ECE2111 Assignment: Gait Analysis

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1 What is gait?

The term gait refers to the way in which a person walks. This is a repetitive pattern with steps and strides. A 'step' is one single step, while a 'stride' is a whole gait cycle. One step lasts from the heel strike of one foot to the heel strike of the other foot. As shown in Figure 1, the gait cycle

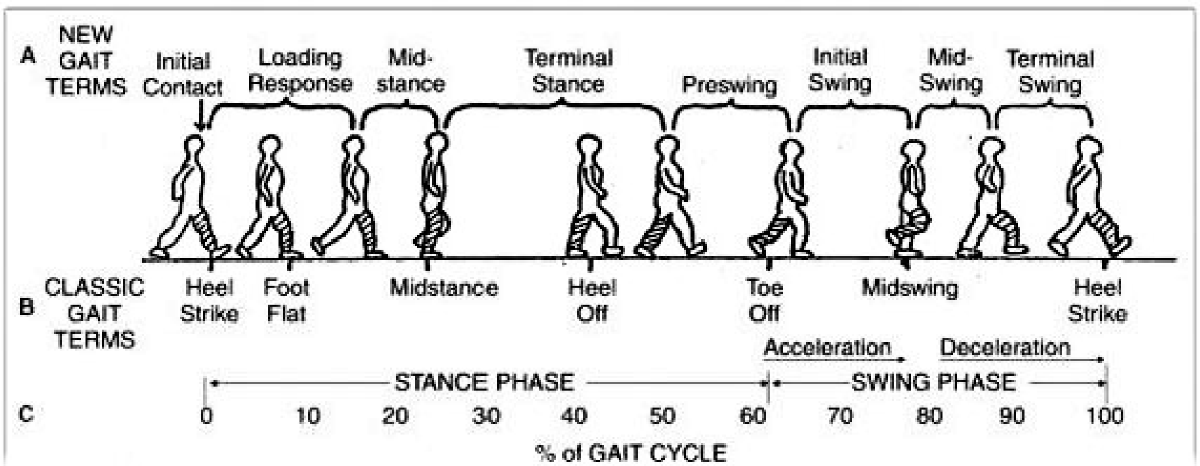

Figure 1: The gait cycle [2]

has two main phases. The 'stance' phase begins with the heel strike, i.e., from the moment the heel begins to touch the ground until the point at which the toe of that foot lifts off (the toe-off stance). The swing phase begins when the stance phase ends, and lasts from the toe-off phase to the heel strike phase [3].

2 Sensors and data

A computerized force-sensitive system can be used to quantify gait and measure swing and stance time and variability. For this project, you will use data from PhysioNet public database (`https://www.physionet.org/pn3/gaitpdb/`) collected by a system which measures the forces underneath each foot as a function of time [1]. The system consists of a pair of shoes and a recording unit. Each shoe contains 8 load sensors that cover the surface of the sole and measure the vertical forces under the foot. For simplicity, you are only working with the total force under each foot.

The total vertical ground reaction force (VGRF) under each foot is recorded (in Newton) and sampled at 120 Hz. From a VGRF signal with sufficiently good quality, it is possible to measure the stance and swing time as shown in Figure 2.

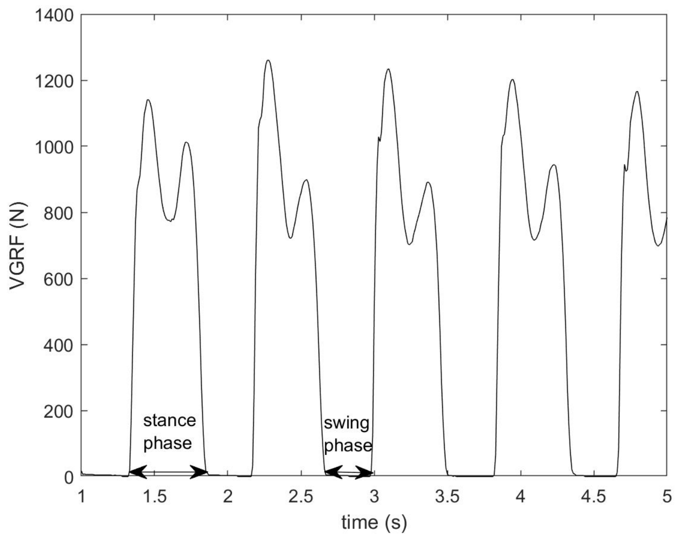

Figure 2: Swing and stance phases during walking can be measured using a clean VGRF signal.

2.1 Data format

You will be given a `.mat` file, containing data collected from a healthy subject, with three columns:

1. Time (in seconds),
2. Total force under the left foot (in Newtons),
3. Total force under the right foot (in Newtons).

However the data are noisy and need to be processed to be able to measure the gait cycle and phases.

3 Tasks

The overall aim of this project is to estimate the sequence of stance times, swing times and stride times (where the stride time is the sum of the stance time and the swing time, as shown in Figure 3) for each foot from the noisy VGRF data.

You will achieve this by carrying out the following basic steps, discussed in more detail below:

1. Plotting the data in different ways (section 3.1 and 3.2) to understand its main features;
2. Filtering the data to remove unwanted frequency components (section 3.3);
3. Computing the gait parameters (swing, stride, and stance time) from the filtered signal (section 3.3).

3.1 Initial plots

Write a matlab script `section31.m` that does the following:

- Plot the VGRF (in Newtons) vs. time (in seconds), for both feet (on the same set of axes, overlaid with different colours), for any 5 second segment of data.

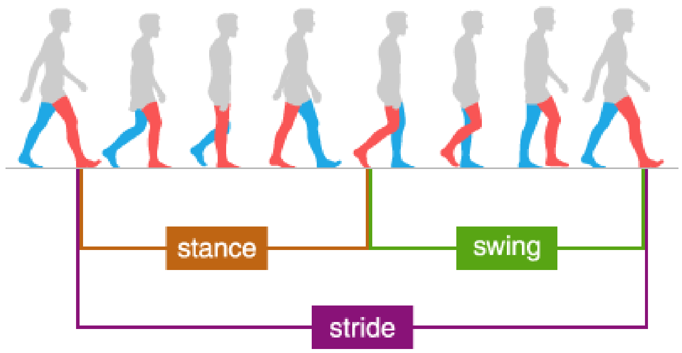

Figure 3: Stride, swing and stance phases during walking
(from: `https://www.kinesis.ie/gait/`)

- Plot the VGRF signal in frequency domain.

Questions: Can you find a simple threshold in the VGRF value such that values above the threshold correspond to the foot being on the ground, and values below th threshold correspond to the foot being off the ground? If so, what is a good threshold value? If not, explain why a simple thresholding approach doesn't work with the noisy data.

3.2 Time-Frequency analysis

For this type of signal we expect frequency characteristics to change over time, while walking. The frequency domain FFT plot does not show the frequency content at each gait phase, but is an aggreagate of the frequency content over all the gait phases in the signal.

Instead, considering that we can divide almost any time-varying signal into time intervals short enough that the signal is essentially periodic in each section, we can then analyze the frequency content of each signal segment. This will allow us to perform 'time-frequency analysis' by windowing the signal into short time segments and estimating the spectrum over sliding windows. The `spectrogram` function in MATLAB computes an FFT-based spectral estimate over each sliding window and lets you visualize how the frequency content of the signal changes over time. **You will need to read the MATLAB documentation related to the function `spectrogram` to help you complete this section.**

The choice of the time window affects the time and frequency resolution of the spectrogram.

- Write a MATLAB script `section32.m` that plots the spectrogram of the VGRF from either the right or left foot for any 30 seconds of the data. Choose three different window lengths: 10, 20 and 50 samples. Mark one stance and one swing phase on the spectrogram. To do this, it may be easier if you:
  - choose the `yaxis` option to display frequency on the vertical axis and time on the horizontal axis.
  - choose the `colormap jet` option for better visualization.

Questions:

- What happens to the spectrogram plots as you change the window length? Why does this happen?
- Locate the main noise component from your spectrogram plots. What might one major source of noise be?

3.3 Filtering and computing gait parameters

Using the information about the signal content that you learned from the spectrogram, write a function `estimateGait.m` with

- **Input:** the raw VGRF signals
- **Outputs:**
  - `STl` a vector of the stance times (durations of stance phases) for the left foot
  - `STr` a vector of the stance times for the right foot
  - `SWl` a vector of the swing times (durations of swing phases) for the left foot
  - `SWr` a vector of the swing times for the right foot
  - `Sl` a vector of the stride times (durations of stride phases) for the left foot
  - `Sr` a vector of the stride times for the right foot

Your function should do this by

- applying (an) appropriate frequency-selective filter(s) (with parameters chosen based on your observations in section 3.1 and 3.2 about the data) to remove noise from the signal;
- automatically find the time at which each swing and stance phase starts for each foot (the swing and stance onset times).
- computing the sequences of swing and stance and stride times (the durations of the swing/stance/stride phases), from the swing and stance onset times.

In addition to computing these times, the function should:

- Plot the filtered VGRF for both feet (overlaid) vs. time (in seconds) for some choice of 5 second interval.
- Mark the onset of swing and stance phases on the filtered VGRF time-domain plot.
- Plot the filtered VGRF signal in frequency domain.
- Plot the stride time vs. cycle, swing time vs. cycle and stance time vs. cycle for each foot. Note that these are discrete-time signals since the gait cycles are indexed by integers.

Questions:

- How does your plot of the filtered signal in the time domain compare with the plot of the raw signal from Section 3.1?
- How does your plot of the filtered signal in the frequency domain compare with the plot of the raw signal from Section 3.1?

4 Submissions

You are required to submit your code (as a single `.zip` archive) and a brief report (at most four A4 pages in `.pdf` format) via Moodle submission links by **Friday 22 October at 5pm**.

Your report should be organized into four sections:

1. Introduction: a brief explanation of the problem.
2. Data exploration: in which you show your plots from sections 3.1 and 3.2, answer the questions from those sections, and explain what you see in each of those plots.
3. Filtering: in which you
   - explain how you come up with the parameters for the frequency selective filters you use in section 3.3, the MATLAB function(s) you use to design the filter(s), and how they are used;
   - show the plots of the filtered signal (in time and frequency domain) and discuss how they compare with the raw signals.
4. Computing gait parameters: in which you explain how (i.e., what method and how your code works) you estimate the stance, swing, and stride times from the filtered signal, and show the plots of the stride, swing, and stance times vs gait cycle.

5 Assessment

The assignment is marked out of 10. Part of the marks are allocated to how well your approach works (how well you have estimated the sequence of stride, swing, and stance times) and part or the marks are allocated to your explanation of your approach and the correctness of the intermediate steps you take. The following is a guide to how the marking will be carried out.

- Quality of estimates (3 marks)
  - (3 marks) Estimates closely match true swing, stride, and stance times
  - (2 mark) Estimates mostly match true times well, but have some outliers and artefacts
  - (1 marks) Estimates consistently far from the true times.
  - (0 marks) Plots of the swing, stride, and stance times for both feet are not submitted or do not match the plots generated by the code.
- Introduction and overall grammar spelling and presentation (1 mark)
  - (1 mark) Clear, concise introduction explaining the problem. Correct spelling and grammar throughout, clearly presented and labeled plots.
  - (0.5 marks) Introduction that explains the problem; some grammatical or spelling errors, and/or some plots that are difficult to read/interpret.
  - (0 marks) Introduction missing, poor spelling and grammar, sloppy and unclear presentation of figures.
- Data exploration (2 marks)

  - (2 marks) Correct plots, explanations and answers to questions that are correct and show understanding of what the plots mean.
  - (1 mark) Some correct plots, partly correct explanations and answers to questions.
  - (0 marks) Missing or largely incorrect plots and missing or mostly incorrect answers to questions.

- Filtering (2 marks)
  - (2 marks) Correct plots of filtered signal (based on choice of filter parameters), clear and convincing explanations of how and why filter parameters were chosen (with reference to plots from the data exploration section), clear explanation of how MATLAB was used to design a filter.
  - (1 mark) Some correct plots, and explanations that are partly correct, but show some misunderstandings and errors in filter design using MATLAB.
  - (0 marks) Missing or largely incorrect plots and missing or mostly incorrect explanation to questions.

- Computing parameters (2 marks)
  - (2 marks) Clear explanations of how gait parameters were computed from the filtered data, including rationale for any choice of thresholds and explanation of how code implements the approach.
  - (1 mark) Explanations are included but are somewhat difficult to follow/understand.
  - (0 marks) Missing or incomprehensible explanations of how gait parameters were computed.

References

[1] Silvi Frenkel-Toledo, Nir Giladi, Chava Peretz, Talia Herman, Leor Gruendlinger, and Jeffrey M Hausdorff. Treadmill walking as an external pacemaker to improve gait rhythm and stability in parkinson's disease. *Movement disorders: official journal of the Movement Disorder Society*, 20(9):1109–1114, 2005.

[2] Physiopedia. File:figure2.jpg — physiopedia,, 2011. [Online; accessed 10-September-2018].

[3] Physiopedia. Gait — physiopedia,, 2018. [Online; accessed 10-September-2018].