GaitAnalysisDataBase – Short Overview

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Abstract: The paper presents our public GaitAnalysisDataBase (http://gaitanalysis.th-brandenburg.de), which contains 3D walking kinematics and muscle activity data from healthy adults walking at normal, slow or fast pace on the flat ground or at incremental speeds on a treadmill. The acceleration, angular velocity and magnetic rate vectors are measured using XSens MTw sensors attached to both feet, shanks, thighs and the pelvis. EMG recordings are acquired using PLUX sEMG sensors applied at various leg muscles. The paper gives not only a detailed description of the data base and the terms (scenario, proband, experiment and trial), but also an overview about the experimental setup, the acquisition of data and procedure of the experiments, data processing and evaluation.

1 INTRODUCTION

This GaitAnalysisDataBase (http://gaitanalysis.th-brandenburg.de) contains 3D walking kinematics and muscle activity data from healthy adults walking at normal, slow or fast pace on the flat ground or at incremental speeds on a treadmill. The acceleration, angular velocity and magnetic rate vectors are measured using XSens MTw sensors applied to both feet, shanks, thighs and the pelvis. EMG recordings are acquired using PLUX sEMG sensors applied at various leg muscles. The data sets include not filtered, gravity compensated kinematic data, transformed into the world coordinate system of Xsens sensors and unprocessed raw data of PLUX acceleration and sEMG sensors.

Since about seven years Gait Analysis is a topic of research and education at the Department of Medical Informatics at the Brandenburg University of Applied Sciences (THB). Students and professors, technicians and researchers have been involved in the process of preparing and executing measurements as well as in storing and evaluating the acquired data. All these volunteers – healthy adults between 18 and 65 from several nationalities – provided informed consent about the experiments, data storing and the future use of data. Measurements were made at THB, at FH Vorarlberg (Austria), at the University of Oulu (Finland) and at MMUST (Kenya), indoor and outdoor, on paved and unpaved trails, at various climatic conditions.

The datasets contain measurement data of walking scenarios (including kinematics and muscle activities) of 108 healthy adults using three types of sensors:

- inertial measurement units (IMU Xsens MTw)
- acceleration and surface EMG sensors (PLUX XYZ and sEMG).

The here included datasets have been acquired in two main scenarios:

- “The Catwalk”: walking a distance of 20 (10 to 80 m) on flat ground at usual / normal, reduced / slowed and increased / fast speed,
- “The Treadmill”: walking on a treadmill at incremental speed settings from 3.5 to 6.5 km/h or 2 to 8 km/h).

Following the initial idea of the PhysioNet platform, they are meant to facilitate “the cooperative analysis of data and the evaluation of proposed new algorithms”, to support the development of robust algorithms and to be used for teaching and other educational purposes. The data were acquired by lecturers and students guided by prescribed procedures and checklists. Recordings containing measurement errors or procedural faults, caused by equipment, probands or instructors, have not been excluded. They serve as useful examples for testing the robustness of new implemented algorithms.

We would like to address exemplary to two of our earlier papers Loose (2015) and Loose et al. (2016).

2 SYSTEM AND EXPERIMENTS

We have focused on human walking, tried to understand the underlying process and to find best positions of sensors. Robust and reliable algorithms which are applicable to a wide range of walking scenarios (~2-8 km/h) were developed. The algorithms were evaluated on data acquired from IMUs attached to the foot, shank, thigh or pelvis or from sEMG applied to various muscles. Two main scenarios - repetitive walking on the flat ground and walking on a treadmill - were addressed with a large number of healthy subjects.

2.1 Experimental Setup

The sensors are clipped on body straps attached similar on left and right lower limbs and one in the middle of the back. Typically one pair is sitting on the metatarsus, two directly above the ankle and the knee. The distances of the sensors from the floor as well as the length of the limbs are fixed in the record of the experiment individual for each subject.

Figure 1: Experimental setup – Xsens and PLUX sensors are applied.

When PLUX sensors are included in the experimental setup sEMG pads are (mostly) placed symmetric on muscles involved in locomotion activities: m. gluteus maximus, m. rectus fermoris, m. biceps fermoris, m. vastus lateralis fermoris, m. vastus medialis fermoris, m. tibialis anterior, m. tibialis posterior, m. gastrocnemius lateralis, m. gastrocnemius medialis, m. soleus. Accelerometers are applied to the heel of the foot or shoe.

2.2 Sensors and Software

During our gait analysis courses we used three generations of the 9DOF Xsens MTw sensors to acquire accelerations, angular velocities and magnetic rates as well as the sensor orientation at a sampling rate between 60 and 100 Hz and two generations of the PLUX equipment to record muscle activities (sEMG) and the related acceleration at a sampling rate of 1 kHZ.

2.2.1 Xsens MTw sensors (xsens.com)

The 9DOF Xsens MTw sensor (Roetenberg, 2009) incorporates three microelectromechanical sensors: triple-axis gyroscope, accelerometer and magnetometer.

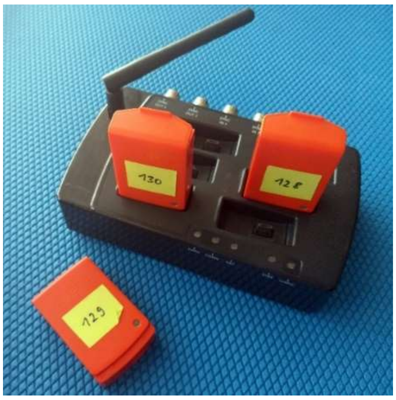


Figure 2: IMU Xsens Mtw sensors and AVIRA unit.

Onboard the data of the primary sensors are sampled with 1800 Hz, strapped down by integration (SDI) incorporating the estimate of orientation to the transfer rate 60 Hz for seven sensors or 100 Hz for two sensors (first generation).

The MTw are connected via Bluetooth to one Awinda station and to the data acquisition software “MT Manager, versions 3.81, 4.21 and 4.9”.

All involved sensors are synchronized with high accuracy (< 0.01 ms). The software provides linear acceleration a, angular velocity ω, magnetic field m and quaternion q (estimated on-board with < 1° of static and 2° RMS of dynamic accuracy).

Before starting measurement the sensors need calm or slow motion for calibration, to determine the initial orientation of the sensor with respect to the world coordinate system.

2.2.2 PLUX sensors (plux.info)

The PLUX biosignal kit (https://plux.info/12-biosignalsplux) includes a wireless 8 channel hub, various sensors and the data acquisition software "OpenSignals".

Figure 3: PLUX Channel hub and connected sensors.

In most of our experiments we used a typical combination of 5 sEMG (electromyography) and triaxial accelerometer sensors on a hub (one for each leg).

The non-filtered sensor data were acquired at a sampling rate of 1 kHZ.

2.3 Scenarios

Standardized indoor and outdoor scenarios typical for health and fitness applications are implemented:

- Repetitive indoor/outdoor walking: passing four times a distance of 10 to 20 meters at a constant speed chosen individually as normal (self-selected comfortable speed), slow (reduced) or fast (increased).
- Repetitive outdoor walking: passing twice a distance of 40 to 80 meters at an individually chosen speed.
- Walking indoor on treadmill with pre-set speed of 3, 4 or 5 km/h over a time period of 1 minute.
- Walking indoor on treadmill with pre-set incremental speed profile over a time period of 7 to 9 minutes and a distance of about 700 meters.
  The speed was increased every minute alternatively:
  - from 2 km/h till 8 km/h with a step of 1 km/h or,
  - from 3.5 km/h till 6.5 km/h with a step of 0.5 km/h.
- An additional test scenario was involved for the examination of distance accuracy:

  Straight forward, steady walking outdoor on a long enough distance (~175 m), on flat and paved ground. The distance was measured alternatively with GPS and tape line. The trial was repeated twice.

2.4 Cohorts

All 108 volunteers participating in the experiments were healthy persons between 17 - (average: 26, median: 23) - 63 years old, 147 – (174) – 194 cm height, 54 – (76) – 120 kg weight and a body mass index of 19 – (24) – 37. There were 45 females and 63 males. Figure 4 shows the distribution of age, height and weight of all volunteers. The 0 kg bin is caused in the gap of data at one scenario.

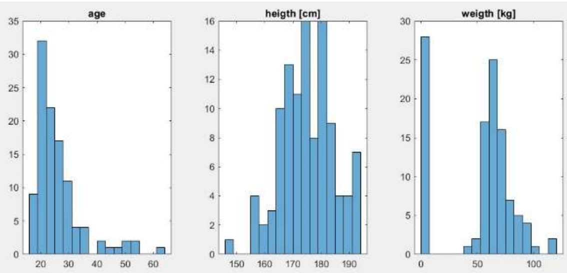


Figure 4: Age, height and weight distribution.

In 2017 (March – October) the recovery after the fracture of the fibula was monitored.

2.5 Procedure

All gait trials were performed in everyday conditions, and the participants were comfortable dressed. Prior to data collection, each participant received a brief explanation of the study and signed the consent form. Body height and body mass were measured, the year of birth was asked.

Each recording was started and terminated with a three second calm phase independent of whether the proband was walking on a flat ground or on the treadmill. The calm can be used for the calibration of the sensors. After any trial the recordings were stopped before turning and repeating.

2.6 Evaluation

All algorithms were developed, implemented and tested in MATLAB® (www.mathworks.com). An open script is organized to process experimental data automatically step by step. After each step the intermediate results are saved.

2.6.1 Xsens sensor data evaluation

The 9DOF Xsens MTw sensor (Roetenberg, 2009) incorporates three microelectromechanical sensors: triple-axis gyroscope, accelerometer and magnetometer.

The following steps are included:

- Pre-processing: reading and reorganizing sensor by sensor the acquired data, given in the sensor related coordinate system (SCS), transformation of sensor data into world coordinate system (WCS), elimination of gravity, calculation of orientation relative to the initial one, calculation of angles between z-axes of a sensor and the vertical or the horizontal plane, calculation of joint angles.
- Processing: estimation of direction of motion, calculation of candidates for gait events, plausibility check, determination of gait cycles, transformation of data into motion coordinate system (CSM), integration of acceleration, calculation of velocity and position data stride by stride.
- Post-processing: calculation of stride related and average features, determination of average motion.
- Evaluation: building figures, extracting and processing tables.

The data base contains the following computed parameters: duration in [s], distance in [m], cadence in [steps/min] and number of strides. Other features are determined during post-processing and evaluation.

2.6.2 PLUX sensor data evaluation

In our scenarios sEMG sensors from PLUX were used in combination with XYZ accelerometers or without them. Following two different approaches to detect gait cycles were implemented. If a XYZ accelerometer is applied to the heel the outstanding local minima related to the heel strike are determined and the signals are partitioned beginning and terminating at heel strikes. If only sEMG sensors are used the main frequency of all available signals is calculated. The correspondent time period (average stride duration) is taken to partition them.

The following steps are included:

- Pre-processing: reading, reorganizing and conditioning the acquired data, calculation of sEMG envelopes based on rms-methods.
- Processing: determination of gait cycles and partitioning the sensor signals and the envelopes in dependence of the sensor configuration.
- Post-processing: calculation of mean and median frequencies, power spectrums and energy characteristics, determination of average curves.
- Evaluation: building figures, extracting and processing tables.

3 ORGANISATION OF THE DATA BASE

The data sets collected in the data base were acquired by lecturers and students of the Brandenburg University of Applied Sciences, in undergraduate and graduate courses dealing with various aspects of gait analysis, experimental and evaluation methods. In each course the scenario, the experimental setup and the procedure of the trials were explained and discussed with all participants. The execution of the experiments following pre-set checklists has been supervised by the lecturer. Any measurement errors or procedural faults, caused by equipment, probands or instructors, were noted and were excluded only in the case that nothing substantial was recorded. They serve as useful examples for testing the robustness of algorithm implementations.

Before getting access to the database, the user needs to register in the system entering his username, password and email address. Later he can sign in by username and password. The personal data of the registration are used only for statistics about access to the database.

3.1 Structure of database

The most important terms in the database are scenarios, probands, experiments, the chosen experiment and the individual recordings.

- A **scenario** describes the conditions of all experiments proceeded during a course: overground or treadmill, speed levels, used sensors, number of trials (see fig. 5).

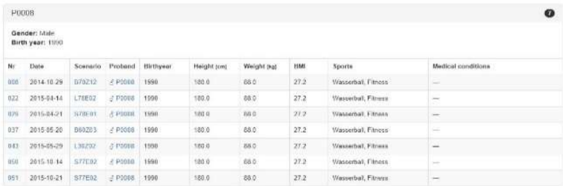
- The code **[B/S/L] A B [X/E/Z] CD** means:
  - **B** - flat floor (mostly normal, slow and fast pace), **S** - treadmill, 7 speed levels between 3.5 and 6.5 km/h, **L** - treadmill, 7 speed levels between 2 and 8 km/h
  - A - number of IMUs from Xsens, B - number of PLUX sensors
  - **X** - sEMG and XYZ sensors from PLUX, **E** - only sEMG sensors from PLUX, **Z** - only IMUs from Xsens
  - CD - number of tests

B06X12

Nr	Date	Scenario	Proband	Birthyear	Height [cm]	Weight [kg]	BMI	Sports	Medical conditions
080	2016-06-08	B06X12	P0030	1983	168.0	65.0	23.0	—	—
081	2016-07-06	B06X12	P0054	1994	172.0	74.4	25.1	—	—
082	2016-07-06	B06X12	P0055	1991	175.0	65.8	21.5	—	—
083	2016-07-06	B06X12	P0056	1991	180.0	92.7	28.6	—	—

Figure 5: Screenshot of scenario B06X12.

- A **proband** relates to a real person participating in one or more experiments. Any proband has an individual ID "Pxxx" (see fig. 6).



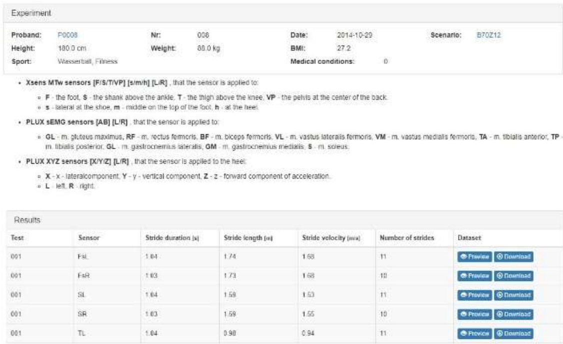
P0008

Gender: Male
Birth year: 1990

Nr	Date	Scenario	Proband	Birthyear	Height [cm]	Weight [kg]	BMI	Sports	Medical conditions
008	2014-10-29	B70Z12	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—
022	2015-04-14	L78E02	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—
029	2015-04-21	S78E01	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—
037	2015-05-20	B60Z03	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—
043	2015-05-29	L30Z02	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—
050	2015-10-14	S77E02	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—
051	2015-10-21	S77E02	P0008	1990	180.0	88.0	27.2	Wasserball, Fitness	—

Figure 6: Screenshot of proband P008.

- An **experiment** relates to one scenario and one proband. It groups all trials and recordings of the chosen experiment. Each experiment is identifiable by a unique number (see fig. 7).



Experiment

Proband: P0008 **Nr:** 008 **Date:** 2014-10-29 **Scenario:** B70Z12
Height: 180.0 cm **Weight:** 88.0 kg **BMI:** 27.2
Sport: Wasserball, Fitness **Medical conditions:** 0

- **Xsens MTw sensors [F/S/T/VP] [s/m/h] [L/R]** , that the sensor is applied to:
  - **F** - the foot, **S** - the shank above the ankle, **T** - the thigh above the knee, **VP** - the pelvis at the center of the back.
  - **s** - lateral at the shoe, **m** - middle on the top of the foot, **h** - at the heel.
- **PLUX sEMG sensors [AB] [L/R]** , that the sensor is applied to:
  - **GL** - m. gluteus maximus, **RF** - m. rectus femoris, **BF** - m. biceps femoris, **VL** - m. vastus lateralis femoris, **VM** - m. vastus medialis femoris, **TA** - m. tibialis anterior, **TP** - m. tibialis posterior, **GL** - m. gastrocnemius lateralis, **GM** - m. gastrocnemius medialis, **S** - m. soleus.
- **PLUX XYZ sensors [X/Y/Z] [L/R]** , that the sensor is applied to the heel:
  - **X** - x - lateralcomponent, **Y** - y - vertical component, **Z** - z - forward component of acceleration.
  - **L** - left, **R** - right.

Results

Test	Sensor	Stride duration [s]	Stride length [m]	Stride velocity [m/s]	Number of strides	Dataset
001	FsL	1.04	1.74	1.68	11	Preview Download
001	FsR	1.03	1.73	1.68	10	Preview Download
001	SL	1.04	1.59	1.53	11	Preview Download
001	SR	1.03	1.59	1.55	10	Preview Download
001	TL	1.04	0.98	0.94	11	Preview Download

Figure 7: Screenshot of experiment N° 008 of P008.

- A **test/trial** is related to a walk of the proband. Each test is characterized by a unique number.

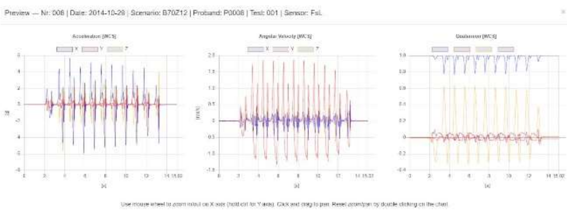


Figure 8: Preview of data of a Xsens sensor of trial 001.

- Each **sensor** has a unique key in the form of [F/S/T/VP] [L/R] or EMG or XYZ, where F - Foot, S - Shank, T - Thigh, VP - Pelvis, L - Left, R - Right, EMG - sEMG, XYZ – accelerometer, e.g. FsL or SR (see fig. 8).

3.2 Xsens recordings

Xsens IMUs record acceleration, angular velocity and magnetic rate vectors, as well as the orientation of the sensor. The acquired data were transformed from the sensor related coordinate system into the world coordinate system and gravity compensated. Each dataset contains the measurements from a single IMU. At the beginning, meta data are included followed by binary coded data blocks.

3.3 PLUX recordings

PLUX units sample up to 8 channels depending on the different primary sensors. While a sEMG has only one signal, a XYZ sensor has three channels - one for each direction. Each EMG or XYZ dataset contains the measurements of a single unit. At the beginning, meta data are included followed by binary coded data blocks.

3.4 Export and Import of Data Files

Any recording can be downloaded from the individual experiment page.

The names of the data files are transliterated as

YYYMMDD_Pnnnn_ttt_XXX_mmm,

where YYYYMMDD - date, Pnnnn - proband ID, ttt - trail, XXX - sensor type and , mmm - sensor id, e.g. . 20141029_P0008_001_FsL_125.dat.

All data sets could be downloaded at once if meaningful.

To import the downloaded data files into the MATLAB workspace, two functions are provided.

Each recording consists of two parts: the meta data block and the binary coded data.

Xsens MTw recordings: The meta data block contains: date, proband ID, number of test, sensor position, sensor id, number of columns, number of samples, precision, sampling rate, duration of recording, number of speed levels, scaling factors of acceleration, angular velocity and quaternions.

PLUX recordings: The meta data block contains: date, alias, number of test, type of sensor, number of columns, abbreviations of muscles, number of samples, sampling rate, precision, duration of recording, number of speed levels.

4 CONCLUSIONS

This paper presents the GaitAnalysisDataBase (http://gaitanalysis.th-brandenburg.de), which provides data sets of walking for public use, to develop and evaluate algorithms, to investigate various research problems without the necessity to collect their on data.

The paper gives a detailed description of the data base and the terms (scenario, proband, experiment and trial) as well as an overview about the experimental setup, the acquisition of data, the procedure of experiments, data processing and evaluation. Results of exemplary investigations are described in the second part of the paper.

The public data base opens manifold chances for research and development tasks in gait analysis.

We would be pleased if the offer would be used. We would be appreciated for any hint to improve or to extend it. We would like to ask you if you will use this data base for your own publications or the research behind to cite this paper.

ACKNOWLEDGEMENTS

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