# Wearable Sensors in Ecological Rehabilitation Environments


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## Technology for Rehabilitation

**Ecological Environments**

Patients with neurological or musculoskeletal injuries often receive inpatient rehabilitation services to regain independence in mobility and activities of daily living. Simulated environments promote functional independence by providing ecological context to therapy.

**The Need for Mobility Assessment Tools**

Therapists use experience to qualitatively assess progress. Since human movement is complex, quantifying mobility details throughout rehabilitation provides more information and insights than human observation alone.

**Proposed Technological Solution**

Wireless inertial sensors provide movement data, are relatively inexpensive, do not interfere with natural movement, are portable, and integrate well with smartphone platforms.

## Wireless Sensor Platform

**Three Shimmer3 Inertial Measurement Units (IMU)**

- www.shimmersensing.com
- Bluetooth communication and SD card logging
- Sampling rate set to 51.2 Hz

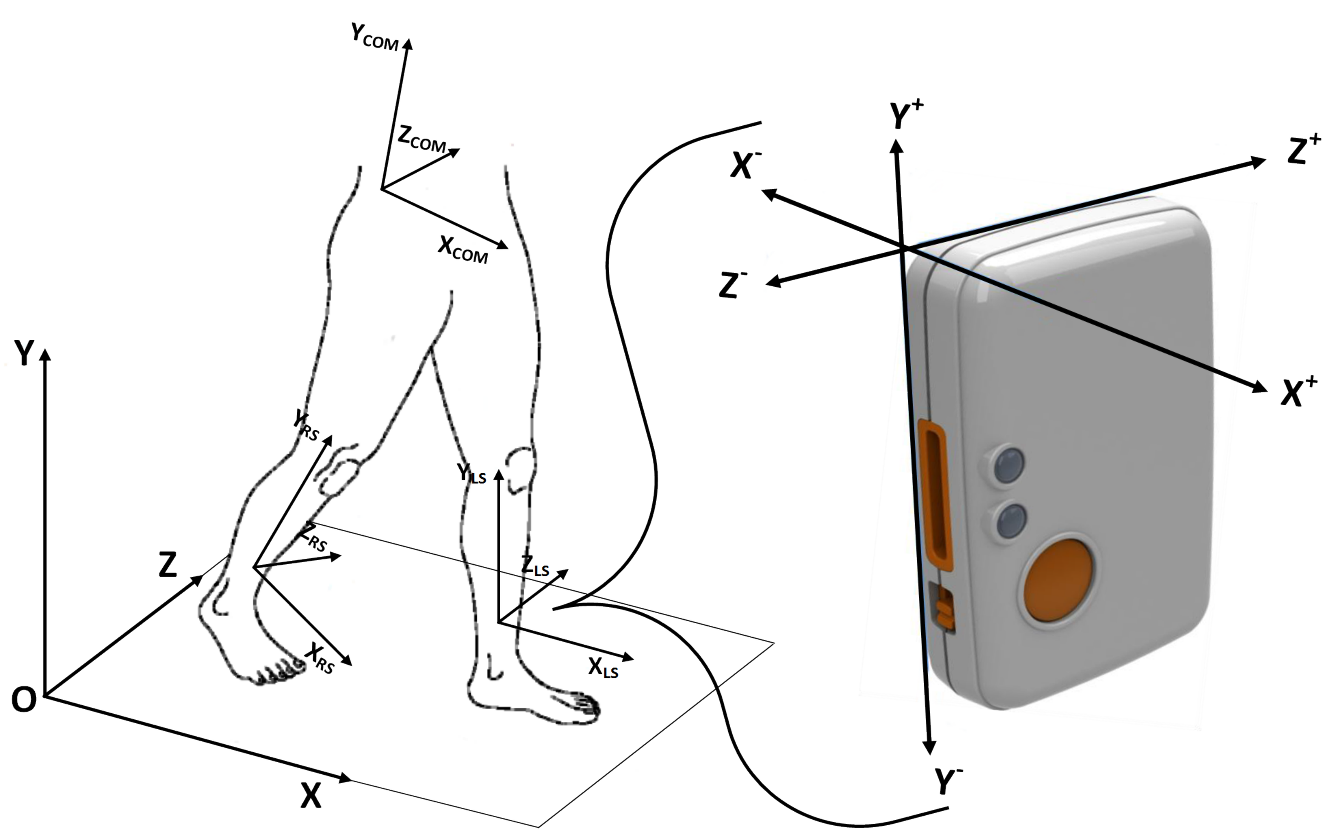


**Figure 1. Sensor Placement.** Sensor units were mounted on the center of mass (COM), left shank (LS), and right shank (RS). Axes are aligned to standardized axes orientations of the International Society of Biomechanics [1].

**Tri-axial Accelerometer**

- Measures acceleration m/s$^2$
- COM range: ± 2g
- Shank range: ± 4g
- 1g = ~9.8 m/s$^2$

**Tri-axial Gyroscope**

- Measures angular velocity in deg/sec
- COM range: 250 deg/sec
- Shank range: 500 deg/sec


**References:** [1] Wu and Cavanagh, 1995. [2] Chen, 2013. [3] Salarian et al, 2004. [4] Greene et al, 2010. [5] Tao et al, 2012.


## Experimental Design

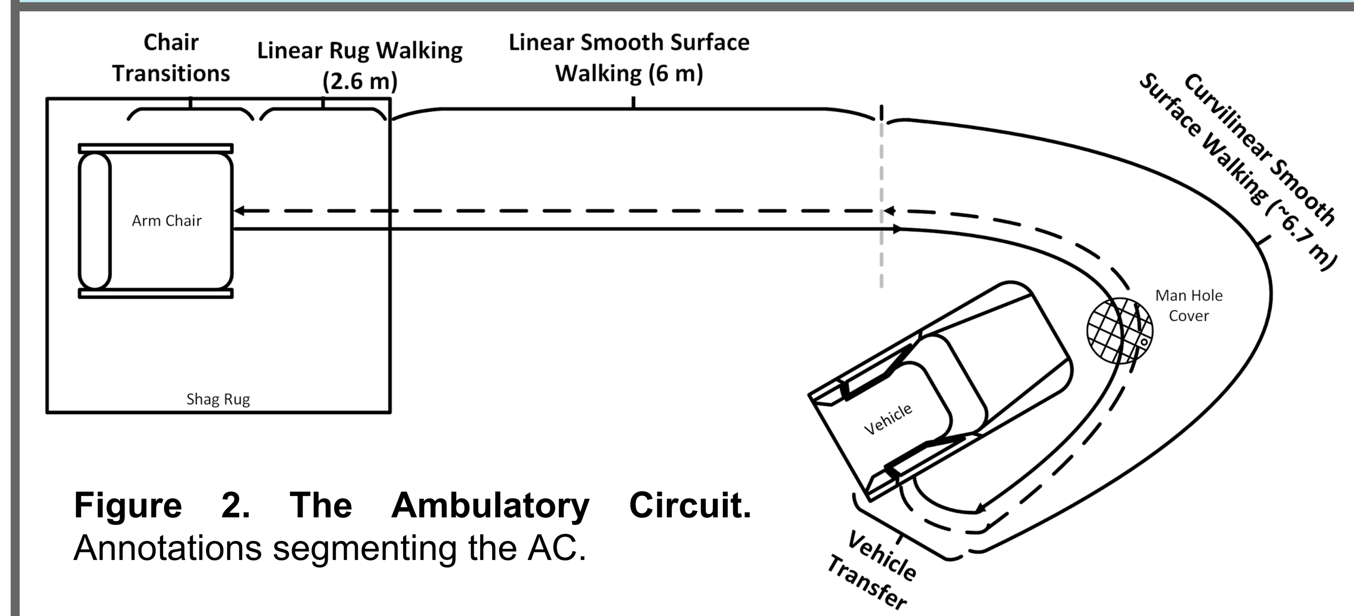


**Figure 2. The Ambulatory Circuit.** Annotations segmenting the AC.

Participants in the study performed an ambulatory circuit (AC) in an indoor, simulated community at St. Luke's Rehabilitation Institute (SLRI) in Spokane, WA. The AC consists of rising from a chair in a hotel lobby, walking to the passenger side of an SUV, and transferring into the vehicle. Once loaded, the participant transfers out of the vehicle, returns to the chair, and sits down.


**Figure 3. Sensor Signals Recorded During AC.** The COM (top figure: accelerometer) and shank (bottom figure: gyroscope) sensor signals were analyzed to quantify the rehabilitative progress.

## Quantitative Changes Exhibited

Ecological data collection occurred in two testing sessions consisting of two separate AC. The first test session (S1) was conducted shortly after the participant was physically able to perform the AC. The second test session (S2) was conducted one week later.

Figures 4-6 show select metrics quantifying ambulation. The data collected from a reference population are denoted with REF. As illustrated by the absence in S1, S2, and REF distribution overlaps, IMUs are suitable for distinguishing between the healthy and patient populations.

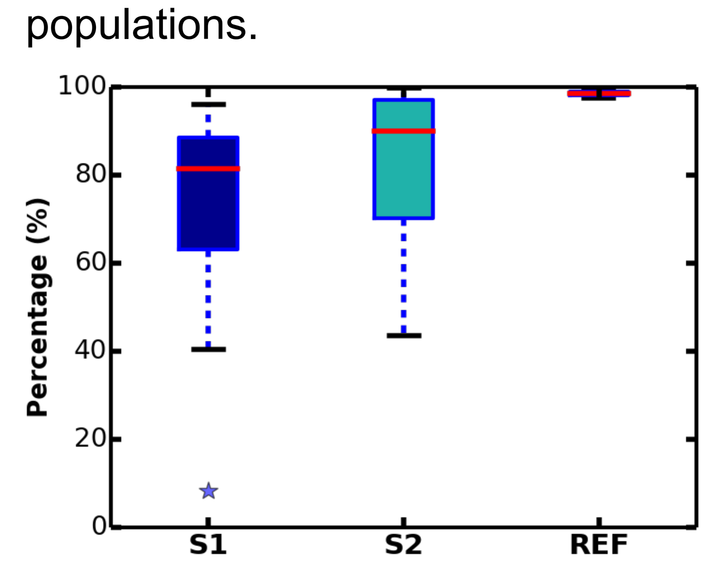


**Figure 4. Step Symmetry Results.** The metric indicates the step consistency while walking. Participants show improvement between S1 and S2.

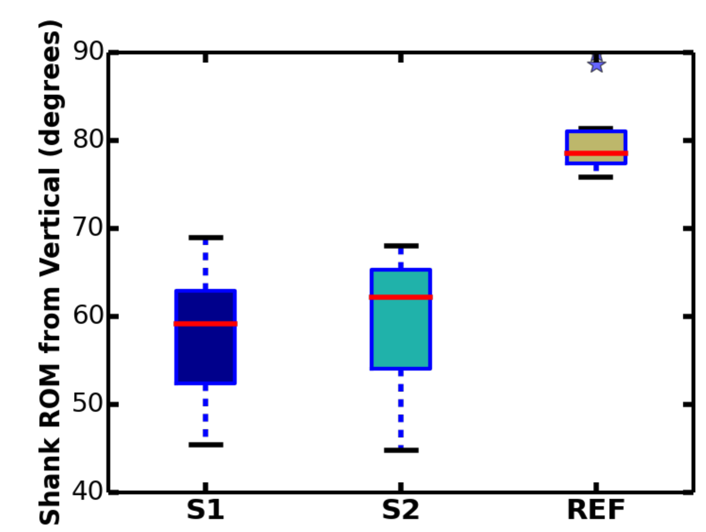


**Figure 5. Shank Range of Motion Results.** The metric is an indicator of joint mobility. The reference group is characterized by a lower variability.

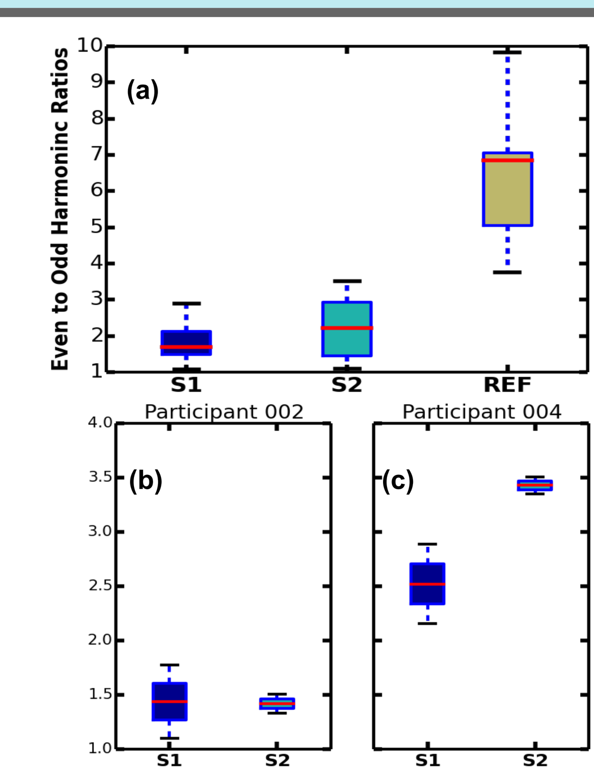


**Figure 6. Smoothness Index Results.** Computed as a ratio of even to odd harmonics in the frequency domain. (a) All participant trials compared to REF. (b and c) individual participants from S1 to S2. (b) shows little change between S1 and S2 while (c) shows substantial improvement.

## Data Processing Overview

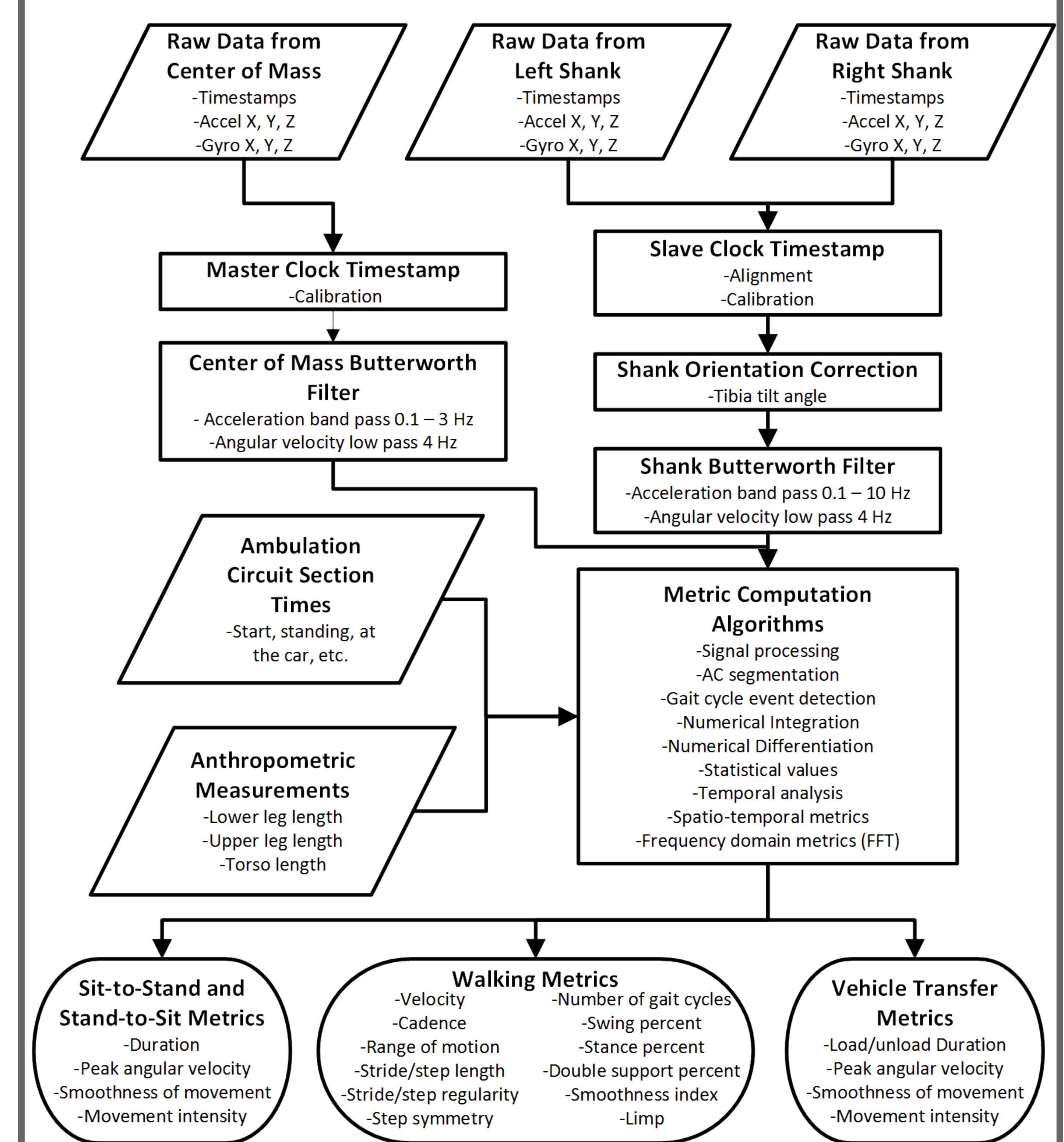


**Figure 7. Signal Processing.** Sensor data were aligned, oriented [1], filtered, and segmented prior to computing AC metrics [2,3,4]. Processing algorithms were implemented using Python and Java.

## Towards Continuous Monitoring

The ecological monitoring system has multiple possibilities for the advancement of mobile healthcare technology:

- Synthesized environmental context for pervasively collected data
- Continuous post-care monitoring and assessment
- Real-time feedback to the patient and physician
- Performance tracking and evaluation of trends over time
- Integration with mobile technology for preventative care
- Encouragement for patients to engage in therapeutic activities


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