Gait Analysis through Animated GIFs: A Novel Approach for Visualizing Step Dynamics

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ABSTRACT
The field of prosthetic knee development has made great progress in recent years, notably with the use of machine learning (ML) approaches. Researchers made significant progress in enhancing the functionality, flexibility, and user experience of prosthetic knees using revolutionary machine learning techniques.

Since gait analysis delivers part of the most important information about human motion patterns, it becomes critical in the development of a prosthetic knee. In this paper, some new techniques for gait analysis with feature extraction are proposed that include visualization using animated GIF images. This methodology extracts key parameters like step length and step width from the frames of a GIF image and can completely represent the dynamics of gait with respect to time.

This methodology is particularly significant to design an efficient prosthetic knee since it shows how combining computer analysis and visual data may enhance gait analysis methods. For this study, brief walking footage of both healthy individuals and amputees are recorded, then turned into GIFs. Subsequently, these GIF data points are retrieved, making it possible to quantify step length and other essential metrics required to analyses gait patterns.

Gait analysis is incorporated as part of the development process for these prosthetic knee joints due to the fact that it gives information on human motion patterns. The methods used in this paper provide novel ways of carrying out gait analysis through feature extraction and visualization using animated GIF images. This method would help in depicting the full picture of gait dynamics with time and assist in extracting important parameters such as step length and width from the frames of the GIF. The work, as described, falls squarely into the use of computer vision techniques for feature extraction and into time-series data analysis for trend identification within the broader application of machine learning in the development of the prosthetic knee. These techniques could be generalized toward designing better prosthetic knee design for more natural and fluent motion.

I. INTRODUCTION

Since gait analysis offers important insights into the biomechanics of human mobility, it is an essential part of the design and assessment process for prosthetics whether it is knee or limb prosthesis Step length is one of the most important gait analysis factors, and it has been well researched in the context of both healthy people and amputees.

Step length is one of the gait metrics that have been the subject of several research on healthy individuals. Researchers have used a variety of methods, including wearable sensors, instrumented pathways, and motion capture devices [1,2], to measure and analyses gait. In depth understanding of variables that affect step length, such as walking speed, gender, and age and different gait patterns is required to deep dive in analyzing gait of any individual .

For instance, a motion capture system was utilized in research by Oberg et al[1], to examine the gait of one hundred healthy people. They discovered that leg length and height had an impact on step length, which rose with walking speed. Similarly, Hollman et al.[3], measured gait characteristics in 291 healthy people using an instrumented walkway, reporting standardized values for step length across different age groups.

Gait analysis When done in groups of amputees, due to the particular difficulties this population faces, gait analysis in amputees has drawn a lot of interest in comparison to healthy people. Researchers have investigated the effects of amputees' walking patterns on prosthesis design, control techniques, and rehabilitation therapies [5, 6].

The measuring of amputees' step length has been the subject of several research. By comparing the step lengths of transfemoral amputees and healthy controls using a motion capture system, Bae et al. [7], discovered that the amputees' step lengths were shorter on the prosthetic side. Similar to this, Schmalz et al.[8], found that step length was shorter on the prosthetic side of transfemoral amputees than on the sound side. They attributed this to the prosthetic knee joint's limits.

Even with the best techniques for studying gait that have been established to date, including motion capture and instrumented pathways, results have been informative, but usually they require specialized equipment and highly controlled laboratory settings. This often limits the applicability and accessibility of such methods in users of prosthetic devices who may find it very difficult to travel to a research facility.

Video-based gait analysis, in particular, has the potential to make this gap shrink. On this note, videotaping using a smartphone or an ordinary video camera of data on gait would give the researchers and clinicians an opportunity to analyze further gait metrics—for example, step length—in settings more natural and Ecological.

II. UNDERSTANDING THE KNEE MOVEMENT

In order to change prosthetic design by using state-of-the-art machine learning methods, we need an initial perception on the physical laws governing leg motion due to their relationships between body parts. An instance whereby biological engineering has been effectively used is the human knee joint which happens to be especially big and complex. It consists of 4 bones accompanied by intricate arrangement of tendons and muscle. Such structures help in ensuring that there is either movement or static alignment at any given moment according to one's needs. parsimonious understanding of such intricate anatomy is needed to come up with the best devices or systems for enhanced personal assistance. This exceedingly advance structure consists of

- **The femur (thigh bone)**
- **the tibia (shin bone),**
- **the patella (kneecap)**
- **the fibula (calf bone).**

Fig 1: Knee joint
Source: https://www.knee-pain explained.com/kneebones.html

During a gait cycle, the angles of the knee joint when walking on a level surface change.The three most crucial angles are as follows:

a) **Flexion angle**: This is the angle formed by the femur (thighbone) and tibia (shinbone). As the knee bends, the flexion angle rises as the knee straightens, it falls.

b) **Extension angle**: When the knee is fully extended, the extension angle is formed by the thighbone and the shinbone. Typically, the extension angle is about 180 degrees.

c) **Varus/Valgus angle**: The angle formed by the lower leg's tibia and fibula is known as the varus/valgus angle. The tibia and fibula's angle when the knee is bent inward is called the varus angle, and the opposite is true when the knee is bent outward, or the valgus angle prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

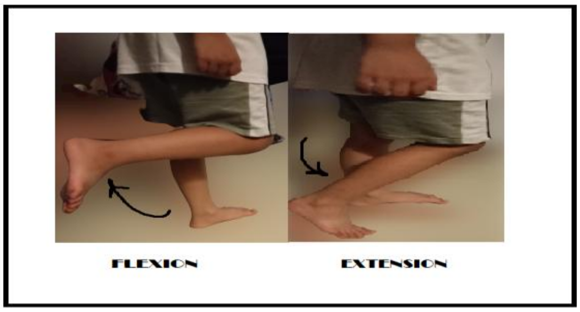

Fig 2: Flexion and Extension

Equations for the four main movements of the knee:

I) FLEXION

torque = force * distance (i)

torque = (hamstring force) * (distance from patella to hamstring attachment) (ii) ii) EXTENSION

torque = force * distance (iii)

torque = (quadriceps force) * (distance from patella to quadriceps attachment) (iv)

iii) MEDIAL ROTATION

torque = force * distance (v)

torque = (medial hamstring force) * (distance from patella to medial hamstring attachment) (vi)

iv) LATERAL ROTATION

torque = force * distance (vii)

torque = (lateral hamstring force) * (distance from patella to lateral hamstring attachment (viii)

Angle = (Initial angle + Change in angle) * (1 - Coefficient of friction) (ix)

- ***Angle is the final angle of the knee***
- ***Initial angle is the initial angle of the knee***
- ***Change in angle is the change in angle of the knee during the gait cycle***
- ***Coefficient of friction is the coefficient of friction between the bones in the knee joint***

The coefficient of friction is a measure of how slippery the surfaces of the bones are. A higher coefficient of friction means that the bones are more slippery, and the knee will be more likely to slide. The formula for knee movement can be used to calculate the angle of the knee at any point in the gait cycle. This information can be used to study the causes of knee injuries, to design new knee implants, and to improve the rehabilitation of people with knee injuries.

- ***When the leg is straight, the starting angle of the knee is usually 0 degrees.***
- ***The shift in knee angle might be either positive or negative.***
- ***A positive angle change indicates that the knee is bending***

- ***Negative angle change indicates that the knee is straightening.***
- ***The coefficient of friction is normally between 0.01 and 0.1.***

Phases of Gait Cycle

Phase	Sub-phases	Description
Stance	Initial contact, Loading response, Mid-stance, Terminal stance, Pre-swing	Foot is on the ground
Swing	Initial swing, Mid-swing, Terminal swing, Pre-contact	Foot is off the ground

Fig 4: Phases of Gait Cycle

III. METHODOLOGY

PROPOSED APPROACH: OPENCV AND IMAGEIO FOR VIDEO-BASED GAIT ANALYSIS

In the proposed methodology, the major libraries for video-based gait analysis are OpenCV—a leading computer vision library—and ImageIO—a Java image and video processing package.
A)Data Collection: Video recording of the gait of prosthesis users and healthy persons walking along corridors or outside spaces is recorded as part of the data collection process.
These video fragments can either be recorded by the study team or be shared, open-source datasets.

B)Video Processing: First, read the video files and extract the individual frames using libraries like OpenCV or ImageIO.Pose estimation methods, such as OpenPose or DeepLabCut, are used to detect and track the movement of relevant body features; examples include joints or limbs.
Spatiotemporal gait metrics, such as step length and stride length, along with cadence, will be computed by algorithms specifically designed for this, paying attention to the monitored body landmarks.

C) ***Time Series Analysis:***
Here, the extracted gait parameters are hence subjected to time series analysis techniques like signal processing, pattern recognition to bring out identification, and quantification of divergence in gait patterns between healthy individuals and prosthetic users.
This would allow for gait assessment with prosthetic components and, in turn, assist in the design and optimization of a prosthesis.
D) ***Visualization and Evaluation:***
The following code is the function plot_gif_with_bar_graph which can be used to visualize the gait data: It takes as input an associated GIF and some related data, and then animates that displays a GIF together with the representation of the data using a bar graph.

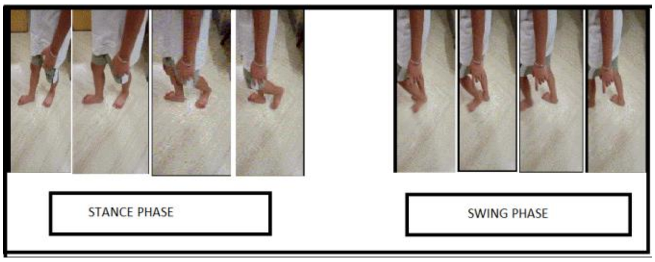

Fig 5: Gait Analysis -Stance to Swing phase

With the above gif to be used as input in the python code to get to the below insights for a normal human being

- Gait pattern: A GIF of a person while walking can be used for analyzing his/her gait by obtaining features from each frame, for example, step length and step breadth, and plotting them on a bar graph, which would help to understand the stride pattern of the person better.
- Time series data: GIF used to be the representation of the time series. That helps to plot the data in bar graph with its associating each frame with a particular data point. That could help in understanding the change or trend over the period in data.
- Relationship visualization: This is also going to help us to visualize the relationship with respect to the visual material and the data that follows being presented together as the GIF frames and their corresponding data to the viewer.

Comparison of Gait pattern of Healthy individual and an Amputee

The study is intended to implement the use of python code. The intention of the Python code is to read a GIF image and showcase it as an animated display while generating a bar graph that updates with every frame of the GIF. Additionally, it saves the animation as a GIF file and documents the data points for each frame in a text file.

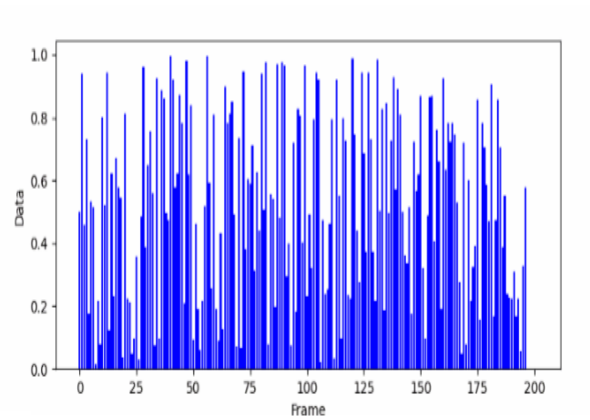

Fig 6: Gait pattern of healthy individual

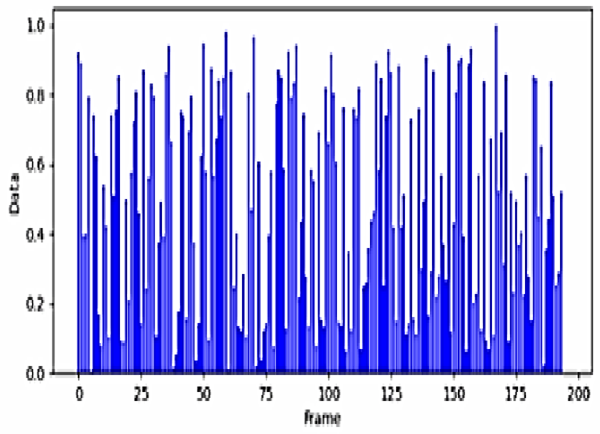

Fig 7: Gait pattern of an amputee

CONCLUSION

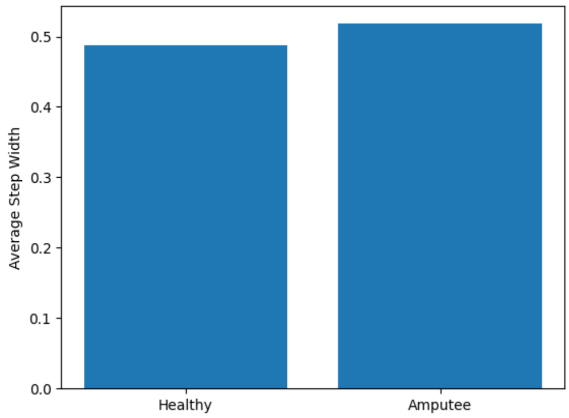

Fig 6: Comparison of Average Step length of Healthy individual and an Amputee

Mean step length in healthy population: 0.4872906403940887

- Mean step length for amputee is 0.518020304568528
- Amputees walk with a greater step width than do persons without amputations.

This can prove useful in the design of efficient prosthetic knees by considering the discrepancy in step lengths between amputees and the healthy population. This knowledge can further enable us to develop an effective prosthetic knee by predicting the optimum step length for the amputee, correlating with other unique traits. For example, if the model predicts a likelihood of an amputee having a wider step length compared to a healthy person, then the prosthetic knee can be made in such a way as to have the provision for a wider step length.

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