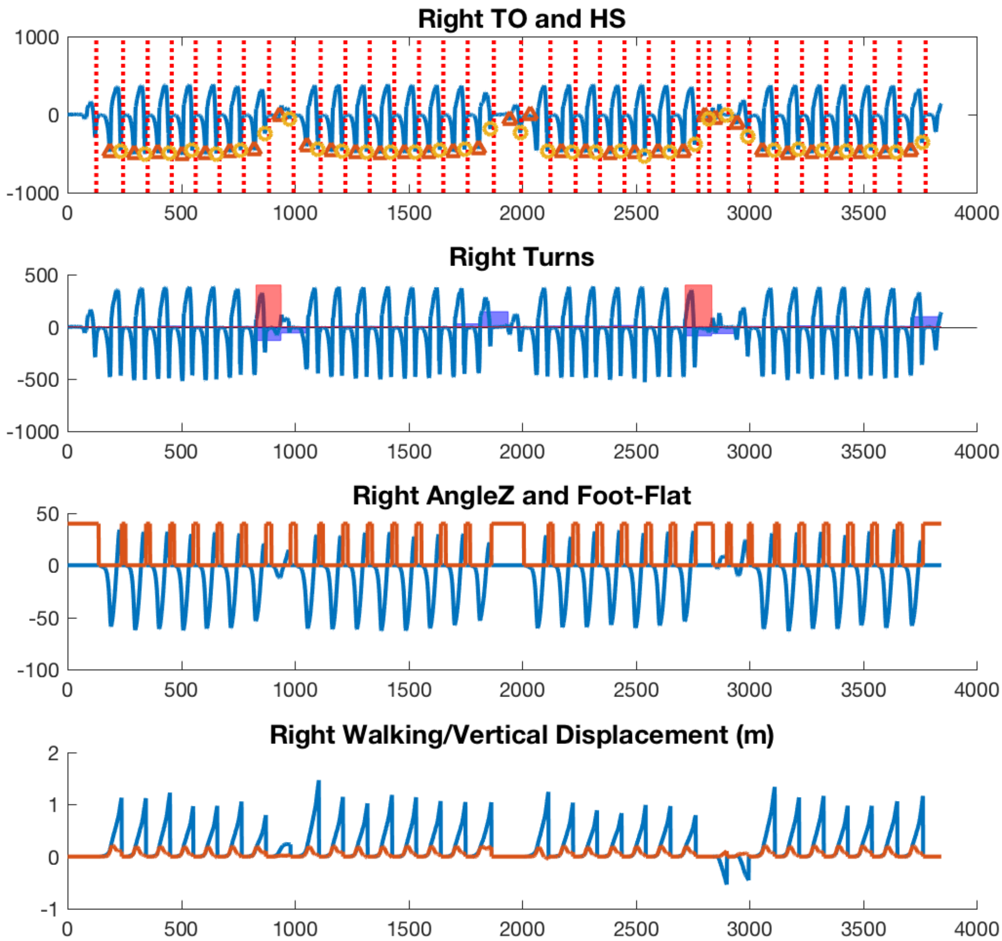

Figure 1: HS, TO, turn, FF and displacement detection

In the Heel Strike (HS) and Toe-off (TO) detection algorithms, only 3-axis gyroscope signals are used. First, z-axis gyroscope signal is smoothed using a Type-II Chebyshev band pass filter with cut-off frequencies 0.5 Hz and 12 Hz, because, as described in [1], human motion has no effect on frequencies that are significantly above 10 Hz. Secondly, a DTW-bad gait cycle detection algorithm is applied to the smoothed z-axis gyroscope signal to extract gait cycles. Sliding window based Dynamic Time Wrapping algorithm is able to maximumly reduce the effect of the high variability in walking speed and stride length. After removing misclassified gait cycles, HS and TO in each gait cycle can be detected as shown in the first graph in Fig. 1. Next, right and left turns are detected by subtracting mean energy of y-axis gyroscope signal from that of x-axis gyroscope signal in each gait cycle. If the energy difference is higher than a predefined threshold value, that gait cycle is a turn. Foot-Flat (FF) events are detected by a sliding-window-based cut-off corner detection algorithm, which is applied between HS and TO. According to [2], it is unlikely to accurately estimate displacement by direct double integration of accelerometer alone, because of the offset bias and drifting effect in gyroscope readings. In our algorithm, displacement is estimated by double integrating the acceleration in walking direction only. Therefore, angles in z-axis, θ_Z, has to be estimated to decompose accelerations in y-axis and z-axis. As gait cycles and FF timing are available, θ_Z can be the integral of gyroZ signal between the end of the previous FF to the start of the current FF as shown in the third graph in Fig. 1. The reset at each FF reduces the bias and drift in gyroscope signals to a certain degree, however, as there is no ground truth available at the time, it is difficult to estimate the accuracy of the algorithm. As indicated in Fig. 2, acc_{x1} and acc_{x2} are the components of the acceleration in the horizontal plane, $acc_{horizontal}$, and they can be calculated using

$$acc_{horizontal} = acc_{x1} + acc_{x2}$$

$$acc_{x1} = acc_X cos(\theta_z)$$

$$acc_{x2} = acc_Y cos(\theta_z)$$

where acc_X and acc_Y are acceleration signals in device x-axis and y-axis. Similarly, the acceleration in vertical plane, $acc_{vertical}$, can be calculated using

$$acc_{vertical} = acc_{y1} + acc_{y2} - g$$

where g is the gravity and

$$acc_{y1} = acc_X sin(\theta_z)$$

$$acc_{y2} = acc_Y sin(\theta_z)$$

Then $acc_{walking}$ can be calculated using

$$acc_{walking} = acc_{horizontal} cos(\gamma)$$

where γ is the angle between the walking direction and foot orientation, which is assumed to be 30 degrees for all the subjects. Finally the displacement in walking direction can be estimated as the double integration of $acc_{walking}$, while the displacement in vertical direction is the double integration of $acc_{vertical}$.

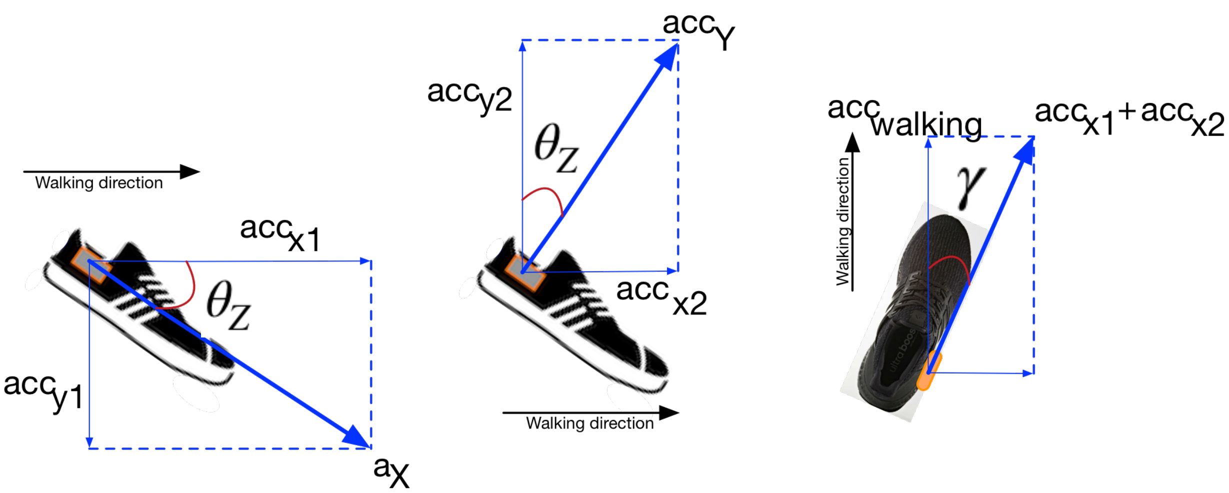

Figure 2: Acceleration decomposition

Bibliography

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[2] Shimmer. (2016). *Shimmer3 IMU User Guide Revision 1.4*. Available: http://www.shimmersensing.com/images/uploads/docs/IMU_User_Guide_rev1.4.pdf