Walking Speed and Incline Estimation: Project Definition

The goal of this project is to measure walking speed and incline in real time on an amputee using a non-obstructive inertial measurement unit (IMU) that consists of an accelerometer and a gyroscope. There are three main walking speed estimation methods that currently exist: abstraction model, human gait model, and direct integration.

The abstraction model method requires the use of artificial neural networks (ANNs), for which a training phase occurs before the actual classification (estimation) phase. The training phase uses previously generated acceleration signal patterns to develop a black-box ANN model that is used to map acceleration signals to the walking speed. Though this method is suitable for real time implementation and is flexible in terms where on the body the IMU is attached, the training phase can be time consuming and exhausting for individuals with gait abnormalities, such as amputees. Moreover, the robustness of the model depends directly on how expansive the training data set is.

The human gait model estimates walking speed based on some predefined human gait models. For example, some studies model each leg as one single segment and assume both legs to be symmetrical, allowing for the formation of an isosceles triangle using the two legs and the distance between the feet. The angle between the leg segments can be calculated by integrating the gyroscope signal, and the step length can be calculated using the properties of an isosceles triangle. From this, the total distance traveled can be calculated and final the walking speed can be obtained. This method depends on a physical model, so its accuracy is highly dependent on the validity of the gait model. Though it does not require any subject-specific training, it does need subject-specific anthropomorphic measurements to construct the gait model.

The direct integration method has been used in many studies to estimate both walking speed and incline. It requires dividing the gait signal into stride cycles through gait event detection, determining the orientation of the inertial sensor with respect to the global coordinate system, projecting the acceleration signal into the global coordinate system, and integrating the acceleration to obtain velocity, stride length, and walking slope. This method does not require subject-specific training or information like the above two models, but it does require the determination of sensor orientation for the model to be accurate. However, it provides accurate estimates of both walking speed and incline.

Unlike the abstraction model which does not require a specific location for sensor placement, both the human gait and direct integration models use sensors placed on the lower half of the body, particularly on the shank or foot. These locations are suitable for our project as placement of sensors on the prosthesis of an amputee subject will be non-obstructive and will not cause discomfort.

For the purposes of this project, a combination of both a human gait model and direct integration method proves to be the most reliable and accurate way to estimate walking speed and incline. Gait events can be accurately determined using either angular velocity from the gyroscope or acceleration signals, and it is important that acceleration signals be corrected by keeping in mind the offsets in the acceleration measurements.

References:

1. Inertial Sensor-Based Methods in Walking Speed Estimation: A Systematic Review
2. Walking Speed Estimation Using Shank-Mounted Accelerometers
3. Walking Speed Estimation Using a Shank-Mounted Inertial Measurement Unit
4. A Concurrent Comparison of Inertia Sensor-Based Walking Speed Estimation Methods
5. First Steps Toward Supervised Learning for Underactuated Bipedal Robot Locomotion, with Outdoor Experiments on the Wave Field
6. Upslope Walking With a Powered Knee and Ankle Prosthesis: Initial Results With an Amputee Subject