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A Reference Data Set for the Study of Healthy Subject Gait with Inertial Measurements Units

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Abstract

This article provides a comprehensive description of a dataset consisting of 110 multivariate gait signals collected using three inertial measurement units. The data was obtained from a sample of 19 healthy subjects who followed a predefined protocol: standing still, walking 10 meters, turning around, walking back, and stopping. One notable aspect of this dataset is the inclusion of extensive signal metadata, including the start and end timestamps of each footstep, along with contextual information for each trial. Part of this dataset was previously used to develop and assess a gait event detection algorithm [Voisard et al., Automatic Gait Events Detection with Inertial Measurement Units: Healthy Subjects and Moderate to Severe Impaired Patients], and as a reference for a multidimensional tool in gait quantification [Voisard et al., Innovative Multidimensional Gait Evaluation using IMU in Multiple Sclerosis: introducing the Semiogram].

Source Code

The source code contains the signals and metadata of the data set described in this article, together with python code snippets to read them. It has been made available on the web page associated with the article[1]. The web page also provides an online demo for the visualization of the dataset. Usage instructions can be found in the `README.md` file within the archive.

Keywords: gait analysis; biomedical dataset; reference dataset; wearable inertial sensors; inertial measurement unit

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1 Introduction

Gait analysis using inertial measurement units (IMUs) is a relatively recent practice that is gaining increasing importance in the field. It allows for the measurement and evaluation of human locomotion characteristics. The analysis of gait patterns using IMUs provides valuable insights into various aspects of walking and has the potential to greatly impact clinical assessments and treatment strategies [6, 2].

There is currently no consensus on the optimal placement of sensors during gait analysis [8]. Various locations, such as the lower back, ankle, dorsal side of the foot, lower limbs, and arms, have been considered. Researchers have explored different sensor configurations to capture gait data accurately. The choice of sensor placement depends on the specific research objectives and the variables of interest.

Sharing databases of gait analysis is essential for both healthy and pathological populations. In healthy populations, it allows for the understanding of the mechanisms and dynamic behaviors of human locomotion, comparing algorithms in healthy individuals, validating algorithms, and establishing normative values as reference points. In pathological populations, sharing databases allows for the validation of analysis algorithms on impaired gait, quantitatively describing the evolution of various gait aspects across cohorts, and promoting collaboration among different research groups.

Several databases have already been referenced, in both open and closed environments [7, 4, 5]. In this way, step detection algorithms can be easily evaluated [3]. The most similar database to the one we are publishing in terms of protocol and the richest in terms of recording hours (1020 multivariate gait signals) has been published in 2019 [9]. The data in this database were acquired with a sensor on each foot. Since then, the literature has shown the importance of a sensor at the trunk level, which appears to be crucial for performing a gait analysis that includes the most clinically relevant parameters [10].

To facilitate the reproducibility of our research and enable other research groups to benefit from our findings, we are sharing a new gait database in this article. This database consists of gait data obtained from a 10-meter test with u-turn conducted during medical consultations with individuals who did not report any walking-related pathologies. The database comprises 110 recordings from a total of 19 subjects.

2 Data Acquisition

2.1 Participants

Participants were consecutively recruited from June 2018 to September 2018, from the hospital and research unit staff of Percy Hospital (Clamart, France). The inclusion criteria required that participants had not reported any falls within the 5-year period prior to inclusion and had to be free from any diseases or conditions that could impact their walking ability. A clinical examination conducted by medical doctors, who were among the investigators, confirmed the participants' overall health. Prior to inclusion, all participants provided written informed consent. The study protocol adhered to the principles outlined in the Helsinki Declaration and received approval from the Ethics Committee "Protection des Personnes Nord Ouest III" (ID RCB: 2017-A01538-45). All participants were followed for 12 months. A total of 19 subjects (7 males and 12 females) participated in the presented dataset. Detailed characteristics of the participants can be found in Table 1.

Characteristics	Values
Sex (M/F)	12/7
Age (years)	51 (17)
Height (m)	1.71 (0.06)
Weight (kg)	71.7 (14.3)
Body mass index (kg/m^2)	24.3 (4.3)

Table 1: Baseline characteristics of healthy subjects. Mean (SD) are given. Data for 3 subjects are partially missing.

2.2 Protocol and Equipment

2.2.1 Sensor Placement

The subjects were equipped with 3 inertial sensors: one on each foot and one on the lower back at the level of the fifth lumbar vertebra. The sensors used for the trunk and feet were MTw Awinda XSens® (weight 16 g, dimensions 47 mm × 30 mm × 13 mm, sensitivity ± 2000 deg/s and ± 160 m/s2, XSens® Technologies, Enschede, the Netherlands). All three sensors were time-synchronized with the Awinda Recording and Docking Station to within 10 μs. The sensor acquisition frequency was set at 100 Hz.

The placement of the sensors and the orientation of the axes in space are indicated in Figure 1A.

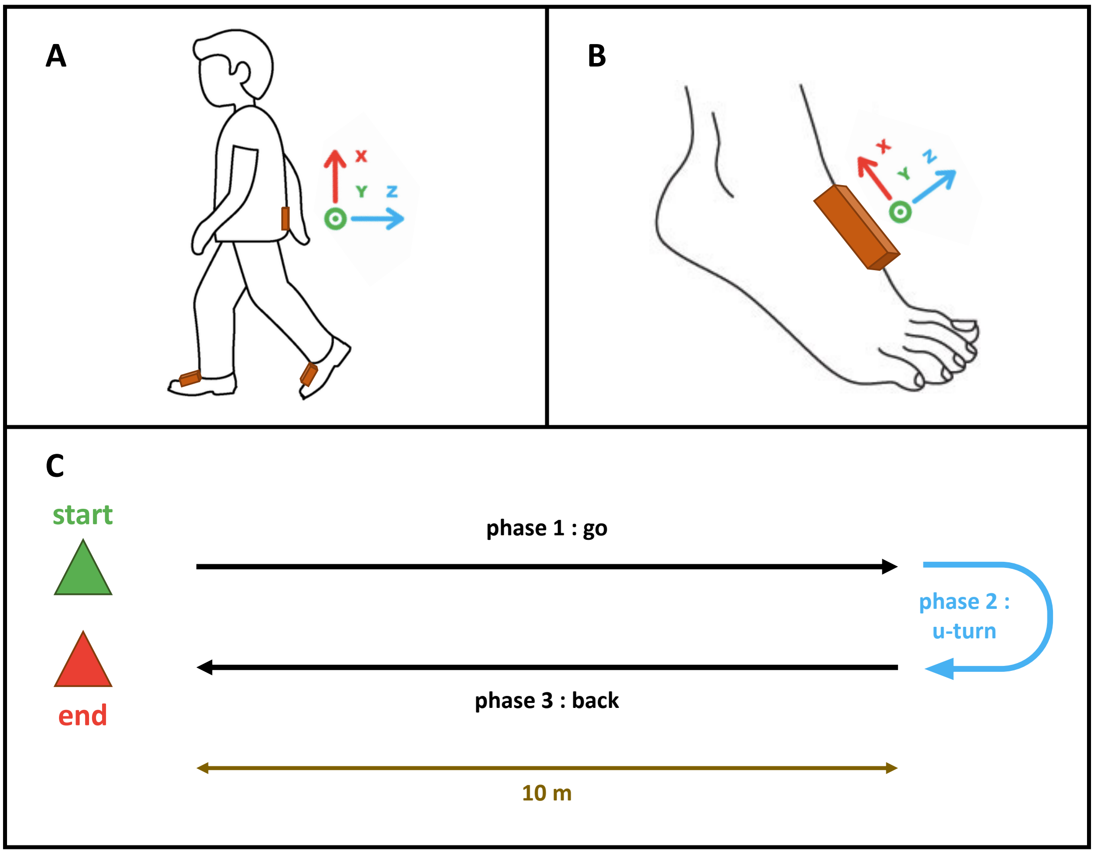

Figure 1: Experiment protocol. A: Position of the sensors using Velcro bands: one sensor on each foot, one sensor in the lower back (vertebra L5); B: Position of the inertial sensor on the dorsal part of each foot; C: Gait trial: 10-meter walk test with a U-turn.

2.2.2 Gait Evaluation Test

The conducted gait test consisted in a 10-meter round trip with a u-turn. The testing location was sufficiently wide to allow the patient to walk without obstacles and perform the turnaround.

2.2.3 Test Protocol Instructions

The instructions given to the patient were the following:

- Wait for approximately 6 seconds in a static standing position after starting the recording, facing the walking test location, until the operator's signal;
- Walk 10 meters at a comfortable and habitual pace ;
- Perform a u-turn within the designated area, without being concerned about slightly stepping outside of it;
- Return to the starting point at a comfortable and habitual pace;
- Wait on the finish line for 2 seconds before the operator's signal and the sensors stop.

Each participant performed between 4 and 6 recordings of the 10-meter round-trip walking test.

3 Data Description

This section provides a comprehensive description of the collected data, which consists of time series data accompanied by relevant metadata. The data format is also explained in detail.

3.1 Data Format

Files are identified by their **filename**, which associates the number dedicated to the subject and the number of the trial. The filename for the third trial of the second subject is 2-3. For each trial, 4 files are provided : 3 files in the **.txt** format corresponding to the 3 inertial sensors, 1 file in the **.json** format corresponding to the metadata. To properly identify them, the suffixes of each are the following:

- For the trunk sensor: **[filename]_lb.txt**;
- For the right foot sensor: **[filename]_rf.txt**;
- For the left foot sensor: **[filename]_lf.txt**;
- For the metadata: **[filename]_meta.json**.

3.2 Time Series

For each file corresponding to a sensor, the data consists of 10 columns, following the same naming format as shown below:

- **PacketCounter**: this column contains the time samples, with an acquisition frequency of 100Hz;
- **Acc_X, Acc_Y, Acc_Z**: these three columns contain the values of acceleration or gravity-free acceleration along each of the three axes in the sensor's reference frame;
- **Gyr_X, Gyr_Y, Gyr_Z**: these three columns contain the values of angular velocity along each of the three axes in the sensor's reference frame.
- **Mag_X, Mag_Y, Mag_Z**: these three columns contain the values of magnetic field along each of the three axes in the sensor's reference frame.

An example of a data mask is given in Figure 2. The accelerations are provided in m/s^2, while the angular velocities are given in deg/s, both with a six-digit numeric precision.

PacketCounter	Acc_X	Acc_Y	Acc_Z	Gyr_X	Gyr_Y	Gyr_Z	Mag_X	Mag_Y	Mag_Z
0.0	3.552714e-14	2.220446e-16	1.154632e-14	-0.003527	0.005281	0.000665	-0.289795	0.073486	-0.801758
1.0	3.552714e-14	2.220446e-16	1.154632e-14	-0.003527	0.005281	0.000665	-0.289795	0.073486	-0.801758
2.0	3.552714e-14	2.220446e-16	1.154632e-14	-0.003527	0.005281	0.000665	-0.289795	0.073486	-0.801758
3.0	3.552714e-14	2.220446e-16	1.154632e-14	-0.003527	0.005281	0.000665	-0.289795	0.073486	-0.801758
4.0	3.552714e-14	2.220446e-16	1.154632e-14	-0.003527	0.005281	0.000665	-0.289795	0.073486	-0.801758
...	...	...	...	...	...	...	...	...	...

Figure 2: Data mask for each file. This example file corresponding to a trunk sensor contains 10 columns. These 10 columns correspond to the: PacketCounter, Acc_X, Acc_Y, Acc_Z, Gyr_X, Gyr_Y, Gyr_Z, Mag_X, Mag_Y, Mag_Z.

3.3 Metadata

A number of metadata are provided with the signals. Firstly, the metadata include information related to the subject, coding of the recordings, and epidemiological characteristics.

1. **Subject** (from 1 to 19). The number of the subject.

2. **Trial** (from 1 to 6). The number of the trial.

3. **Filename**. Unique identifier for the trial, which determines the name of the files. It is equal to "Subject-Trial" (for instance, "10-2" for the subject n° 10 and the trial n° 2).

4. **Age** (in years).

5. **Gender**. Male ("M") or female ("F").

6. **Weight** (in kilograms).

On the other hand, we provide a proposition for the segmentation of gait through annotations of the u-turn and gait events for each foot. This includes the initial heel strike, marking the end of the swing phase, and the toe-off, marking the end of the stance phase. These detections are derived from two previously validated algorithms from the literature [1, 12], and the demonstration of their effectiveness is available [11]. All these detections were then manually checked. An example is given in Figure 3. Regarding the metadata, they are added to the list, and include the following information:

7. **UturnBoundaries**. List $[u_{start}, u_{end}]$ which corresponds to the time estimations of the start and the end of the u-turn phase.

8. **LeftFootEvents**. List $\left[\left[t_1^{left}, h_1^{left}\right], \left[t_2^{left}, h_2^{left}\right], \ldots\right]$ of final ground contact (Toe-Off, TO) and initial ground contact (Heel-Strike, HS) indexes of the gait events of the left foot.

9. **RightFootEvents**. List $\left[\left[t_1^{right}, h_1^{right}\right], \left[t_2^{right}, h_2^{right}\right], \ldots\right]$ of final ground contact (TO) and initial ground contact (HS) indexes of the gait events of the right foot.

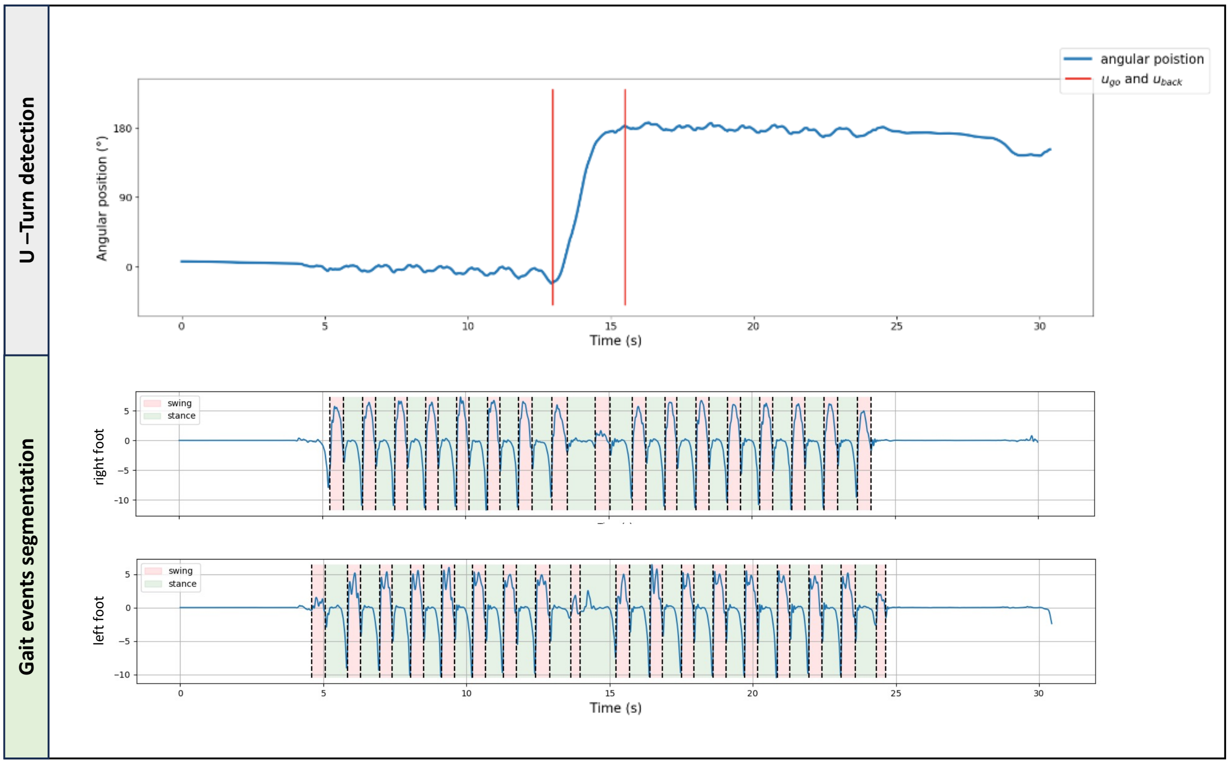

Figure 3: Example for gait segmentation. Top: segmentation of the u-turn (red dashed lines) from the angular estimation of the trunk sensor in the axial plane; Bottom: detection of the gait events (angular gyration in the sagittal plane is represented).

4 Conclusion

This article presents a comprehensive description of a dataset comprising 110 time series, accompanied by contextual metadata. The data was collected from 19 healthy subjects following a standardized protocol that can be easily adapted for routine clinical practice. This dataset serves as a valuable resource for testing and comparing clinical hypotheses, as well as evaluating the effectiveness of algorithmic procedures, such as step detection. The data is available in universal file formats (JSON and TXT) to facilitate accessibility and usage.

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