Sensors & Algorithms: The Implementation

The Mechanics

Sensor: tri-axial (medio-lateral, anterior-posterior, longitudinal) accelerometer
Battery: data digitization and associated memory within the wearable makes it so that one full battery charge is sufficient to gather data every 0.01s (100 Hertz) for 7 days = 180 mil data points
What: accelerometers quantity acceleration, meters per second squared. This is calculated from the voltage generated in the sensor during movement

Current Options

Commercial wearables for gait:
- GaitUp (foot)
- Opal (ankle)
- StepWatch (shank)
- DynaPort (lower back)

Note: these commercial gait wearables don't have the same high sampling rates.

Instrumenting Gait

Gait research usually locates wearables as close to the centre of mass as possible.

Device attachment:
- Commercial devices are usually equipped with a strap/belt/clip for attachment
- Direct attachment to the skin with a combination of dermatological adhesive(s) (*e.g.* Hypafix, BSN Medical Limited, Hull, UK) and double-sided tape
- If the participant's skin (if frail/dry) can become compromised as a result of chafing, due to lack of protection from thin double-sided tape, adopt an adhesive hydrogel (*e.g.* PALstickies, PALTechnologies, Glasgow, UK) which provides additional padding due to its thicker design

Gait Characteristics:
- One wearable on L5 can capture 14 clinically relevant gait characteristics
- Generally, a participant should perform a 2min walk over a straight path
- Steady state walking requires you to exclude the first 2.5m of walking
- Gait initiation/termination influences results, so just exclude the first and last

steps of the walks before pooling the data

Data Import:

- MATLAB = general scientific computing
- Use script or command structure interfaces to process data with existing/prototypic algorithms
- Data needs to be downloaded from the wearable with associated software (hmm)
- Importing data to MATLAB can be done with *xlsread* function
- Data is saved to MATLAB workspace as a variable
- *ginput* function is used to segment data (define exact start/end and click on a plot to save the x-axis values)

Data Pre-Processing

- Noise is a problem for data collected by wearables
- Filtering = choose properly because it impacts algorithm analysis and feature extraction (e.g. Butterworth, Chebyshev)
- Generally, filter with a 4th order Butterworth filter with a cut-off frequency of 15-20Hz

Correcting Misalignments:

- Orientation/alignment of wearables is generally offset because of attachment error and the individual's body shape
- Gravity exerts a force on one axis as well
- Ask the participant to remain still upon initial attachment and record a few seconds of motionless standing for static activity reference values (subtract from corresponding values)
- Post-processing:
  - Transform tri-axial data into a horizontal/vertical orthogonal coordinate system (e.g. using trig to transfer to Cartesian)
  - Calculate/correct the best estimates of the offset angles between the true horizontal-vertical and that of the raw anterior-posterior and medio-lateral accelerations
  - No rotational angle, but average value of medic-lateral and anterior-posterior accelerations gets close to sin of the angles in the same directions
  - Apply arcsin to derive necessary values needed to correct offset

(i) Correction in the anterior-posterior plane (a_A, note change of subscript case):

$$a_A = a_a \cos \theta_a - a_v \sin \theta_a \qquad (1)$$

(ii) An interim correction (a'_v) in the vertical direction must be derived before a true value for a_V:

$$a'_v = a_a \sin \theta_a + \theta_v \cos \theta_a \qquad (2)$$

(iii) Interim values in the vertical direction used to derive a_M

$$a_M = a_m \cos \theta_m - a'_v \sin \theta_m \qquad (3)$$

(iv) Finally, a_V may now be estimated:

$$a_V = a_m \sin \theta_m + a'_v \cos \theta_m - 1\text{g} \qquad (4)$$

Algorithms

These methodologies aim to identify initial contact and final contact (heel strike vs toe off).

- Good temporal method = wavelets
- Wavelets = signal processing tool that's been used successfully in gait analysis
  - Extends the Fourier transform by two procedures:
    - Continuous and discrete wavelet transforms
    - CWT = correlation between waveforms (raw signal and probing function, i.e. wavelet) at different scales (~ frequencies) and positions in time. The resulting coefficients correspond to the best match
    - DWT = combination of high/low pass filters to divide up a raw signal in multiple components
  - Use MATLAB's Wavelet Toolbox for CWT IC/FC event detection

Wavelets:
1. Numerical integration of raw vertical acceleration with *cumtrapz* function
2. Differentiation of signal with *cwt* function, which results in signal S1
3. Find S1's local minima times, which are initial contact events (use *findpeaks* function)
4. Differentiate signal S1 with *cwt* function to get signal S2
5. Find local maxima, which are final contact events (use *findpeaks* function again)

Temporal Characteristics

- To fully replicate the characteristics of gait: step, stance, stride and swing times must be derived
- This is achieved through the sequence of IC/FC events in relation to the double support phase of the gait cycle
- From the sequence (*i*) of IC/FC events, both left and right (opposite) events are identified, and subsequently step, stride, stance and swing times are estimated

Spatial Characteristics

- Spatial algorithm based on inverted pendulum model tracks the centre of mass
- The model is reliant on a known variable (wearable height)
- Requires a known input, which is a weakness
- *l* is wearable height and *h* is change in height of the wearable
  - By fusing the algorithms, you can quantify an estimate for step velocity
  - Implementing the *cumtrapz* function to do this causes drift, which can be somewhat solved with filtering

$$\text{Step length} = 2\sqrt{2lh - h^2}$$

$$\text{Step velocity} = \frac{\text{step length}}{\text{step time}}$$

Variability

- Distinguish between left/right step characteristics for variability and asymmetry outcomes in asymmetrical diseases
- Differentiating between left/right during a long continuous walk is easier (assume first as left or right and alternate values thereafter)
- A protocol could also request the participant initiates walking with the same foot.
- Left/right steps may be identified by automated but more complex algorithms and can be found in linked papers)

Calculate variability and asymmetry:

$$\mathrm{Variability}_{left\,\&\,right} = \sqrt{\frac{\mathrm{variance}_{left} - \mathrm{variance}_{right}}{2}}$$