Portable, Inexpensive, and Unobtrusive Accelerometer-based Geriatric Gait Analysis

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What is Gait Analysis?

Clinical gait analysis is the quantitative and interpretive study of human locomotion.

There are currently two types of clinical gait analysis:
a) Observational Gait Analysis
Extensive observation by highly trained physician, sometimes with slow-motion video camera
-Problems: Qualitative nature, time consuming
b) Laboratory Based Analysis
Considerable analysis in expensive motion laboratory
-Problems: High cost, time consuming, based in specific location


Observational gait analysis is highly quantitative


A typical motion laboratory

Motivation

There is a need for a low cost, portable device that produces quantifiable and reliable data.

We would like to analyze the gait of the patient simply by having them walk down a hallway (approximately 15-20 steps), turn around, and walk back.

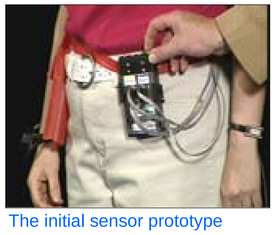
Benefits: Low cost, unobtrusive, no need to travel to laboratory, constant monitoring is possible

Applications: pre-emptive prediction of geriatric disorders, telemedicine, long-term analysis

The initial prototype is wired, using a DataFlash® memory card to store data

Next version (already developed) transmits all information wirelessly through Bluetooth™

Four sensors are attached to:
- The left and right ankle
- Right wrist
- Sacrum


The initial sensor prototype

Each sensor contains an accelerometer, which measures locomotion based on remote sensing. The sample rate of measurement is 90 Hz.

The accelerometers take measurements in the X (dorsal/ventral), Y (caudal/cranial), and Z (medial/lateral) directions.

Much of our analysis was done on what we call the “three-dimensional vector magnitude” (VecMag). The VecMag is a way to sum and normalize the data from all directions.
We calculate the VecMag with the following pseudocode:

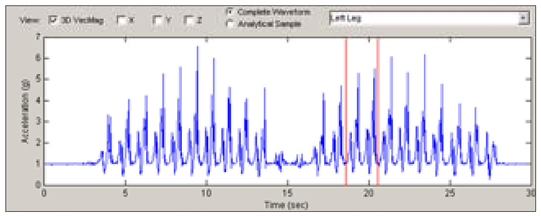
$$\text{for } (i = 0;\ i < \text{size(axialOutput)};\ i{+}{+}) \ \{\ \text{VecMag}[i] = \sqrt{\text{axialX}[i]^2 + \text{axialY}[i]^2 + \text{axialZ}[i]^2}\ \}$$

Equation for computing 3D VecMag

The Analytical Sample

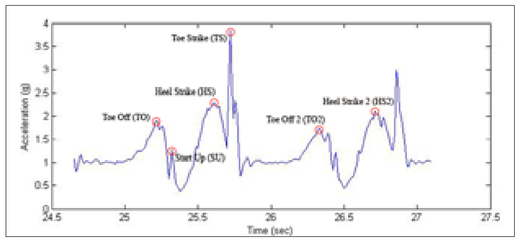
We have found that the best data to analyze is a few steps into the waveform after the patient has turned around.

We call this section the **analytical sample**, and its length is two periods of the waveform.



Plot of the VecMag with the analytical sample shown

The Essential Points



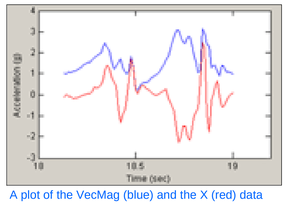
Analytical sample showing the six “essential points”

Once an analytical sample has been found, six essential points are calculated for each leg.

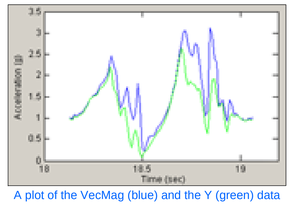
These essential points are found by using signal processing techniques on the analytical sample.

The six essential points consist of:
- Toe Off (x2)
- Start Up
- Heel Strike (x2)
- Toe Strike

The essential points were all found in a similar manner. First, a noise filter was applied to the waveforms to smooth small inconsistencies. For the toe strike and start up, points that correspond to a change in the x-direction, the VecMag and X directional waveforms were inspected for local maxima and minima. For the heel strike and toe off points, which both are associated with y-directional fluctuations, the VecMag and Y directional waveforms were used to find the extrema.

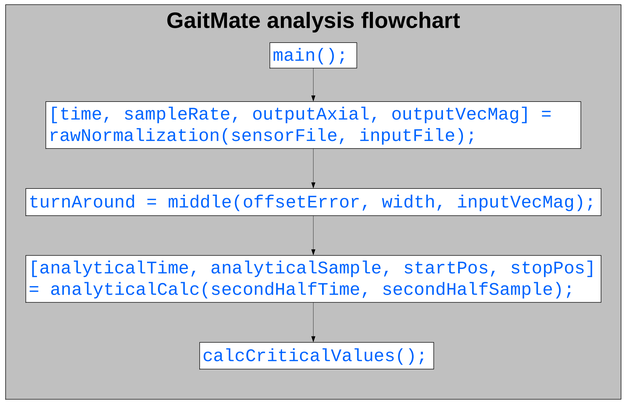


A plot of the VecMag (blue) and the X (red) data



A plot of the VecMag (blue) and the Y (green) data

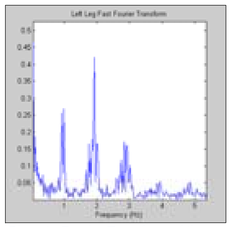
Below is a chart of the basic program flow of GaitMate. First, the raw data is normalized and sent to middle(), which finds the turn-around. Next, the vector (from turn-around to end) is sent to analyticalCalc(), which finds the analytical sample. Finally, this sample is sent to calcCriticalValues(), which finds the six essential points and uses them to calculate the 53 critical values.



The Critical Values

Once the six essential points for each leg are found, we can find 53 “critical values” in the waveform with minimal calculations. For example:
- Heel-strike interval (difference in time between two consecutive heel strikes)
- Toe-off amplitude (acceleration in g’s of the toe off)
- Amplitude and frequency of Discrete Fourier Transform peaks
- Percent of time in double stance (both feet grounded)
- Steps per minute


An individual outfitted with the wired sensor system



Discrete Fourier Transform of the VecMag

These critical values contain the results that physicians inspect to better understand problems with the patient’s gait.

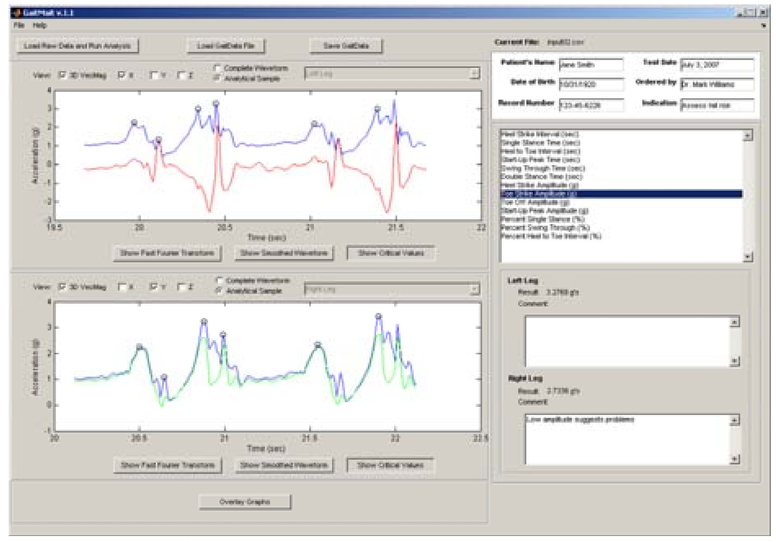
In order to enable a physician to gain a better view of the waveform as a whole, a Discrete Fourier Transform is applied to the VecMag. The frequency and amplitudes of the first two peaks relay useful information about possible gait problems and disorders.

Developing and Testing the GaitMate Tool

All coding for GaitMate was done in MATLAB 7.4.0 (R2007a). No MATLAB plug-ins are required to run the program. Both GUI and console-based versions are available.

GaitMate was evaluated on a pool of 56 geriatric patients, ranging from 67 to 94 years of age. The subjects suffered from afflictions such as Parkinson’s disease, memory impairment, spastic hemiparesis and paraparesis, arthritis, and stroke. Healthy patients were included, as well as subjects with a history of falling.

Our algorithm correctly identifies 97 percent of the essential points.



The Graphical User Interface

Future Work

- Use of GaitMate tool by physician to aid in diagnosis
- Create a large database of “registered” gaits
- Comparison of sample waveform to database to determine the probability with which a patient has a particular affliction
- Determine probability that a patient will need assisted living