Gait Phase Classification and Prediction

Abstract

Gait is the manner of walking or the analysis of each step when walking. It can be used to determine if the person has abnormalities in their walking and it is important in analyzing how a person should walk if they are missing a limb. There are different phases in gait. These are separated based on time of occurrence. Each gait cycle includes two periods which are stance and swing phase. Stance phase accounts for 60% of the total time for one step and is when both feet are on the ground. Swing phase, accounts for 40% of the total step time and is when the feet is in midair. Stance phase of gait is divided into loading response, midstance, terminal stance, and pre-swing. Swing phase is divided into initial swing, mid-swing, and terminal swing. It is rare to find gait data that has classified each gait phase, although it's important in understanding the muscular condition of a patient. In this project, one of the objectives was to preprocess EMG data by smoothing it then labelling it the corresponding gait phase associated with it. The second objective was to make predictions of how a person should walk on the other foot given the manner of walking on the right foot. The results show that a good classification was made, and the prediction had a Mean Squared Error of 25.25 and r2 score of 0.29 on a small dataset of one subject walking for less than 40 second.

Introduction

This paper is about gait. Gait is the science of walking. Each step that we take is classified into stance and swing phase. Stance is the period our feet is in contact with the ground while swing is the period of time that our feet is in mid-air in a single step. Stance takes 60% of the total step time and is further divided into periods: loading response, midstance, terminal stance, and pre-swing.

1. Loading response begins with initial contact, the instant the foot contacts the ground, considering that normally the heel contacts the ground first. Loading response ends with contralateral toe off when the opposite extremity leaves the ground.
2. Midstance begins with contralateral toe off and ends when the center of gravity is directly over the reference foot.
3. Terminal stance begins when the center of gravity is over the supporting foot and ends when the contralateral foot contacts the ground. During terminal stance, around 35 percent of the gait cycle, the heel rises from the ground.
4. Pre-swing begins at contralateral initial contact and ends at toe off, at around 60 percent of the gait cycle and corresponds to the gait cycle's second period of double limb support.

Swing phase takes 40% of the total gait cycle time and is subdivided into Initial Swing, Midswing and Terminal Swing.

1. Initial swing begins at toe off and continues until maximum knee flexion.
2. Midswing is the period from maximum knee flexion until the tibia is vertical or perpendicular to the ground.
3. Terminal swing begins where the tibia is vertical and ends at initial contact.

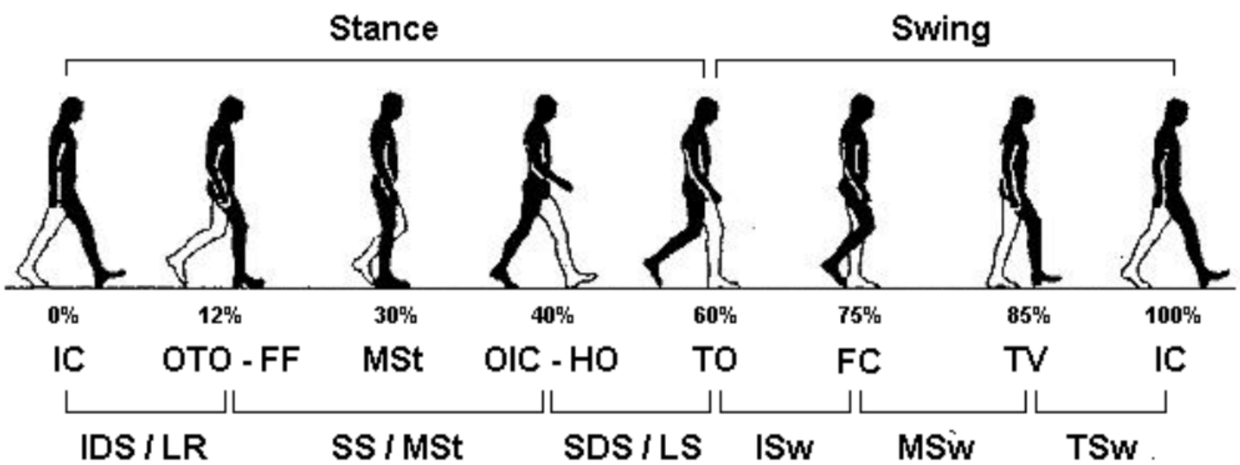

Figure 1 Gait Phase: Initial Contact(IO) LR(Loading Response), MSt(Mid-stance), ISw(Initial Swing),MSw(Mid-swing), TSw(Terminal Swing)

The reason gait is studied is because it helps us to understand the style or manner a person walks in and enables to either understand if the person has a healthy walking pattern or has some sort of abnormality. If they have abnormality, this study helps us understand what phase has abnormality and hence the muscle that is unhealthy by recognizing the muscle that is involved with that muscle. Another case this study is useful is in prosthesis/Orthosis. We can make gait prediction for people missing a limb or need support in using their limb by understanding their pattern of walking and making correct predictions of how they would like to walk.

The problem faced is that gait data is not classified into different phases or even steps. This is challenging in creating models as the dataset does not exist. In this project, the objective is to classify this dataset into steps for gait prediction and gait phases for analysis of any muscular abnormalities.

Methods

To implement this project, I worked on the dataset available here. It consists of walking patterns of healthy people and people with muscular abnormalities. The recordings are of the knee angle, and EMG signals from Rectus Femoris, Biceps Femoris, Tibialis Anterior and Gastrocnemius Muscle. In this project only the EMG signals were utilized but the knee angle can be useful in future works. This EMG signals were useful because it helps to differentiate each step based on the pattern of EMG plot in one step. Figure 2 depicts the patterns of each muscle that Is used in the project and how their EMG response are for each step.

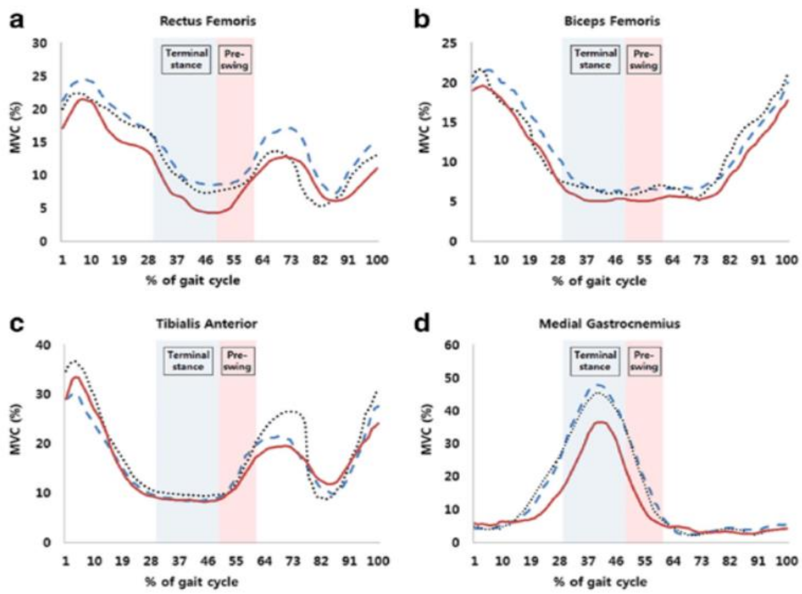

Figure 2 Muscle patterns for a single step

Description of the signal processing step	**Rationale**	**Inputs and outputs of the step**
Filtering	Filtering the EMG signal to remove noise and filter out the unimportant data	Raw data as input and filtered data as output
Statistical Inference	Separate each step and from each step separate the gait phases	EMG data → separated EMG steps → Gait phases
Power Spectrum	Find the power spectrum of the filtered EMG data	Filtered EMG signal of each muscle → Power spectrum of each muscle
Data Visualization	Visualizing the raw and filtered data, the power spectrum, the onset of each step	Raw Data→ filtered data Filtered EMG signal → onset of each step
Machine Learning	Linear regression for prediction of gait data given right foot limb and predicting the left limb	Right Limb EMG data → predicted Left limb EMG data

Results

The objective of the project was successfully implemented. The EMG signals were filtered for each muscle from 10-400 HZ and low pass filtered then rectified as can be seen on figure 3.

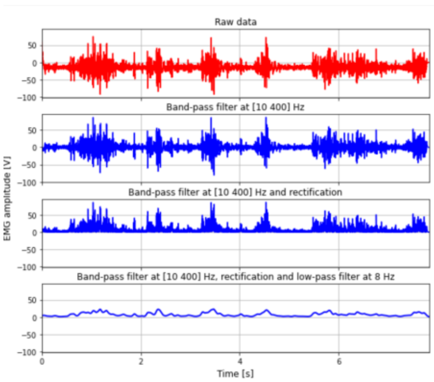

Figure 3 Raw and Smoothed data

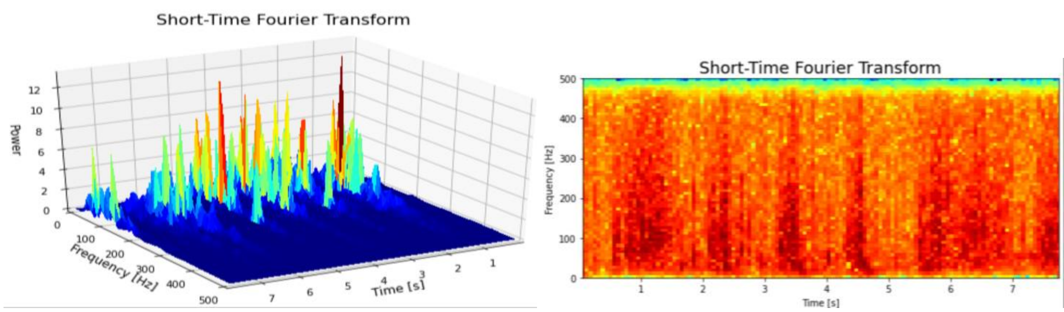

Figure 4 Power Spectrum

The power spectrum as can be seen on figure 4 is from 10-400 Hz. This gives a plot of the portion of a signal's power (energy per unit time) falling within given frequency bins

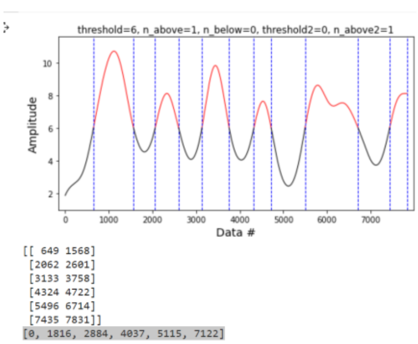

Figure 5 Onset Detection of each step

The steps of each muscle were separated from each other using the patterns as seen on figure 2. The time steps where each step is separated is shown in figure 2 as highlighted in grey.

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Mean squared error: 25.25
Coefficient of determination: 0.29
RMSE 5.0247672235256085
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Figure 6 Linear Regression Prediction

Given the data only from the right for the four muscles: Rectus Femoris, Biceps Femoris, Tibialis Anterior, and Gastrocnemius, prediction for these four muscles of the left limb is made. The method used was done using linear regression. The mean squared error is 25.25. The prediction is not good enough, but more data is needed. This was done using data from a person walking for less than 40 second.

Conclusions

Gait is an important study to assess the walking pattern of a person. This can be studied from EMG. Most EMG data is unpreprocessed but many useful information can be extracted. The gait phases can be extracted after separating each step. These gait phases can be used to understand the abnormalities in a person's walking. Prediction can also be made using the data from only one of the limbs. More data is needed to make better prediction with good accuracy.