SCA3000 ACCELEROMETER IN SPEED, DISTANCE AND ENERGY MEASUREMENT

Objective

Multi-axis acceleration caused by human walking can be measured and converted into speed, distance travelled and energy consumed. This document presents how VTI's sensing technology enables inertia measurement to be carried out in walking related applications.

Applications

Hand-held sports and wellness applications measure speed, energy consumed or distance travelled during exercise. These features can be carried out by accelerometers and, often, tri-axial measurement provides the most accurate result.

Portable navigation devices use dead reckoning based on motion information. Distance measurement combined with direction information e.g. from an electronic compass, can be used for assisting GPS positioning when signals from satellites are not available.

Solution

Measuring walking distance accurately by integrating continuous longitudinal acceleration is difficult due to errors coupled to acceleration signal over time. In order to reduce such errors, time and acceleration measurement of walking can be divided into steps. Steps cause a periodic movement of a human hip as in Figure 1. Length of a single step (l) can be integrated from angular velocity of the hip's arc shape profile. Vertical z- axis acceleration of the hip and effective length of a leg defines the angular velocity and thus velocity walked (v), length of the step (l), total distance walked (S) and energy consumed (dW / ds) can be calculated by:

$$v = \text{Velocity walked} = \sqrt{h} \times \sqrt{(1g - a_{z\,\min})} \qquad \text{formula 1}$$

$$l = \text{Length of a single step} = T \times v = (T_{1\,step\;n+1} - T_{1\,step\;n}) \times v \qquad \text{formula 2}$$

$$S = \text{Distance walked} = \sum_{i=2}^{n} l_i = \sum_{i=2}^{n} (T_i - T_{i-1}) \times v_{i-1} \qquad \text{formula 3}$$

$$dW / ds = \text{Energy consumption per walked meter} = \frac{m}{8} \times v^2 \times \frac{l}{h^2} \qquad \text{formula 4 , where}$$

m = weight of the walker

T_1 = time of a step, when below 1 g vertical acceleration has been reached

h = effective length of a leg

$a_{z\,min}$ = minimum vertical acceleration of a hip

g = 9.81 m/s^2

The Figure 1. below shows the vertical acceleration caused by the dynamics of walking. The arc shape profile of the hip might vary between individuals.

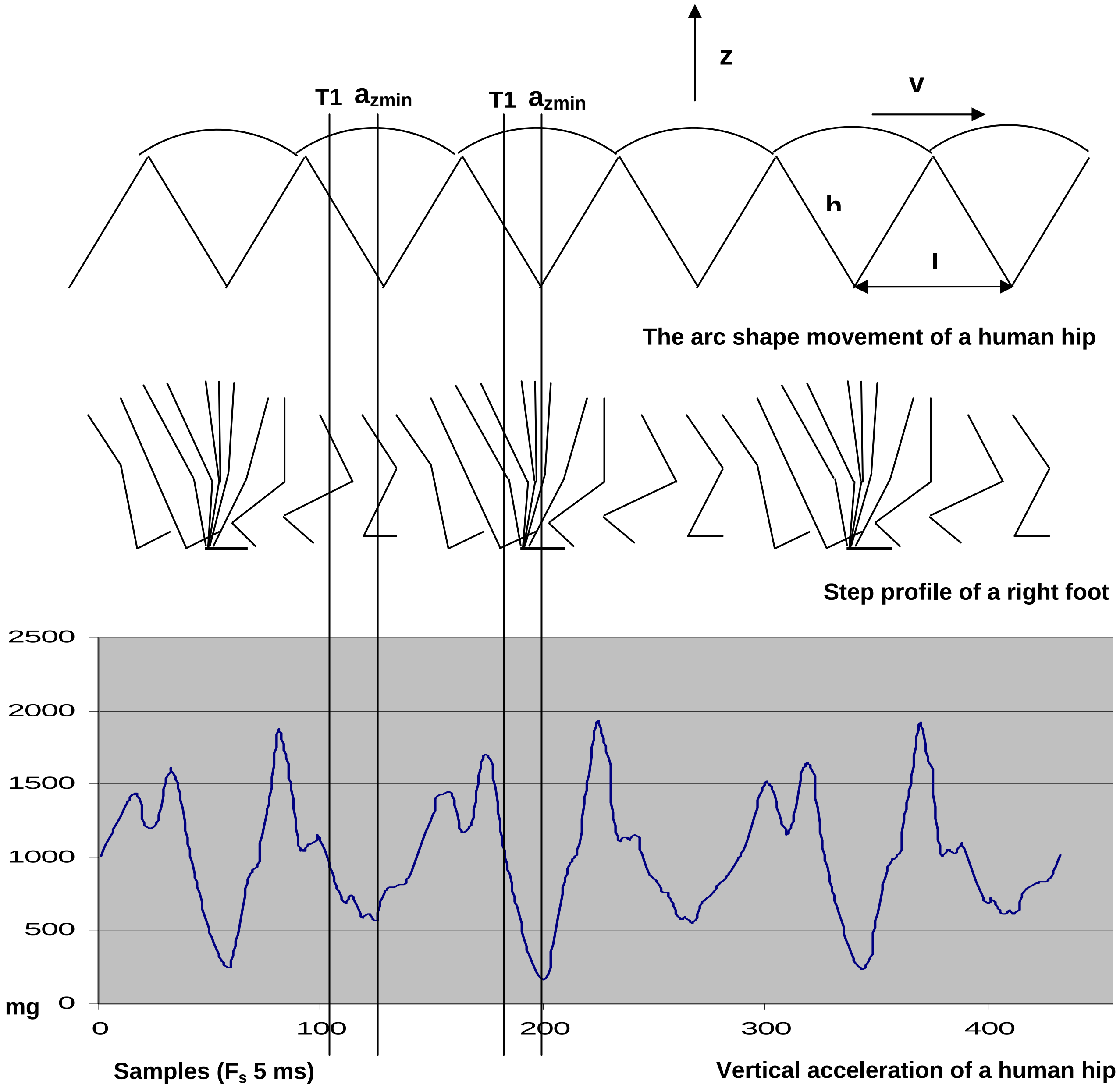


Figure 1. Vertical acceleration caused by the dynamics of walking

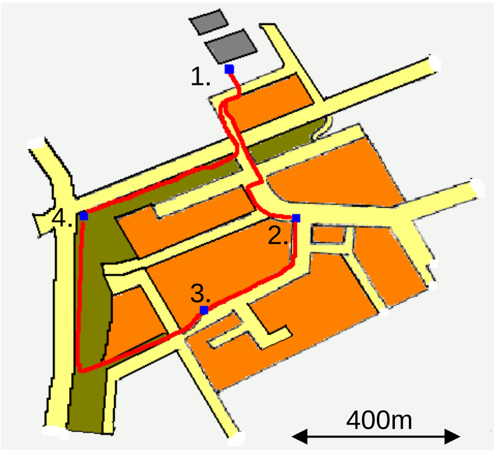
Results and the Test Set Up

The walked route (distance 1960 m measured by GPS) was started and returned to the point 1. as in the Figure 2. Sections 1 - 4. were recorded during the walk. The SCA3000 accelerometer was attached to the right side of the hip as in a pedometer style. Tri- axes acceleration data was captured. Vertical acceleration data was filtered by 10 samples, averaging. The sampling frequency was 10 ms. Following statements were assumed:

$$\sqrt{\sum(\bar{x}^2+\bar{y}^2+\bar{z}^2)} = 1g,$$

Average of z over time = $\bar{z}$ = 1g,

Effective length of the test subjects' legs were 0.90 – 1.02 m. Length of the test subjects' steps were between 30...100 cm yielded by Formula 2. The total error of the measuring results in the walked distance varied between +/- 3.4...+/- 15 % depending on the test subjects.



Section	GPS (m)	Algorithm(m)	Diff(%)
1	425	411	3.4
2	355	352	0.8
3	640	654	-2.2
4	540	551	-2.0

Figure 2. The walked route. The error of the most accurate measuring result was better than +/- 3.5 %.

Benefit of the SCA3000 in distance measurement

A single-axis motion sensor used for the distance measurement is sensitive to its orientation. If the single-axis sensor is tilted during exercise, the measuring direction of the sensor deviates from the vertical direction. This reduces the accelerometer's sensitivity in the vertical direction and causes error to the measuring result. An end-user device incorporating the SCA3000 accelerometer is not sensitive to its orientation, because a resultant of the three measuring axes defines the vertical direction by gravity of earth regardless of the axes' orientation.

The SCA3000 3-axis accelerometer component has a ring buffer option and other built-in measuring modes for detection free fall and on-off motion, which help to support the incorporation of different motion based features to an end-user device. More information about these features can be read from SCA3000- Product Family Specification available on the Internet at www.vti.fi.

Use of the Ring Buffer Feature in a Pedometer Application

The ring buffer is a built-in memory for the SCA3000 accelerometer that captures measured data and releases it frequently. This feature saves the processing capacity of e.g. a cell phone's MCU for other features. Using a narrow band mode (50 Hz sample rate) and decimation by 4 (12.5 Hz sample rate), the ring buffer can store data for approximately 15 seconds.