4GAIT: Synchronized MoCap, Video, GRF and EMG datasets: acquisition, management and applications

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Abstract. Presented is the 4GAIT, a group of multimodal, high quality Reference Human Motion Datasets. The described in this article Multimodal Human Motion Lab provides a comprehensive environment for multimodal data acquisition, management and analysis. Introduced is a proposed PJIIT Multimodal Human Motion Database (MHMD) model for multimodal data representation and storage, along with Motion Data Editor – a toolkit for multimodal motion data management, visualization and analysis. As an example a group of three synchronized, multimodal, motion datasets using MHMD model: 4GAIT-HM, 4GAIT-Paarkinson and 4GAIT-MIS are described.
Comparing to the currently available Human Motion Datasets, 4GAIT offers multiple data modalities presented within a unified model, higher video resolution, and larger volume of motion data for specific medical tasks, which better fulfills the needs of medical studies and human body biomechanics research.

Keywords: multimodal acquisition, reference human motion, clinical gait analysis

1 Introduction

Human motion, or motion capture, data describes articulated human body motion in three dimensions. The usual form of the description is a time series consisting of vectors of joint angles plus root position, with respect to a defined skeleton. Human motion data is used in biomechanics, sports, human factors and ergonomics, entertainment, robotics, computer vision research, gait analysis, biometrics, human-computer interfaces, multiple subfields of medicine, such as orthopedics, orthotics, prosthetics, characterization and diagnosis of movement impairments and rehabilitation, and many other applications.

Human motion databases have been constructed by research and industrial centers to serve as reference sets for research studies or as human motion repositories for applications, such as animation in video games or film. These databases usually contain metadata such as the names and descriptions of actions, gender of actors or parameters of the acquisition configuration, and additional signal information associated with the motion data. The nature of such additional signal information depends on the needs of applications for which the database is intended. Audio data is useful for studies of expressions, behavior or emotions, video from single or multiple cameras is needed in computer vision research, force measurements are used in studies related to sport, biomechanics, gait, ergonomics or in rehabilitation, electromyography (EMG) signals may be required in study or diagnosis of neuromuscular diseases and movement disorders, research in prosthetics, biomechanics and robotics and in rehabilitation. If additional signal information is associated with the motion data, the issue of signal synchronization appears. This issue is not usually present in case of metadata. The additional signal information is most useful if the additional signals are synchronized with the motion data signal. The signal synchronization should be as precise as possible, since more precise synchronization leads to more accurate modeling of relations between the signals, for example the relation between the signal from a sensor that measures forces between a foot and the floor and the acceleration of a body part computed from the motion data. The signal synchronization should be provided by the data acquisition hardware.

This article describes a system for acquisition of motion data and other signals that is used in Human Motion Laboratory (HML) of the Polish Japanese Institute of Information Technology (PJIIT) in Bytom, Poland, and databases created using this system. Many publicly accessible motion databases existed before the HML system was built. The list below is representative of such motion database, although it is not exhaustive.

1. **CMU Mocap database** [1] is an extensive motion data set used in many research projects. It contains more than six hours of full body motion data in 2605 motion clips, organized into a hierarchy of activities and actions that were recorded from 144 subjects. The activities include single person motions and interactions with environment, and two people interactions.
2. **CMU Multi-Modal Activity Database (CMU-MMAC)** [2] contains multimodal measurements of subjects performing tasks related to cooking in a specially built kitchen. The database contains associated video with maximum resolution 1024 x 768, audio, and signals from accelerometers attached to the body. The main dataset consists of data from 43 subjects cooking five recipes, the anomalous dataset consists of data from three subjects cooking five recipes.
3. **CMU Motion of Body (MoBo) database** [3] is focused on human gait. It contains four walking actions, described as slow, fast, inclined, and carrying a ball, which are performed on a treadmill by 25 subjects. The data contains only video recorded from six cameras placed around the subject. The main goal of this dataset was research on biometric identification of humans from their gait characteristics.
4. **IEMOCAP Database** [4] from University of Southern California is oriented towards human communication and expression of emotions. Its motion data is recorded from face, head, hands and torso. The dataset contains a

large number of emotions performed by ten trained subjects. The motion data is associated with audio recordings.

5. **HumanEva Database** [5] main objective is to provide ground-truth data computer vision research, specifically, for testing and evaluation of pose estimation and motion tracking methods. Associated signal data are video sequences synchronized with the motion capture data. The video resolution is relatively low, the highest resolution is 659x694. The dataset contains six actions performed by four subjects wearing natural clothing.
6. **HDM05 MoCap Database** at the Hochschule der Medien [6] consists of 1457 motion clips that represent 100 action classes, performed by five actors. The set for each action class contains between 10 and 50 clips. The goal of the dataset was research on analysis, synthesis and classification of motion.
7. **SMILE lab Human Motion Database** [7] consists of five subsets: the praxicon containing around 350 actions of the same subject, the cross-validation dataset of 70 actions performed by 50 subjects, the generalization dataset that contains samples of nine action classes each sample of the same action performing it differently, the compositionality dataset containing complex actions each composed of two or three simple actions, and the interaction dataset consisting of 150 actions performed by two interacting subjects. The goal of the database is research on analysis and synthesis of motion.
8. **Korea University Gesture (KUG) database** [8] contains actions performed by 20 actors of different gender and age. The set of actions contains 14 typical, normal motions such as sitting on a chair and walking, 10 atypical actions such as falling, and 30 gestures representing answers or instructions such as yes, no, pointing, or selecting a number. The goal of the database was to serve as reference in research on gesture recognition and people tracking. The motion data is associated and synchronized with video data from multiple stereoscopic cameras looking at the action from different directions.
9. **Human Identification at Distance (HID) database** [9] at Georgia Tech contains gait data recorded from 20 subjects indoor and outdoor. The goal of the database is gait recognition and identification of people from characteristics of their walk. The motion data is associated with video data recorded from different distances and angles.
10. **ICS Action Database** [10] at the University of Tokyo contains 25 action classes with five motion samples representing each class. The data samples are annotated on a per-frame basis, such that a frame can be a part of more than one action class. The goal of the database is to serve as reference for research on human action segmentation and recognition.

The creation of Human Motion Laboratory at PJIIT and the subsequent activity in building human motion databases was motivated by a plan to work along multiple aspects of human motion, collaborating with other institutions in multidisciplinary groups in three main directions: medical, entertainment, and research in computer vision, biometrics, and motion analysis and synthesis. This objective imposed a tough set of demands on the acquisition system. The vision research required video data of high quality synchronized with motion data, the medical research needed additional measurement modalities such as force and EMG, also synchronized with motion. The entertainment applications, such as animation for videogames, demanded highest quality motion capture data. None of the available databases possessed the required combination of modalities or the quality of video and motion capture that was possible to achieve at the time when the project has begun, and the obvious solution was to build a new lab – the HML described in the next section.

2 Laboratory

A multimodal laboratory for motion analysis – Human Motion Lab allows for simultaneous measurement of a number of patient motion parameters. It enables acquiring of motion data through simultaneous and synchronous measurement and recording of motion kinematics, muscle potentials, ground reaction forces and video streams. Owing to that there occurs the opportunity for spatio-temporal correlation between the video sequences, values of angles, forces, moments of forces, powers in selected joints (one or a few), potentials of muscles determining their activity and ground reaction forces.

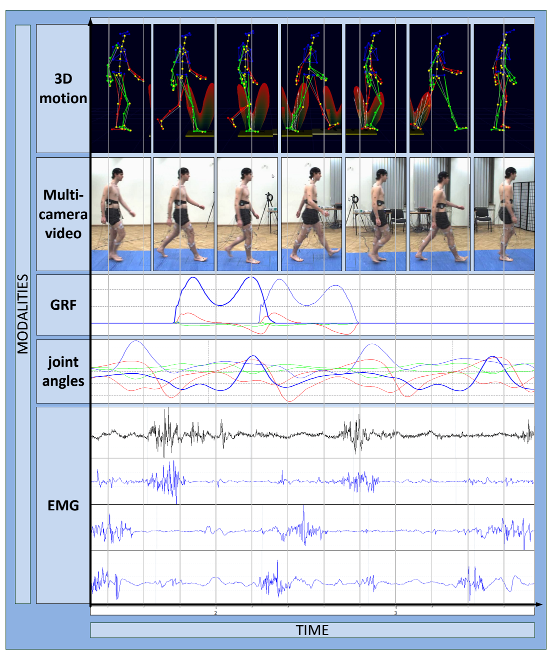

Fig. 1. An example of trial from dataset 4GAIT-HM. Simultaneous visualization of data from mocap, video stream, ground reaction forces, trajectories of joint angles and electromyographic signals with visible contractions of muscles.

HML takes measurements used in orthopedics and rehabilitation and cooperates with the major medical centers in Poland, developing the laboratory's research methods and work techniques.

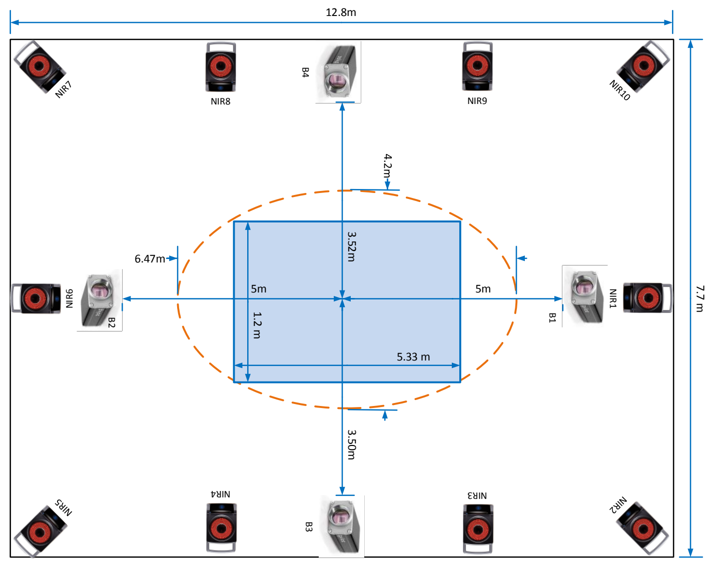

Fig. 2. Camera setup for 4GAIT data acquisition

Basic equipment of the laboratory includes:

- **Vicon's Motion Kinematics Acquisition and Analysis System** equipped with 10 NIR cameras with the acquisition speed of 30 to 2000 frames per second at full frame resolution of 4 megapixels and 8-bit grayscale.
- **Noraxon's Dynamic Electromyography (EMG) System** allowing for 16-channel measurement of muscle potentials with non-gel electrodes in compliance with the SENIAM guidelines. For the purposes of registration 4GAIT datasets containing EMG , have been defined four measurement configurations (see fig. 3).
- **Kistler's Ground Reaction Force (GRF) Measurement System** used for measuring ground reaction forces with two dynamometric platforms with measurement ranges adjusted to gait analysis research. The system measures forces with equal accuracy on the entire surface of the platform in a measurement range not smaller than 5 times the body of an adult person for dynamic function research. The system has a 6-meter path masking two platforms situated in the middle of its length.
- **A system for simultaneous multi-camera video image recording equipped with Basler's cameras** that allows for simultaneous image recording from all the cameras in Full HD and lossless video recording. The

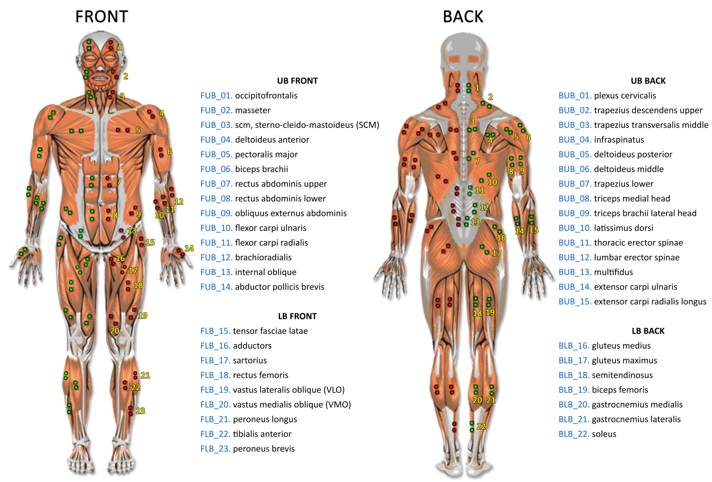

Fig. 3. EMG measurement configurations for the purposes of registration 4GAIT datasets

system uses color video recorders using the GigE Vision standard and industrial lenses.

- **A system for scene lighting** composed of 40 independent light points with fluorescent lights with color temperature 5400K and ballast frequency > 35000 Hz.

Hardware Synchronization

MX-Giganet Lab is responsible for hardware synchronisation during data acquisition from base systems. Our MX-Giganet Lab is equipped with Analog ADC Option Card for connecting up to 64 analog channels in simple Vicon MX T-series system with a single primary MX Giganet.The analog ADC card is a 64-channel device for generating 16-bit offset binary conversions from analog sources.The maximum rate at which we can sample data via the ADC card is 192000 samples/second (192 kHz) for one channel configuration and 3000 samples/second (3kHz) for 64 channels configuration. So for simultaneous data acquisition from GRF and EMG, sample rate is equal to 3 kHz. To incorporate a Basler GigE camera in a T-Series system for hardware based synchronization of simultaneous data acquisition our four Basler GigE Cameras are connected by four Powered Sync Outputs in MX Giganet Lab.

3 Databases

The PJIIT Multimodal Human Motion Database (MHMD) consists various datasets of time synchronized and calibrated data from: optical high resolution motion capture system, high definition cameras from multiple views, two dynamometric platforms and dynamic electromiography system. In this paper we focus on 4GAIT type datasets, each containing a human gait data with registered up to four types of modalities at the same time. Each presented dataset has the same uniform structure with the following hierarchy **Subject** → **Session** → **Trial** → **Segment**. Subject identifies a subject of motion. Session describes measurement sessions for a given subject. Trial identifies trials which may be done by a subject during a single session. Each instance of multimodal trial is composed of one C3D file containing (kinematic and kinetic motion parameters) up to 4 video streams and configuration files. Segment describes a part of the trial sequence distinguished based on some criteria of interest. At each level of this hierarchy it should be possible to assign instances to categories and to equip them with custom attributes. Technical details of assumptions, used data structures and database have been outlined in [11].

Table 1. The summary and origin of presented datasets

Dataset Name	Modalities	Summary of the project
4GAIT-MIS	4 video streams (25 fps, 1920x1080), motion capture (100 fps)	Novel commercializable technology and industrial grade software for a scalable cloud-based video surveillance system with advanced video analysis functions that include object or person tracking over extended range and time, identification of people, activities and behavior, and automatic learning.
4GAIT-Parkinson	4 video streams (25 fps, 1920x1080), motion capture(100 fps), EMG(EMG_LB_3), GRF	Diagnosis of Parkinson's disease, the correlation of UPDRS with motion descriptors. Evaluation of the drug influence and stimulation.
4GAIT-HM	4 video streams (25 fps, 1920x1080), motion capture(100fps), EMG (EMG_UB_1, EMG_LB_3, EMG_FB_1), GRF	System with a library of modules for advanced analysis and an interactive synthesis of human motion.

4GAIT-MIS The main goal of this dataset is research on biometric re-identification of humans from their gait characteristics.The dataset contains walking actions which are performed by 33 subjects aged 25-35 years. The actors are dressed in skin-tight red, green, orange or blue T-shirts and black mocap trousers. Each new recording session is preceded by an empty scene. Video cameras are positioned at the same height in the greatest possible distance from the center of the stage (see fig. 1).

Fig. 4. An example of trial from dataset 4GAIT-MIS. Simultaneous visualization of data from mocap and four video streams.

4GAIT-Parkinson The main goal of this dataset is research on gait recognition and identification of PD patients symptoms and stage of the disease progression. In the future multimodal tests should lead to automation of patients' disease stage assesment without doctor participation and replace subjective UPDRS measure by "golden neurologist". Participants performed 12 tasks under four experimental conditions called sessions. Medication ON/OFF means that patient was with/without drugs during the session. Stimulation ON/OFF means that patient was with stimulator turned on/turned off during the particular session. Each session groups the following tasks: sway, gait/tandem gait, turnover, walk at normal/fast speed, heel to toe walk in a straight line, sensomotoric test related to tracking light spots, pulling back test, arizing from chair and leg agility test. During the sway task participants stood motionless on force platform with hands lowered at both sides and feet together, once with eyes open (EO), once closed, (EC). The experiment has been performed two times for EO and EC. Duration of one test is 30 s; between attempts was a rest period. The scope of interest has been marked on the paper covering the platform, to ensure the same position between successive attempts. In the case of EO study, patients looked at the sign "x", located 1.6 m above ground and 2 m in front of them. This sign was surrounded by a black circle with a radius of 18 cm. The final dataset contains 1781 trials (including 803 trials of gait) grouped in 12 tasks which were performed by 18 subjects - 14 males and 4 females.

4GAIT-HM The main goal of this dataset was to investigate the relationship between the kinematics and kinetics of 34 patients with diagnosed coxarthrosis (10 subjects), knee arthrosis, degenerative spinal disorders (19 subjects), stroke

(4 subjects) and arthritis (1 subject). The final dataset exceed 1144 trials of gait which were performed by 23 males and 11 females.

4 Applications

Datasets 4GAIT presented in this paper, still growing. The frequent and regular measurements are collected and organized in the cloud based **Human Motion Database**. A client application software, **Motion Data Editor (MDE)**, enables access to datasets in natural way, visualization and processing of data from any number of multimodal measurements simultaneously and synchronously. It supports dozens of industrial formats used for medical data storage. The application has modular structure, that enables simple extensions of its capabilities with a dedicated plugin system. MDE uses an intuitive data flow approach involving data sources, processing modules and data visualization sinks. Processing modules perform appropriate data manipulations such as filtering and transforming data. MDE allows the user to easily swap and extend modules. The developed system demonstrates features that benefit medical informatics applications. It provides centralized storage for medical data and associated descriptions, allows users to exchange data, giving them a possibility to consult and discuss specific cases. Users are able to filter the data and manage filters themselves. This stage supports browsing, viewing, processing and comparing data records. More information can be found at http://hm.pjwstk.edu.pl/mde. During last 3 years the research on motion analysis have been conducted. Eventually one group of researchers utilized and second group extended existing datasets. In [12] the 4GAIT-HM dataset was extended by 90 gaits coming from 15 different patients – 7 of them with diagnosed coxarthrosis on the basis of an earlier different examinations and 8 of them without coxarthrosis. This dataset has been extensively used by [13], [14], [15], [16] for gait based re-identification. At the same time 4GAIT-MIS has been used by 3D inference research in [17], [19] and multiscale processing performance for motion capture in [18].

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