see in figure 6 the error increases depending on the depth of the object. Due to the error we can not go too far away from the device, the distance where the error is low enough would be from 1 meter to 3 meters. [17]

Now, the next step is to evaluate the data in order to say if a person is healthy or not, we will approach this matter by creating a classifier with the recollected data, we will teach our classifier the healthy states of the person's gait and then the non healthy ones.

The data we will classify is the angles that the joints of the leg form, given that the diseases manifest in specific angles we don't have to address all the joint's angles, instead we will focus on the angles needed to evaluate the diseases. For example the angle formed by the hip,knee and ankle joints, a healthy person would have a 180 angle, since the joints are aligned, having a disease like in the figure 2 . This way we can tell if a person has this disease.

The classifier we want to use is clustering due to the fact that is versatile, this classifier needs numerical data, and since the data we analyze is the joint's angle then it fits perfectly, and depending on the classifier's parameters we can adjust it's accuracy. [18]

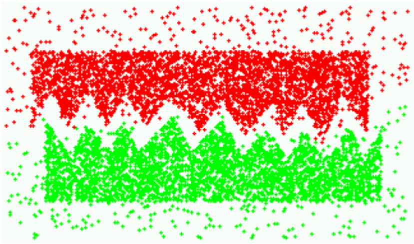

Fig. 7. Clusters example

We can see the adaptability of the classifier in figure 7 , which is one of the reasons we chose the clustering classifier.

5.2 System limitation

This system has some limitations that are very known in the computer vision filed, and it is occlusion, which is when an object passes in front of another from the camera or sensor. This makes the software to not know what to do and throw incorrect data. Another limitation is the accuracy, because it can be less precise if the device is far from the object, but if it is close enough from the object it can be almost as accurate as the other motion capture methods.

6 Expected contributions

We want to provide a non invasive classifier that will help medics evaluate if a person has a disease in it's gait. We want to present a software that will classify accurately the angles of a person's gait and return a accurate enough diagnosis.

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