Using Inertial Sensors to Quantify Changes Exhibited During Rehabilitation

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Technology for Rehabilitation

Simulated Environments

After stroke or injury, patients struggle with 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. At inpatient facilities, patients are rarely mobile on admission. Since human motion is complex, quantifying mobility details throughout rehabilitation provides more information and insights than human observation alone.

Proposed Technological Solution

Wireless inertial sensors are a technology especially suitable for quantitatively tracking mobility in simulated environments. The sensors provide movement data, are relatively inexpensive, do not interfere with natural movement, are quite portable, and are easy for non-technical staff to use.

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

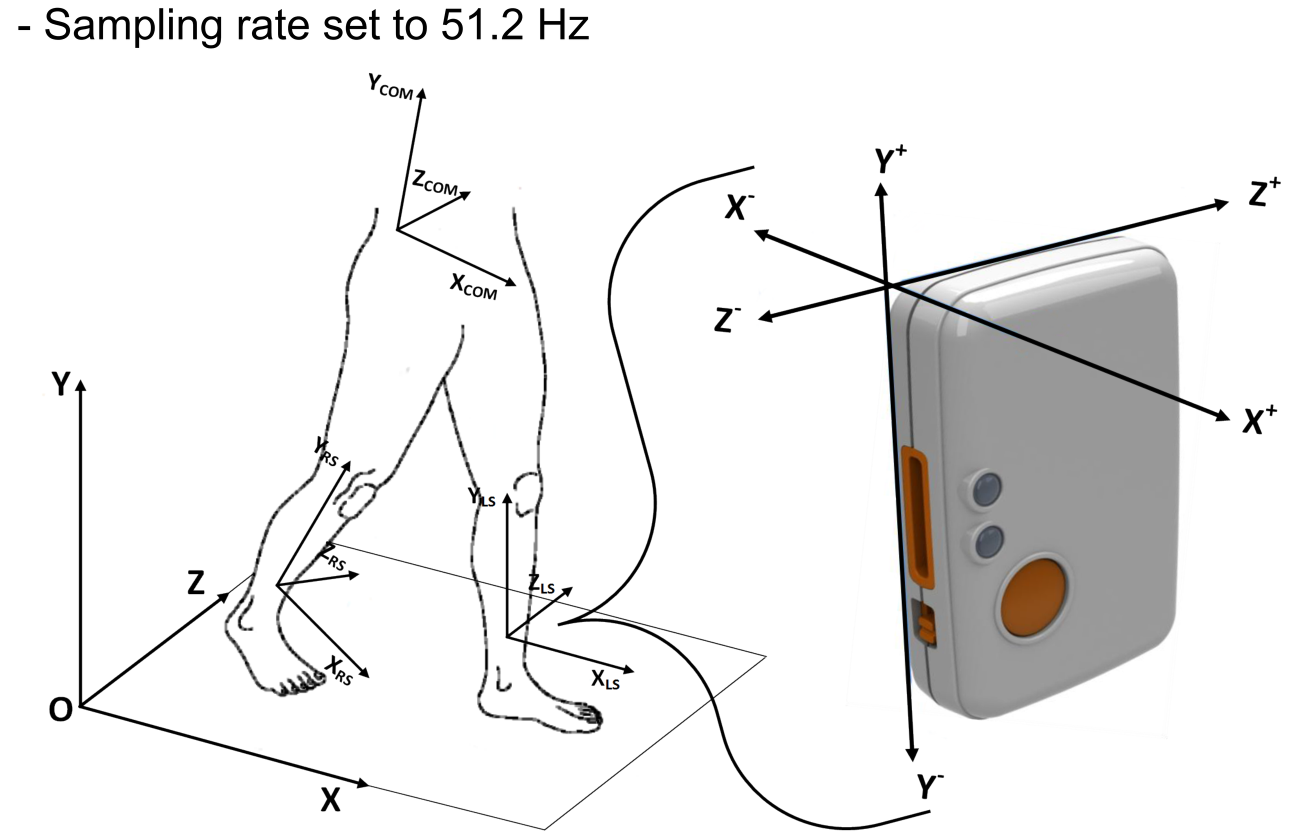

Figure 1. Sensor Placement. Sensor units were mounted on the center of mass (COM), left shank (LS), and right shank (RS). The figure is enlarged to show axes aligned to standardized axes orientations of the International Society of Biomechanics [1].

Tri-axial Accelerometer

- Measures acceleration in 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

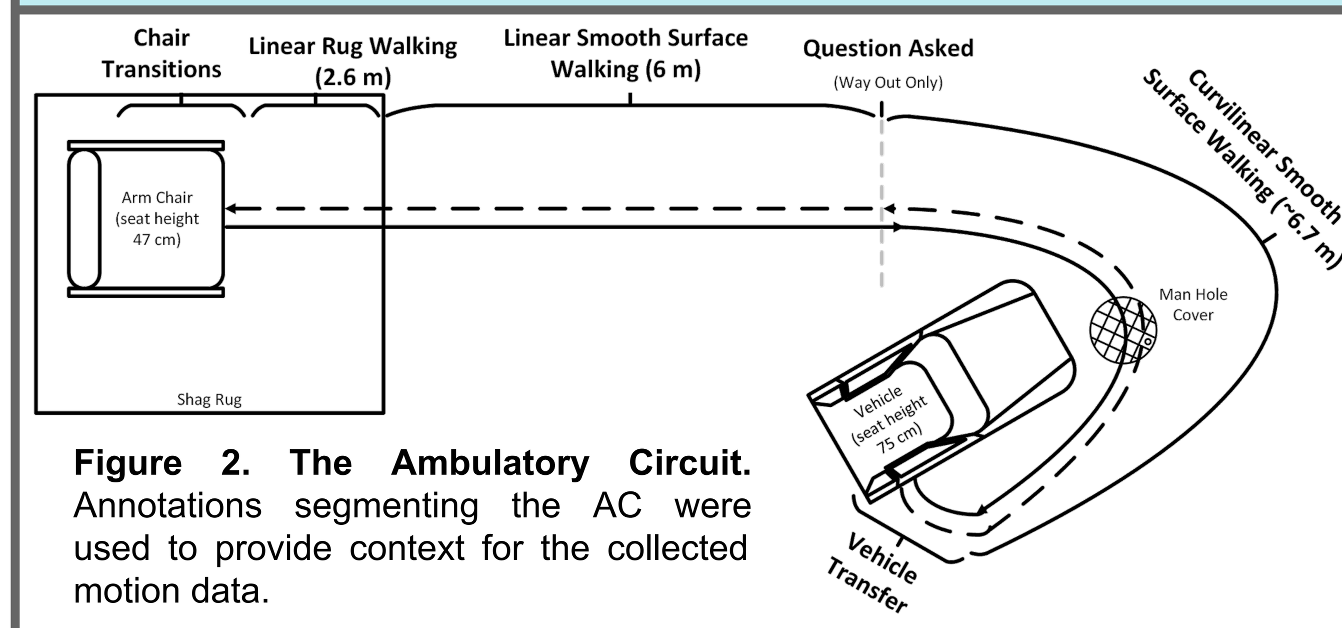

Figure 2. The Ambulatory Circuit. Annotations segmenting the AC were used to provide context for the collected motion data.

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 and 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

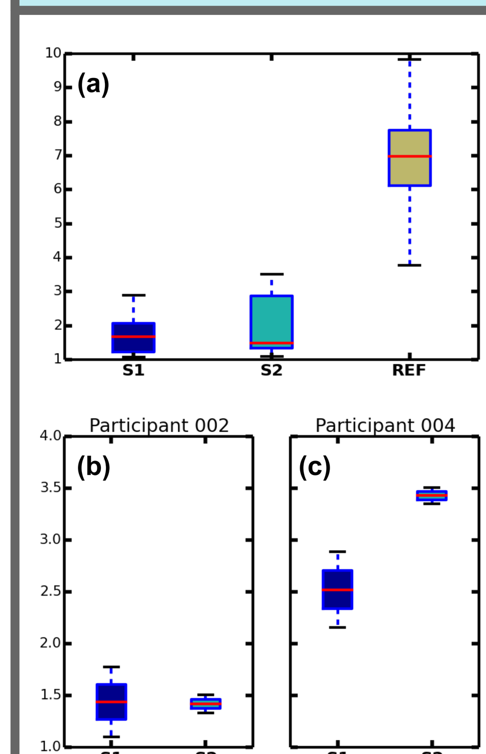

Figure 4. Smoothness Index Metric Results. (a) All participant trials compared to a reference control group. (b and c) individual participants from S1 to S2. (b) shows little change between S1 and S2 while (c) shows substantial improvement.

Data were collected on the AC from participants receiving inpatient rehabilitation at SLRI. Data collection occurred in two testing sessions. Each testing session consisted of two separate trials on the AC. Minimum recovery requirements to qualify for Session 1 (S1) testing included: a Mini-COG score above zero, aptitude for safe ambulation, and informed consent. Session 2 (S2) testing was conducted following a one week inpatient therapy course.

Preliminary data suggest that changes exhibited by individuals as a result of rehabilitation can differ dramatically (Figure 4). The large intersubject variability is grossly overshadowed when comparisons include a reference control group (Figure 4a and Figure 5). These results demonstrate that the current platform is sufficient for identifying injury related deficits in movement.

For some metrics, a change in variance may have a stronger correlation to progress during rehabilitation than the metric itself (Figure 6). This would indicate that consistency in performance is closely related to the recovery progress.

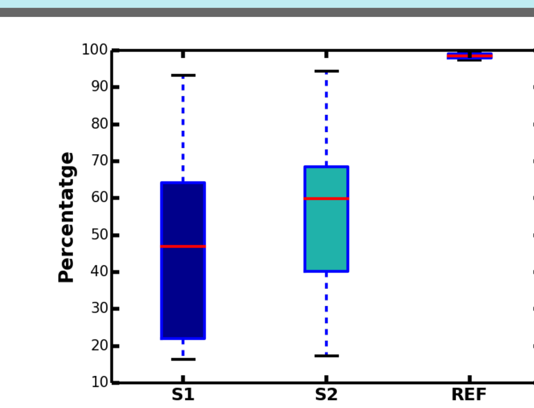

Figure 5. Stride Regularity Metric Results. All participant trials during S1 and S2 compared to a reference control group.

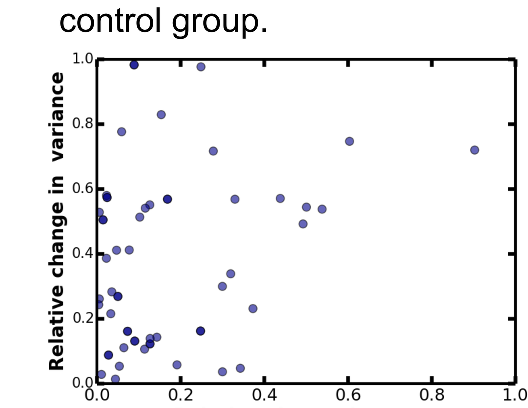

Figure 6. Mean Versus Variance for All Metrics. Relative change in metrics and their variance for all participants between S1 and S2.

Data Processing Overview

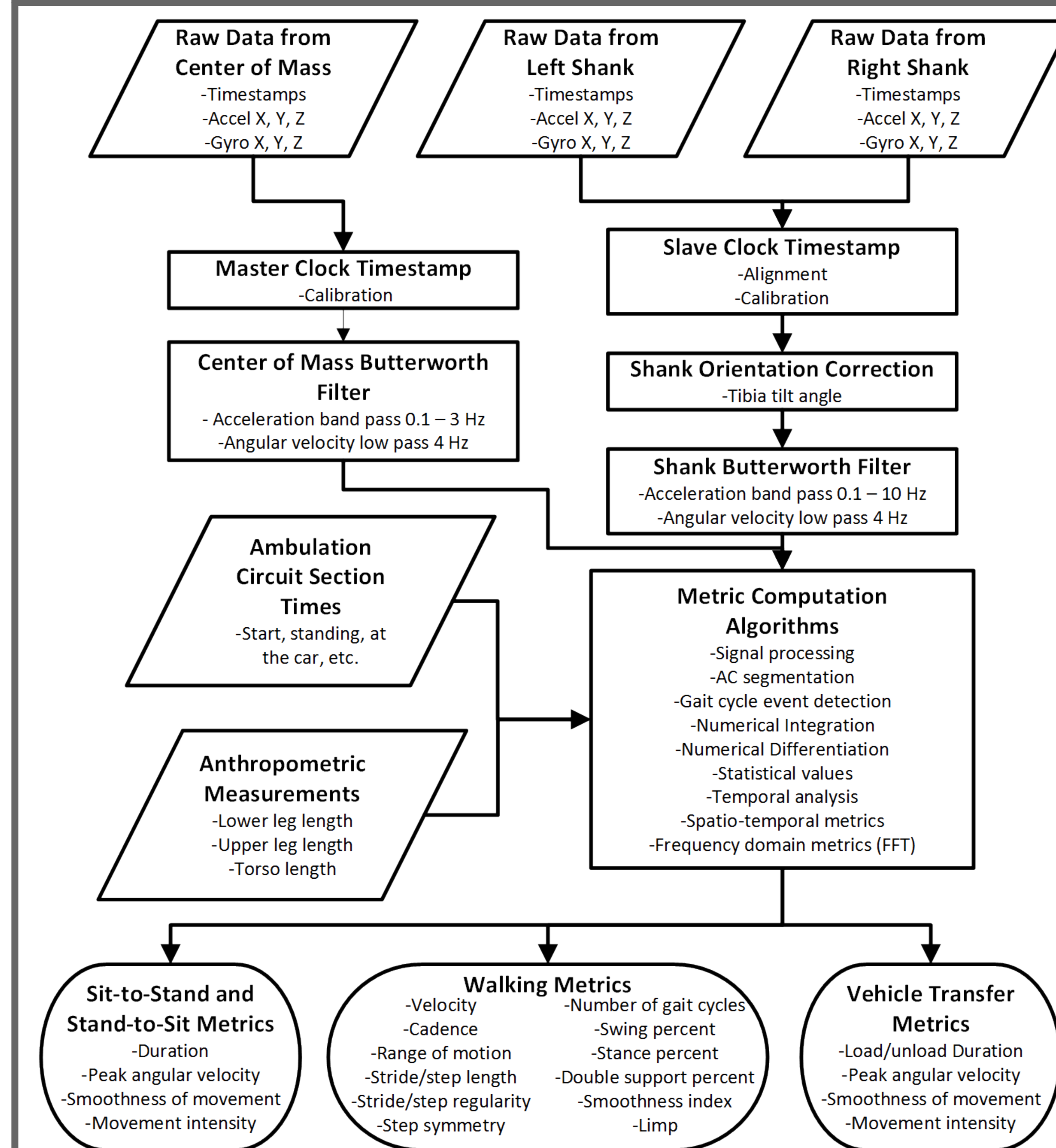

Figure 7. Signal Processing. Sensor data were aligned, oriented [1], filtered, and segmented prior to computing AC metrics [2,3,4]. Processing algorithms were implemented using Python and Java.

Clinical Relevance

The preliminary results with wireless sensors provide recovery information beyond the traditional clinical evaluation. This information can be utilized to make decisions about therapy, evaluate responsiveness to therapeutic regimens, and justify third party reimbursements for therapy units.

Our collaboration with researchers and physical therapists at SLRI in the future aims to:

- Better understand how underlying injuries affect recovery
- Synthesize the environmental context with the sensor data
- Develop therapeutic feedback to impact recovery by:
  - Motivating patients with progress tracking
  - Communicating the detected deficits to:
    - Encourage patients to engage in therapeutic activities
    - Help patients conceptualize movement strategies
- Utilize additional modules within the simulated community

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