Documentation Mocap database HDM05

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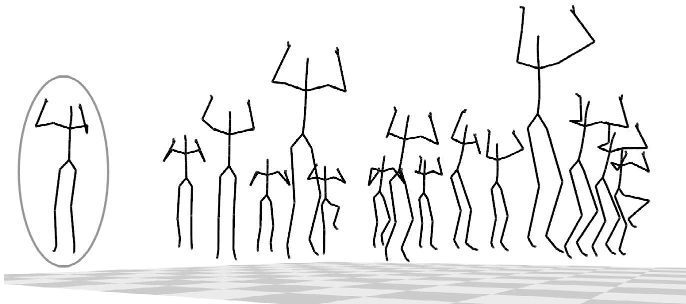
Mocap Database HDM05



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Preface

In the past two decades, motion capture (mocap) systems have been developed that allow to track and record human motions at high spatial and temporal resolutions. The resulting motion capture data is used to analyze human motions in fields such as sports sciences and biometrics (person identification), and to synthesize realistic motion sequences in data-driven computer animation. Such applications require efficient methods and tools for the automatic analysis, synthesis and classification of motion capture data, which constitutes an active research area with many yet unsolved problems.

Even though there is a rapidly growing corpus of motion capture data, the academic research community still lacks publicly available motion data, as supplied by [4], that can be freely used for systematic research on motion analysis, synthesis, and classification. Furthermore, a common dataset of annotated and well-documented motion capture data would be extremely valuable to the research community in view of an objective comparison and evaluation of the achieved research results. It is the objective of our motion capture database HDM05[1] to supply free motion capture data for research purposes. HDM05 contains more than tree hours of systematically recorded and well-documented motion capture data in the C3D as well as in the ASF/AMC data format. Furthermore, HDM05 contains for each of roughly 70 motion classes 10 to 50 realizations executed by various actors amounting to roughly 1,500 motion clips.

In this documentation, we give a detailed description of our mocap database HDM05. In Sect. 1, we provide some general information on motion capture data including references to various application fields. A detailed description of the database structure of HDM05 as well as of the content of each mocap file can be found in Sect. 2. We also provide several MATLAB tools comprising a parser for ASF/AMC and C3D as well as visualization, renaming and cutting tools, which are described in Sect. 3. Finally, Sect. 4 summarizes some facts on the mocap file formats ASF/AMC and C3D as used in our database.

We appreciate any comments and suggestions for improvement.

Bonn, June 2007 — Meinard Müller, Tido Röder

[1]The motion capture data has been recorded at the Hochschule der Medien (HDM) in the year 2005 under the supervision of Bernhard Eberhardt.

Contents

1 General Information

This section provides some general information on motion capturing and its applications. Links to the literature and an overview of the database HDM05 can be found in Sect. 1.1. In our recordings, we used an optical marker-based Vicon system. In Sect. 1.2 we discuss some problems that arise in the process of converting marker-based data (e. g., given in C3D format) into skeleton-based data (e. g., given in ASF/AMC format). The technical and recording setup for HDM05 is described in Sect. 1.3. Finally, contact information as well as a list of the contributors can be found in Sect. 1.4.

1.1 Motivation

Historically, the idea of motion capturing originates from the field of gait analysis, where locomotion patterns of humans and animals were investigated using arrays of analog photographic cameras. With technological progress, motion capture data or simply *mocap data* became popular in computer animation to create realistic motions for both films and video games. Here, the motions are performed by live actors, captured by a digital mocap system, and finally mapped to an animated character. However, the lifecycle of a motion clip in the production of animations is very short. Typically, a motion clip is captured, incorporated in a single 3D scene, and then never used again. For efficiency and cost reasons, the reuse of mocap data as well as methods for modifying and adapting existing motion clips are gaining in importance. Applying editing, morphing, and blending techniques for the creation of new, realistic motions from prerecorded motion clips has become an active field of research [2, 8, 11, 12, 16, 19]. Such techniques depend on motion capture databases covering a broad spectrum of motions in various characteristics. Larger collections of motion material such as [4] have become publicly available in the last few years. However, prior to reusing and processing motion capture material, one has to solve the fundamental problem of identifying and extracting logically related motions scattered in a given database. In this context, automatic and efficient methods for content-based motion analysis, comparison, classification, and retrieval are required that only access the raw mocap data itself and do not rely on manually generated annotations [6, 7, 9, 10, 12, 13, 14, 17, 20]. Such methods also play an important role in fields such as sports sciences, biomechanics, and computer vision.

One of the first publicly available mocap database has been provided in the year 2003 by the Carnegie-Mellon University [4], which contains several hours of motion data comprising various motions ranging from locomotion over sports to pantomine. The CMU database has been extensively used by the academic research community, thus providing important test data for the aforementioned research fields. Furthermore, the CMU database is a first step towards a common database that can be used by the research community for an objective comparison of different motion analysis and synthesis methods as well as a comprehensible evaluation of research results.

It is the object of our database HDM05 to supply the research community with an additional set of motion capture data. Opposed to the CMU database, which contains a wide range of different motion, HDM05 database mainly contains motions from a limited num-

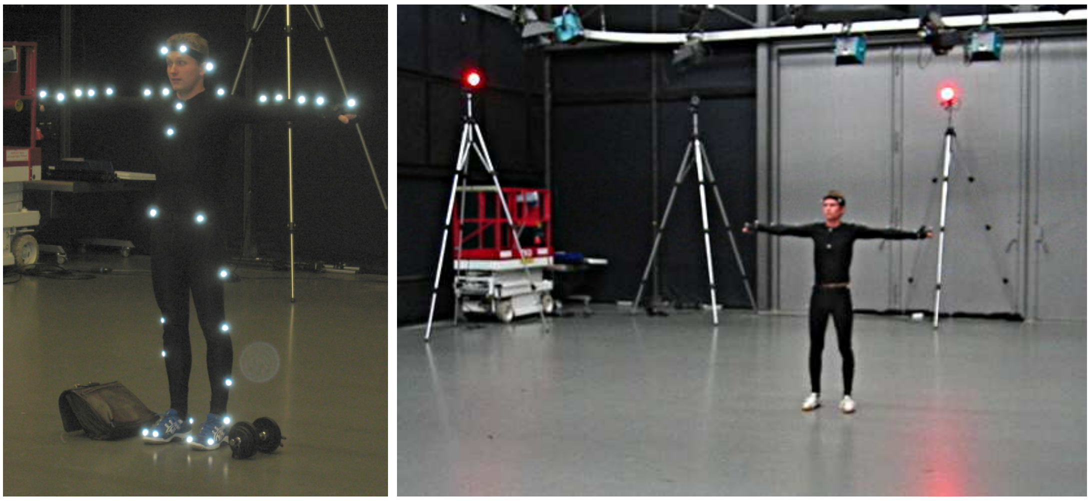

Figure 1. Optical motion capture system based on retro-reflective markers attached to the actor's body. The markers are tracked by an array of six to twelve calibrated high-resolution cameras arranged in a circle.

ber of roughly one hundred motion classes including various walking and kicking motions, cartwheels, jumping jacks, grabbing and depositing motions, squatting motions, and so on. Following stage directions, we systematically recorded several hours of motion capture data containing a number of well-specified motion sequences, which were executed several times and performed by five (non professional) actors. Using this data, we built up a data set $\mathcal{D}_{210}$ that consists of roughly 210 minutes of motion data. Then, we manually cut out suitable motion clips from $\mathcal{D}_{210}$ and arranged them into roughly 100 different motion classes. Each such motion class (MC) contains 10 to 50 different realizations of the same type of motion, covering a broad spectrum of semantically meaningful variations. For example, the motion class 'CartwheelLeft' contains 21 variations of a cartwheel motion, all starting with the left hand. The resulting motion class database $\mathcal{D}^{\mathrm{MC}}$ contains $1,457$ motion clips, amounting to 50 minutes of motion data. Supplying a set of systematically recorded and well-documented set of motions that contains multiple realizations for each motion class, we hope that the HDM05 database will constitute a useful testbed for motion analysis, synthesis and classification algorithms.

1.2 Motion Capture Data

There are many ways to generate motion capture data using, e. g., mechanical, magnetic, or optical systems, each technology having its own strengths and weaknesses. For an overview and a discussion of the pros and cons of such systems we refer to [18]. For our HDM05 database, we used a system based on an optical marker-based technology, which yields very clean and detailed motion capture data. Here, the actor is equipped with a set of 40–50 retro-reflective markers attached to a suit. These markers are tracked by an array of six to twelve calibrated high-resolution cameras at a frame rate of up to 240 Hz, see Fig. 1. From the recorded 2D images of the marker positions, the system can then reconstruct the 3D marker positions with high precision (present systems have a resolution of less than a millimeter). Then, the data is cleaned with the aid of semi-automatic gap filling algorithms exploiting kinematic constraints. Cleaning is necessary to account for missing and defective data, where the defects are due to marker occlusions and tracking errors. In our HDM05 database, the resulting 3D trajectory data is stored in the C3D mocap file format, see also Sect. 4.3.

For many applications, the 3D marker trajectories are then converted to a skeletal kinematic chain representation based on joint angles by means of appropriate fitting algorithms [5, 15]. Such an abstract model has the advantage that it does not depend on the specific number and the positions of the markers used for the recording. However, the mapping process from the marker data onto the abstract model can introduce significant artifacts that are not due to the marker data itself. Here, one major problem is that skeletal models are only approximations of the human body that often do not account for biomechanical issues, see [21]. Another problem is that skeletal fitting software usually works with heuristics that may lead to invalid poses such as "knees bent backwards". Also, there are systematic artifacts such as "elbow angled even when arm is stretched". Such problems also occurred during the skeletal fitting stage in the preparation of the HDM05 database. Specifically, we only had access to the skeletal fitting package *Vicon BodyBuilder*, which is a very old product that is no longer properly supported by Vicon. BodyBuilder turned out to produce many artifacts of the types described above. Nevertheless, for each C3D file in the database HDM05, we also included the output of BodyBuilder in the skeleton-based mocap file format ASF/AMC, see Sect. 4.1.

For practical applications, there are three important differences between C3D data (3D trajectory-based) and ASF/AMC data (skeleton-based). First, ASF/AMC data comprises an explicit skeleton structure, providing information about bones, joints, and the assembly of these basic elements into a skeleton, whereas hierarchy information for C3D data can only be deduced by the names of the markers, see also Fig. 3. Second, consider the bone lengths for the two data formats: fixing a pair of markers (in C3D data) or joints (in

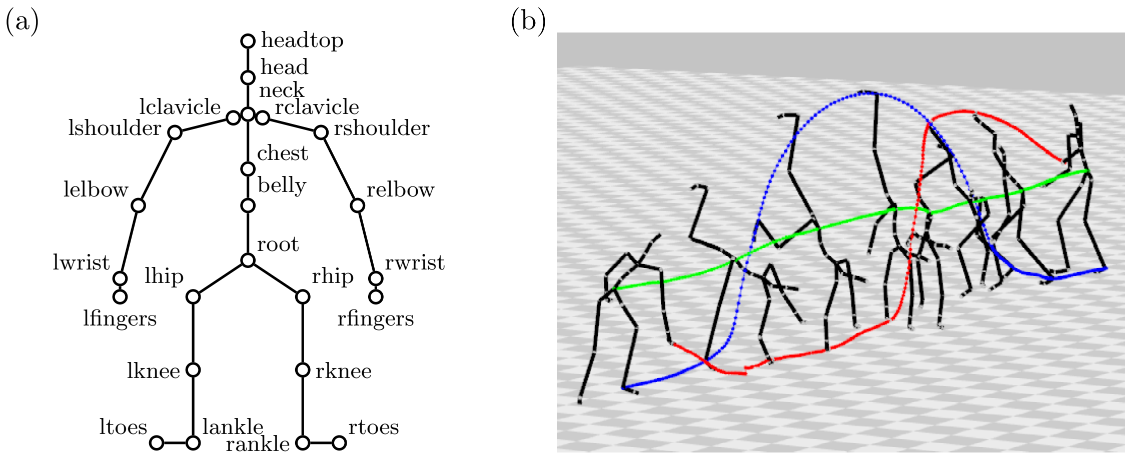

Figure 2. **(a)** Skeletal kinematic chain model consisting of rigid *bones* that are flexibly connected by *joints*, which are highlighted by circular markers and labeled with joint names. **(b)** Motion capture data stream of a cartwheel represented as a sequence of poses. The figure shows the 3D trajectories of the joints 'root', 'rfingers', and 'lankle'.

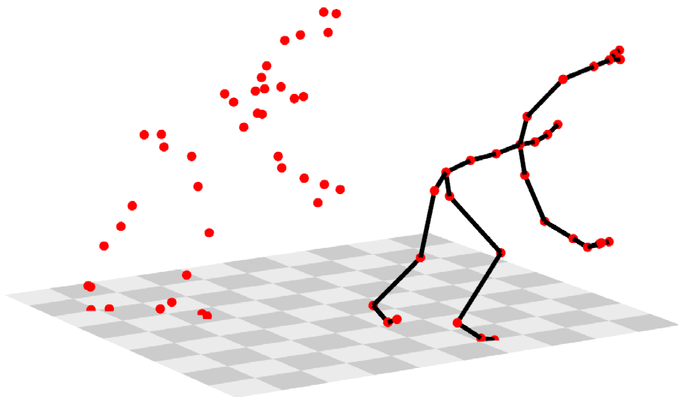

Figure 3. Comparison of corresponding poses from a C3D file (left, point cloud) and an AMC file (right, skeleton).

ASF/AMC data) that are attached to the same bone, the bone length can be approximated as the 3D distance of the markers/joints. Bone lengths will be constant in the case of the skeleton-based ASF/AMC format and not constant in the case of the C3D format. In fact, major variations of bone lengths over the course of a motion may be observed in C3D data. Such variations are caused by skin shifting, shifting of the nylon suit worn during recording, wobbling mass, and violations of the assumption that the human skeleton is a kinematic chain. Third, C3D data contains a lot of redundant markers clustered around certain joints of the human skeleton, whereas ASF/AMC data usually has only one virtual joint for each real-world joint, see also Fig. 3.

1.3 Technical and Recording Setup

For our recordings, we used a Vicon MX system comprising twelve high-resolution cameras, six of which operated in the visible red and six of which operated in the infrared spectral range. All recordings were performed at a sampling rate of 120 Hz. The cameras were set up to yield a viewing volume diameter of about five meters.

Based on a script (see Sect. 2.2) containing detailed instructions on the motions that were to be recorded, we had five actors performing several repetitions of each motion sequence. Additionally, several freestyle sequences containing miscellaneous motions were recorded for some of the actors.

1.4 Contributors and Contact Information

The HDM05 database has been designed and set up under the direction of Meinard Müller and Tido Röder, University of Bonn. The motion capturing has been conducted at the Hochschule der Medien, Stuttgart, supervised by Bernhard Eberhardt. HDM05 is a collaboration of the following three research groups:

- Prof. Dr. Michael Clausen, "Multimedia Signal Processing Group", Computer Science Dept. III, University of Bonn.

- Prof. Dr. Bernhard Eberhardt, Hochschule der Medien, Fachhochschule Stuttgart, Germany.
- Prof. Dr. Andreas Weber, "Multimedia, Simulation and Virtual Reality", Computer Science Dept. II, University of Bonn.

The contributors are listed in alphabetic order: Jochen Bomm, Harun Celebi, Michael Clausen, Bastian Demuth, Bernhard Eberhardt, Hendrik Ewe, Daniel Goldbach, Björn Krüger, Meinard Müller, Tido Röder, Andreas Weber.

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- Prof. Dr. Andreas Weber (weber@cs.uni-bonn.de)

2 Structure of Database

The HDM05 database contains more than tree hours of systematically recorded and well-documented mocap data in the C3D as well as in the ASF/AMC format. The motion sequences were performed by five non-professional actors, each actor executing several repetitions of the sequences based on a script, see Sect. 2.1. From this data, suitable motion clips have been manually cut out and arranged into roughly 100 different motion classes. Most of these classes contain 10 to 50 different realizations amounting to roughly $1,500$ motion clips and 50 minutes of motion data. The HDM05 database does not only consists of the mocap data itself, but also includes the documentation, several MATLAB tools including a C3D and ASF/AMC parser, as well as some selected video clips of parts of the performances. The database is subdivided into seven subdirectories as illustrated by Fig. 4.

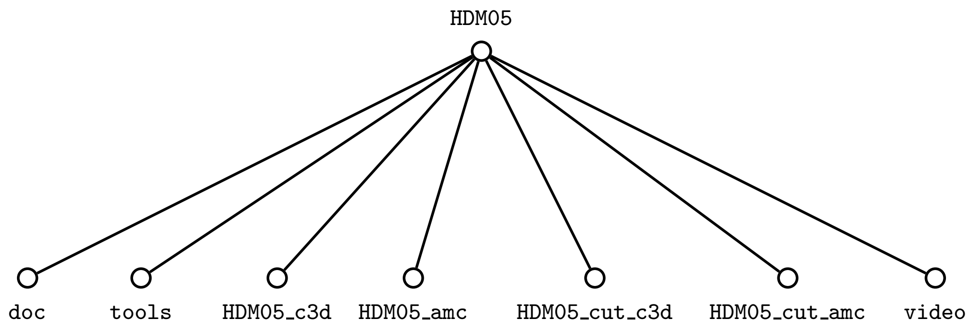

Figure 4. Structure of the HDM05 database.

We now give an overview of the contents of each subdirectory, which will be described in detail in the later part of this section.

- `doc`: this directory contains a PDF-version of this documentation.
- `tools`: this directory contains several MATLAB tools including a MATLAB parser both for ASF/AMC and C3D data, MATLAB animation tools, as well as renaming and cutting tools. A detailed description of these tools, which have been programmed in MATLAB 6.5, can be found in Sect. 3. Furthermore, the mapping from the full mocap takes to the manually trimmed clips of the motion classes can be found in `tools\cut_script.txt`.
- `HDM05_c3d`: this directory contains the C3D files of the full takes of our mocap recordings. The files are stored in five subdirectories corresponding to the five different actors. A list of all recorded takes along with a description of the contents and further comments can be found in Sect. 2.2.
- `HDM05_amc`: this directory contains the AMC files corresponding one-to-one to the files in `HDM05_c3d` as well as the ASF-files for the skeletons.
- `HDM05_cut_c3d`: this directory contains the C3D files of roughly 1500 short motion clips that have been manually cut out from `HDM05_c3d`. The files are arranged into

roughly 100 different subdirectories, each subdirectory corresponding to some specific motion class, see Sect. 2.3.

- `HDM05_cut_amc`: this directory contains the AMC files corresponding one-to-one to the files in `HDM05_cut_c3d` as well as the ASF-files for the skeletons.
- `video`: for some of the motions we have produced an additional AVI movie clip recorded with a customary digital camcorder. Each of the movie clips has been manually trimmed to correspond to an explicitly given fragment of a mocap file in `HDM05_c3d`, see Sect. 2.4.

2.1 Script

Most of the motion sequences have been performed according to the guidelines fixed in our script, which is described in this section. The script consists of five parts, where each part is subdivided into several scenes. Each full take corresponds to one of the scenes. All motion sequences begin and end with a short T-pose as indicated by Fig. 1.

1 Walking, Running, Jumping

1-1 Walking: [1] walk 5 steps [2] turn around (right) [3] walk 5 steps (ducked) [4] walk 5 steps (backwards) [5] walk 5 steps (sideways, to the right, feet cross over alternately front/back) [6] 3 double steps (sideways, to the left, no cross over) [7] 3 double steps (sideways, to the right, cross over only front) [8] walk 5 steps (happily) [9] turn around (left) [10] walk 5 steps (sadly) [11] turn around (right) [12] walk 5 steps (creep) [13] turn around [14] walk 5 steps (shuffle)

1-2 Locomotion on the spot: [1] walk 5 steps on spot [2] jog 5 steps on spot [3] run 5 steps on spot [4] bend knees [5] walk 5 steps with bent knees

1-3 Locomotion: [1] walk 6 steps (semicircle left) [2] turn around [3] walk 6 steps (semicircle right), back to start [4] turn around [5] transition: walking to running [6] turn around [7] run 5 steps (semicircle left) [8] run 5 steps (semicircle right), back to start

1-4 Locomotion with weights: [1] walk 5 steps (4 kg in right hand) [2] turn around [3] run 5 steps (4 kg in right hand) [4] turn around, switch weight to left hand [5] run 5 steps (4 kg in left hand) [6] turn around [7] walk 5 steps (4 kg in left hand) [8] turn around, deposit 4 kg weight to floor and grab 10 kg weight from floor [9] walk 5 steps (10 kg in right hand) [10] turn around [11] run 5 steps (10 kg in right hand) [12] turn around, switch weight to left hand [13] run 5 steps (10 kg in left hand) [14] turn around [15] walk 5 steps (10 kg in left hand)

1-5 Hopping and jumping: [1] 5 jumps (on right leg) [2] turn around [3] 5 jumps (on left leg) [4] turn around [5] 5 steps (skipping) [6] turn around [7] 5 jumps (on both legs) [8] walk to staircase [9] climb 4 stairs [10] jump down sideways from stairs

1-6 Climbing stairs: [1] walk 5 steps [2] climb 4 stairs [3] turn around (right) [4] descend 4 stairs [5] walk 5 steps

2 Grabbing and Depositing

2-1 Table and floor: [1] walk 3 steps to table and grab item A [2] turn around left and walk halfway towards item B [3] deposit item A on floor (knees bent) [4] walk to item B and grab item B (knees bent) [5] turn around left and walk back to item A [6] deposit item B next to item A and grab item A (knees not bent) [7] deposit item A on table

2-2 Shelf (while walking): [1] walk 3 steps to shelf [2] grab item from shelf (middle) [3] turn around left and walk 3 steps away from shelf [4] turn around left and walk 3 steps to shelf [5] deposit item on shelf (top) [6] turn around left and walk 3 steps away from shelf [7] turn around left and walk 3 steps to shelf [8] grab item from shelf (top) [9] turn around left and walk 3 steps away from shelf [10] turn around left and walk 3 steps to shelf [11] deposit item on shelf (bottom) [12] turn around left and walk 3 steps away from shelf [13] turn around left and walk 3 steps to shelf [14] grab item from shelf (bottom) [15] turn around left and walk 3 steps away from shelf [16] turn around left and walk 3 steps to shelf [17] deposit item on shelf (middle)

2-3 Shelf (while standing): [1] grab item from shelf (middle) [2] deposit item on shelf (top) [3] grab item from shelf (top) [4] deposit item on shelf (bottom) [5] grab item from shelf (bottom) [6] deposit item on shelf (middle)

3 Sports

3-1 Dancing: [1] 4 basic steps waltz [2] 4 basic steps waltz with turning [3] wait [4] 4 basic steps cha cha [5] 4 promenades cha cha [6] 4 cha cha turns

3-2 Kicking and punching: [1] 2 kicks (right foot forwards) [2] 2 kicks (right foot sideways) [3] 2 kicks (left foot forwards) [4] 2 kicks (left foot sideways) [5] 2 punches (right hand forwards) [6] 2 punches (right hand sideways) [7] 2 punches (left hand forwards) [8] 2 punches (left hand sideways)

3-3 Throwing: [1] sit down on floor [2] 1 throw (pitching) and 1 throw (tossing a stone, low, sideways) [3] stand up [4] 1 throw (pitching), 1 throw (tossing a stone, low, sideways), and 1 shot (basketball) [5] run and 1 throw (pitching)

3-4 Rotating arms: [1] 4 forward rotations (right arm) [2] 4 backward rotations (right arm) [3] 4 forward rotations (left arm) [4] 4 backward rotations (left arm) [5] 4 forward rotations (both arms) [6] 4 backward rotations (both arms) [7] 4 swings in front of body (both arms) [8] 4 forward rotations while walking (both arms) [9] turn around [10] 4 backward rotations while walking (both arms)

3-5 Workout: [1] 4 jumping jacks [2] 4 times skiing exercise [3] 4 times elbow-to-knee exercise (start with right elbow to left knee) [4] 4 squats

3-8 Workout I: [1] 5 times moving arms an legs together in the airs (while lying on floor) [2] turn body around (face to floor) [3] 3 push-ups [4] 5 jumps (from the floor up to the air with stretched arms)

3-9 Workout II: [1] 5 sit-ups [2] turn body around (face to floor) [3] 3 Indian push-ups

3-10 Rope skipping: different speeds and styles

3-11 Badminton: [1] low serve [2] clear [3] drop [4] smash

4 Sitting and Lying Down:

4-1 Chair, table, floor: [1] walk 3 steps to chair [2] sit down on chair [3] stand up [4] walk 3 steps away from chair and turn around [5] walk 3 steps to chair [6] sit down on chair [7] stand up [8] walk 3 steps away from chair and turn around [9] walk 3 steps to table [10] sit down on table [11] stand up [12] walk 3 steps away from table and turn around [13] walk 3 steps to table [14] sit down on table [15] stand up [16] walk 3 steps away from table and turn around [17] walk 3 steps to lying position [18] sit down on floor [19] stand up [20] walk 3 steps away from lying position and turn around [21] walk 3 steps to lying position [22] sit down on floor [23] stand up [24] walk 3 steps away from lying position and turn around [25] walk 3 steps to lying position [26] lie down on floor [27] stand up [28] walk 3 steps away from lying position and turn around [29] walk 3 steps to lying position [30] lie down on floor [31] stand up [32] walk 3 steps away from lying position and turn around

5 Miscellaneous Motions:

5-1 Clapping and waving: [1] 5 seconds waving (right hand) [2] 5 seconds waving (left hand) [3] 5 seconds waving (right arm) [4] 5 seconds waving (left arm) [5] 5 seconds waving above head (both arms) [6] 5 seconds clapping (applauding) [7] 5 seconds clapping above head (cheering)

5-2 Shouting and tying shoes: [1] shout with both hands on mouth [2] lower hands [3] bend knees and tie left shoe [4] stand up [5] shout with both hands on mouth [6] lower hands [7] bend knees and tie left shoe [8] stand up [9] hit head with one hand

5-3 Variations of locomotion: [1] stumbling [2] limping [3] running with acceleration and deceleration [4] cartwheel

2.2 `HDM05_c3d` and `HDM05_amc`

The directory `HDM05_c3d` contains the raw marker-based mocap data in the C3D format. The files are stored in five subdirectories corresponding to the five different actors. Similarly, the directory `HDM05_amc` contains the corresponding skeleton-based versions in the AMC format, which were obtained by some semi-automatic fitting procedure using the "Vicon Bodybuilder"-software. Besides the AMC files that contain the pure motion data, there is, for each of the five actors, also an ASF-file that contains the skeletal information.

In view of faster access, all C3D and AMC files go along with a corresponding MATLAB file that contains preprocessed MATLAB structures as described in Sect. 3. These files work as a cache for our MATLAB parser (see Sect. 3.1). Our parser tries to read the data from these MATLAB files first, which is much faster than parsing the original C3D and AMC files.

For the mocap files, we use the following naming convention:

```
HDM_{actor}_{part}_{scene}_{take}_{framerate}.C3D
HDM_{actor}_{part}_{scene}_{take}_{framerate}.AMC
HDM_{actor}.ASF
```

Here, the field `actor` refers to one of the five actors encoded by the initial `bd` (Bastian Demuth), `bk` (Björn Krüger), `dg` (Daniel Goldbach), `mm` (Meinard Müller), or `tr` (Tido Röder). The fields `part` and `scene` refer to the corresponding numbers in the script, see Sect. 2.1. The field `take` denotes the take number of the respective scene. Finally, the frame rate is given by the field `framerate`. The corresponding MATLAB files have an additional suffix `.MAT`.

In the following table one finds a list—sorted first by actor and then by scene—of all takes, the respective lengths in frames, a contents description, and, possibly, a comment.

File Name Prefix	#(fr.)	Description	Comments
HDM_bd_01-01_01_120	9842	1-1 Walking	
HDM_bd_01-01_02_120	8091	·	
HDM_bd_01-01_03_120	7965	·	
HDM_bd_01-02_01_120	2900	1-2 Locomotion on the spot	
HDM_bd_01-02_02_120	2864	·	
HDM_bd_01-02_03_120	2923	·	
HDM_bd_01-03_01_120	4025	1-3 Locomotion	
HDM_bd_01-03_02_120	4089	·	

File Name Prefix	#(fr.)	Description	Comments
HDM_bd_01-03_03_120	4166	·	
HDM_bd_01-03_04_120	4086	·	
HDM_bd_01-04_01_120	6461	1-4 Locomotion with weights	
HDM_bd_01-04_02_120	7098	·	
HDM_bd_01-04_03_120	6454	·	
HDM_bd_01-04_04_120	6117	·	
HDM_bd_01-05_01_120	4457	1-5 Hopping and jumping	
HDM_bd_01-05_02_120	4655	·	
HDM_bd_01-05_03_120	4851	·	
HDM_bd_01-05_04_120	4633	·	
HDM_bd_01-05_05_120	4518	·	
HDM_bd_01-06_01_120	2219	1-6 Climbing stairs	
HDM_bd_01-06_02_120	1886	·	
HDM_bd_01-06_03_120	2046	·	
HDM_bd_02-01_01_120	3578	2-1 Table and floor	
HDM_bd_02-01_02_120	3670	·	
HDM_bd_02-01_03_120	3457	·	
HDM_bd_02-02_01_120	6324	2-2 Shelf (while walking)	
HDM_bd_02-02_02_120	6080	·	
HDM_bd_02-03_01_120	2684	2-3 Shelf (while standing)	
HDM_bd_02-03_02_120	2539	·	
HDM_bd_03-02_01_120	3958	3-2 Kicking and punching	
HDM_bd_03-02_02_120	4084	·	
HDM_bd_03-02_03_120	4046	·	
HDM_bd_03-03_01_120	3134	3-3 Throwing	
HDM_bd_03-03_02_120	2764	·	
HDM_bd_03-03_03_120	2765	·	
HDM_bd_03-04_01_120	6334	3-4 Rotating arms	
HDM_bd_03-04_02_120	6190	·	
HDM_bd_03-04_03_120	6126	·	
HDM_bd_03-04_04_120	6073	·	
HDM_bd_03-05_01_120	3316	3-5 workout	
HDM_bd_03-05_02_120	3707	·	
HDM_bd_03-05_03_120	3458	·	
HDM_bd_03-10_01_120	2686	3-10 Rope skipping	
HDM_bd_03-10_02_120	1056	·	
HDM_bd_03-10_03_120	939	·	
HDM_bd_03-11_01_120	4210	3-11 Badminton	
HDM_bd_03-11_02_120	2636	·	
HDM_bd_03-11_03_120	2258	·	
HDM_bd_04-01_01_120	11843	4-1 Chair, table, floor	
HDM_bd_04-01_02_120	10434	·	
HDM_bd_05-01_01_120	5920	5-1 Clapping and waving	
HDM_bd_05-01_02_120	4645	·	
HDM_bd_05-01_03_120	3862	·	
HDM_bd_05-02_01_120	1737	5-2 Shouting and tying shoes	
HDM_bd_05-02_02_120	1758	·	
HDM_bd_05-02_03_120	1828	·	
HDM_bd_05-03_01_120	3280	5-3 Variations of locomotion	
HDM_bd_05-03_02_120	3992	·	
HDM_bd_05-03_03_120	3501	·	
HDM_bd_06-01_01_120	3133	Different boxing and kicking motions	
HDM_bd_06-01_02_120	2490	Handstand	
HDM_bd_06-01_03_120	5659	Different clapping, cheering, and provoking motions	
HDM_bk_01-01_01_120	10282	1-1 Walking	
HDM_bk_01-01_02_120	8747	·	
HDM_bk_01-01_03_120	8969	·	
HDM_bk_01-02_01_120	3421	1-2 Locomotion on the spot	
HDM_bk_01-02_02_120	2834	·	
HDM_bk_01-02_03_120	3406	·	
HDM_bk_01-03_01_120	6707	1-3 Locomotion	
HDM_bk_01-03_02_120	6211	·	
HDM_bk_01-03_03_120	5115	·	
HDM_bk_01-03_04_120	4562	·	
HDM_bk_01-03_05_120	4467	·	
HDM_bk_01-04_01_120	7677	1-4 Locomotion with weights	
HDM_bk_01-04_02_120	7752	·	
HDM_bk_01-04_03_120	6722	·	

File Name Prefix	#(fr.)	Description	Comments
HDM_bk_01-05_01_120	5364	1-5 Hopping and jumping	
HDM_bk_01-05_02_120	5920	·	
HDM_bk_01-05_03_120	5171	·	
HDM_bk_01-06_01_120	2964	1-6 Climbing stairs	
HDM_bk_01-06_02_120	2345	·	
HDM_bk_01-06_03_120	2222	·	
HDM_bk_01-06_04_120	2117	·	
HDM_bk_02-01_01_120	3645	2-1 Table and floor	
HDM_bk_02-01_02_120	3714	·	
HDM_bk_02-01_03_120	3304	·	
HDM_bk_02-02_01_120	6680	2-2 Shelf (while walking)	
HDM_bk_02-02_02_120	7095	·	
HDM_bk_02-02_03_120	6449	·	
HDM_bk_02-03_01_120	2530	2-3 Shelf (while standing)	
HDM_bk_02-03_02_120	1867	·	
HDM_bk_02-03_03_120	2143	·	
HDM_bk_02-03_04_120	1915	·	
HDM_bk_03-01_01_120	9701	3-1 Dancing	
HDM_bk_03-01_02_120	8783	·	
HDM_bk_03-01_03_120	8289	·	
HDM_bk_03-02_01_120	4981	3-2 Kicking and punching	
HDM_bk_03-02_02_120	4141	·	
HDM_bk_03-02_03_120	4269	·	
HDM_bk_03-03_01_120	4412	3-3 Throwing	
HDM_bk_03-03_02_120	5018	·	
HDM_bk_03-03_03_120	4789	·	
HDM_bk_03-04_01_120	11398	3-4 Rotating arms	
HDM_bk_03-04_02_120	7422	·	
HDM_bk_03-04_03_120	7828	·	
HDM_bk_03-04_04_120	7330	·	
HDM_bk_03-05_01_120	6041	3-5 workout	
HDM_bk_03-05_02_120	4639	·	
HDM_bk_03-05_03_120	4612	·	
HDM_bk_03-08_01_120	4998	3-8 workout	
HDM_bk_03-11_01_120	3113	3-11 Badminton	
HDM_bk_03-11_02_120	3277	·	
HDM_bk_03-11_03_120	3008	·	
HDM_bk_04-01_01_120	13318	4-1 Chair, table, floor	
HDM_bk_04-01_02_120	12539	·	
HDM_bk_04-01_03_120	12649	·	
HDM_bk_05-01_01_120	5544	5-1 Clapping and waving	
HDM_bk_05-01_02_120	6154	·	
HDM_bk_05-01_03_120	5841	·	
HDM_bk_05-02_01_120	4192	·	
HDM_bk_05-02_02_120	4386	5-2 Shouting and tying shoes	
HDM_bk_05-02_03_120	4163	·	
HDM_bk_05-03_01_120	4128	5-3 Variations of locomotion	
HDM_bk_05-03_02_120	4594	·	
HDM_bk_05-03_03_120	3909	·	
HDM_dg_01-01_01_120	7542	1-1 Walking	
HDM_dg_01-01_02_120	7660	·	
HDM_dg_01-01_03_120	7687	·	
HDM_dg_01-01_04_120	7647	·	
HDM_dg_01-02_01_120	2867	1-2 Locomotion on the spot	
HDM_dg_01-02_02_120	2762	·	
HDM_dg_01-02_03_120	2786	·	
HDM_dg_01-03_01_120	3498	1-3 Locomotion	
HDM_dg_01-03_02_120	3794	·	
HDM_dg_01-03_03_120	3584	·	
HDM_dg_01-04_01_120	5509	1-4 Locomotion with weights	
HDM_dg_01-04_02_120	6394	·	
HDM_dg_01-04_03_120	6047	·	
HDM_dg_01-05_01_120	4489	1-5 Hopping and jumping	
HDM_dg_01-05_02_120	3947	·	
HDM_dg_01-05_03_120	4660	·	
HDM_dg_01-06_01_120	2348	1-6 Climbing stairs	
HDM_dg_01-06_02_120	2216	·	

File Name Prefix	#(fr.)	Description	Comments
HDM_dg_01-06_03_120	1909	·	
HDM_dg_02-01_01_120	3034	2-1 Table and floor	
HDM_dg_02-01_02_120	3526	·	
HDM_dg_02-01_03_120	3108	·	
HDM_dg_02-02_01_120	6087	2-2 Shelf (while walking)	
HDM_dg_02-02_02_120	4198	·	
HDM_dg_02-02_03_120	4750	·	
HDM_dg_02-02_04_120	5461	·	
HDM_dg_02-03_01_120	2436	2-3 Shelf (while standing)	
HDM_dg_02-03_02_120	2900	·	
HDM_dg_02-03_03_120	2225	·	
HDM_dg_03-01_01_120	8336	3-1 Dancing	
HDM_dg_03-01_02_120	7430	·	
HDM_dg_03-01_03_120	7951	·	
HDM_dg_03-02_01_120	6823	3-2 Kicking and punching	
HDM_dg_03-02_02_120	5861	·	
HDM_dg_03-02_03_120	3454	·	
HDM_dg_03-03_01_120	3219	3-3 Throwing	
HDM_dg_03-03_02_120	3312	·	
HDM_dg_03-03_03_120	3531	·	
HDM_dg_03-04_01_120	7101	3-4 Rotating arms	
HDM_dg_03-04_02_120	6307	·	ASF/AMC does not fit C3D
HDM_dg_03-04_03_120	6444	·	
HDM_dg_03-05_01_120	3839	3-5 workout	
HDM_dg_03-05_02_120	3866	·	
HDM_dg_03-05_03_120	3551	·	
HDM_dg_03-09_01_120	5314	sit-ups, push-ups, workout	flipping markers during push-ups
HDM_dg_03-09_02_120	4844	·	
HDM_dg_03-09_03_120	4052	·	
HDM_dg_03-11_01_120	2859	3-11 Badminton	
HDM_dg_03-11_02_120	3138	·	
HDM_dg_03-11_03_120	2711	·	
HDM_dg_03-11_04_120	6188	·	
HDM_dg_04-01_01_120	9088	4-1 Chair, table, floor	
HDM_dg_04-01_02_120	8316	·	
HDM_dg_05-01_01_120	5607	5-1 Clapping and waving	
HDM_dg_05-01_02_120	6865	·	
HDM_dg_05-01_03_120	6617	·	
HDM_dg_05-02_01_120	2468	5-2 Shouting and tying shoes	
HDM_dg_05-02_02_120	2063	·	
HDM_dg_05-02_03_120	1995	·	
HDM_dg_05-03_01_120	3276	5-3 Variations of locomotion	
HDM_dg_05-03_02_120	3425	·	
HDM_dg_06-01_01_120	9130	wobbling	
HDM_dg_06-02_01_120	8136	walking and jogging in circles	
HDM_dg_06-03_01_120	331	walking	
HDM_dg_06-03_02_120	285	·	
HDM_dg_06-03_03_120	202	jogging	
HDM_dg_06-03_04_120	99	running	
HDM_dg_06-04_01_120	3987	provoking	
HDM_dg_07-01_01_120	3436	inline skating in circles	
HDM_dg_07-01_02_120	279	inline skating straight	
HDM_dg_07-01_03_120	183	inline skating straight	
HDM_dg_07-01_04_120	234	inline skating backwards	
HDM_dg_07-01_05_120	309	inline skating straight	
HDM_dg_07-01_06_120	251	inline skating jumping	
HDM_dg_07-01_07_120	269	inline skating turning	
HDM_dg_07-01_08_120	285	inline skating backwards	
HDM_dg_08-01_01_120	2131	opening bottle and drinking	
HDM_mm_01-01_01_120	8361	1-1 Walking	
HDM_mm_01-01_02_120	8257	·	
HDM_mm_01-01_03_120	7487	·	
HDM_mm_01-02_01_120	3059	1-2 Locomotion on the spot	
HDM_mm_01-02_02_120	2712	·	

File Name Prefix	#(fr.)	Description	Comments
HDM_mm_01-02_03_120	3990	·	
HDM_mm_01-03_01_120	3928	1-3 Locomotion	
HDM_mm_01-03_02_120	4020	·	
HDM_mm_01-03_03_120	3674	·	
HDM_mm_01-04_01_120	6918	1-4 Locomotion with weights	
HDM_mm_01-04_02_120	6687	·	
HDM_mm_01-04_03_120	6806	·	
HDM_mm_01-05_01_120	4673	1-5 Hopping and jumping	
HDM_mm_01-06_01_120	2514	1-6 Climbing stairs	
HDM_mm_01-06_02_120	3188	·	
HDM_mm_01-06_03_120	1816	·	
HDM_mm_02-01_01_120	3673	2-1 Table and floor	
HDM_mm_02-01_02_120	2449	·	
HDM_mm_02-01_03_120	3576	·	
HDM_mm_02-01_04_120	1845	·	
HDM_mm_02-02_01_120	5810	2-2 Shelf (while walking)	
HDM_mm_02-02_02_120	8500	·	
HDM_mm_02-02_03_120	4237	·	
HDM_mm_02-03_01_120	3464	2-3 Shelf (while standing)	
HDM_mm_02-03_02_120	2205	·	
HDM_mm_02-03_03_120	2240	·	
HDM_mm_03-01_01_120	7767	3-1 Dancing	
HDM_mm_03-01_02_120	6995	·	
HDM_mm_03-01_03_120	8040	·	
HDM_mm_03-02_01_120	7671	3-2 Kicking and punching	
HDM_mm_03-02_02_120	4850	·	
HDM_mm_03-02_03_120	3313	·	
HDM_mm_03-02_04_120	8340	·	
HDM_mm_03-03_01_120	3900	3-3 Throwing	
HDM_mm_03-03_02_120	4299	·	
HDM_mm_03-04_01_120	10361	3-4 Rotating arms	
HDM_mm_03-04_02_120	7244	·	
HDM_mm_03-04_03_120	4543	·	
HDM_mm_03-05_01_120	1994	3-5 workout	
HDM_mm_03-05_02_120	4290	·	
HDM_mm_03-05_03_120	3485	·	
HDM_mm_03-10_01_120	5553	rope skipping (two-legged)	
HDM_mm_03-10_02_120	5270	rope skipping (one-legged)	
HDM_mm_03-10_03_120	6226	rope skipping (alternating legs)	
HDM_mm_03-10_04_120	2476	rope skipping (two turns per jump)	
HDM_mm_03-10_05_120	2468	rope skipping (very fast)	
HDM_mm_03-10_06_120	979	rope skipping (2 people turning rope)	
HDM_mm_03-10_07_120	1679	rope skipping (2 people turning rope)	
HDM_mm_04-01_01_120	12848	4-1 Chair, table, floor	
HDM_mm_04-01_02_120	7535	·	
HDM_mm_05-01_01_120	6361	5-1 Clapping and waving	
HDM_mm_05-01_02_120	6953	·	
HDM_mm_05-01_03_120	6218	·	
HDM_mm_05-02_01_120	2428	5-2 Shouting and tying shoes	
HDM_mm_05-02_02_120	2103	·	
HDM_mm_05-02_03_120	2556	·	
HDM_mm_05-03_01_120	4170	5-3 Variations of locomotion	
HDM_mm_05-03_02_120	4167	·	
HDM_mm_05-03_03_120	4328	·	
HDM_mm_06-04_01_120	5795	provoking	
HDM_mm_08-01_01_120	2450	opening bottle and drinking	
HDM_tr_01-01_01_120	8893	1-1 Walking	
HDM_tr_01-01_02_120	7967	·	
HDM_tr_01-01_03_120	7889	·	
HDM_tr_01-02_01_120	2952	1-2 Locomotion on the spot	
HDM_tr_01-02_02_120	2922	·	
HDM_tr_01-02_03_120	2972	·	
HDM_tr_01-03_01_120	3611	1-3 Locomotion	
HDM_tr_01-03_02_120	3959	·	
HDM_tr_01-03_03_120	3690	·	
HDM_tr_01-03_04_120	3735	·	
HDM_tr_01-04_01_120	6629	1-4 Locomotion with weights	
HDM_tr_01-05_01_120	4792	1-5 Hopping and jumping	

File Name Prefix	#(fr.)	Description	Comments
HDM_tr_01-05_02_120	4638	·	
HDM_tr_01-05_03_120	4548	·	
HDM_tr_01-06_01_120	1704	1-6 Climbing stairs	
HDM_tr_01-06_02_120	1351	·	
HDM_tr_01-06_03_120	2063	·	
HDM_tr_02-01_01_120	3402	2-1 Table and floor	
HDM_tr_02-01_02_120	3321	·	
HDM_tr_02-01_03_120	3307	·	
HDM_tr_02-02_01_120	5922	2-2 Shelf (while walking)	
HDM_tr_02-02_02_120	5883	·	
HDM_tr_02-02_03_120	5088	·	
HDM_tr_02-02_04_120	5573	·	
HDM_tr_02-03_01_120	2402	2-3 Shelf (while standing	
HDM_tr_02-03_02_120	2746	·	
HDM_tr_02-03_03_120	1720	·	
HDM_tr_03-01_01_120	9459	3-1 Dancing	
HDM_tr_03-01_02_120	8250	·	
HDM_tr_03-01_03_120	7516	·	
HDM_tr_03-01_04_120	8590	·	
HDM_tr_03-02_01_120	4761	3-2 Kicking and punching	
HDM_tr_03-02_02_120	4572	·	
HDM_tr_03-02_03_120	4452	·	
HDM_tr_03-02_04_120	4255	·	
HDM_tr_03-03_01_120	3721	3-3 Throwing	
HDM_tr_03-03_02_120	3723	·	
HDM_tr_03-03_03_120	3323	·	
HDM_tr_03-04_01_120	6239	3-4 Rotating arms	
HDM_tr_03-04_02_120	6988	·	
HDM_tr_03-04_03_120	7553	·	
HDM_tr_03-05_01_120	4999	3-5 workout	
HDM_tr_03-05_02_120	4500	·	
HDM_tr_03-05_03_120	4357	·	
HDM_tr_03-10_01_120	2855	rope jumping while spinning	
HDM_tr_03-10_02_120	2479	·	
HDM_tr_03-10_03_120	1578	·	
HDM_tr_03-11_01_120	3635	3-11 Badminton	
HDM_tr_03-11_02_120	2581	·	
HDM_tr_03-11_03_120	2209	·	
HDM_tr_04-01_01_120	11201	4-1 Chair, table, floor	
HDM_tr_05-01_01_120	5842	5-1 Clapping and waving	
HDM_tr_05-01_02_120	4942	·	
HDM_tr_05-01_03_120	4316	·	
HDM_tr_05-02_01_120	1691	5-2 Shouting and tying shoes	
HDM_tr_05-02_02_120	1726	·	
HDM_tr_05-02_03_120	1705	·	
HDM_tr_05-03_01_120	3224	5-3 Variations of locomotion	
HDM_tr_05-03_02_120	3634	·	
HDM_tr_05-03_03_120	3338	·	
HDM_tr_05-03_04_120	6453	·	
HDM_tr_06-01_01_120	10767	various volleyball motions	
HDM_tr_06-01_02_120	16136	various weight lifting motions	

2.3 `HDM05_cut_c3d` and `HDM05_cut_amc`

From the full mocap takes listed in Sect. 2.2, suitable motion clips have been manually cut out and arranged into roughly 100 different motion classes. The mapping from the full takes to these clips can be found in `tools\cut_script.txt`. Most of these classes contain 10 to 50 different realizations amounting to roughly 1,500 motion clips and 50 minutes of motion data. The directory `HDM05_cut_c3d` contains these clips in the C3D format. It is subdivided into further subdirectories each corresponding to a motion class. Furthermore, as in described in Sect. 2.2, one finds to each clip a preprocessed cache MATLAB file. The directory `HDM05_cut_amc` has exactly the same directory structure as `HDM05_cut_c3d` and contains the corresponding ASF/AMC files.

The naming conventions are similar to the ones described in Sect. 2.2.

```
HDM_{actor}_{motion class}_{framerate}.C3D
HDM_{actor}_{motion class}_{framerate}.AMC
HDM_{actor}.ASF
```

In the following table, one finds a list of all motion classes. The first and second column contains the name of the motion class and the total number of realizations, respectively. The third to seventh column indicate the number of realizations for each actor separately. The last two columns give a content description of the motion class, and, possibly, further comments. The technical aspects of the cut files, such as the number and name of markers and the framerate, are inherited from the whole motion clips they have been cut out from.

MotionClass	#	bd	bk	dg	mm	tr	Class Description	Comments
cartwheelLHandStart1Reps	21	4	3	0	3	11		
cartwheelLHandStart2Reps	4	0	0	0	0	4		
cartwheelRHandStart1Reps	3	0	0	2	0	1		
clap1Reps	17	3	3	3	5	3		
clap5Reps	17	3	3	3	5	3		
clapAboveHead1Reps	17	3	3	3	5	3		
clapAboveHead5Reps	14	3	3	3	3	2		
depositFloorR	32	6	6	6	8	6		
depositHighR	28	4	6	5	6	7		
depositLowR	29	4	7	6	6	6		
depositMiddleR	29	4	7	5	6	7		
elbowToKnee1RepsLelbowStart	27	6	6	6	2	7		
elbowToKnee1RepsRelbowStart	27	6	6	6	2	7		
elbowToKnee3RepsLelbowStart	13	3	3	3	1	3		
elbowToKnee3RepsRelbowStart	13	3	3	3	1	3		
grabFloorR	16	3	3	3	4	3		
grabHighR	29	4	6	6	6	7		
grabLowR	29	4	7	6	6	6		
grabMiddleR	28	4	7	6	5	6		
hitRHandHead	13	3	3	3	1	3		
hopBothLegs1hops	36	12	9	9	3	3		
hopBothLegs2hops	12	4	3	3	1	1		
hopBothLegs3hops	12	4	3	3	1	1		
hopLLeg1hops	41	11	9	9	3	9		
hopLLeg2hops	14	4	3	3	1	3		
hopLLeg3hops	14	4	3	3	1	3		
hopRLeg1hops	42	12	9	9	3	9		
hopRLeg2hops	14	4	3	3	1	3		
hopRLeg3hops	14	4	3	3	1	3		
jogLeftCircle4StepsRstart	17	2	5	3	3	4		
jogLeftCircle6StepsRstart	15	1	5	2	3	4		
jogOnPlaceStartAir2StepsLStart	14	3	3	2	3	3		
jogOnPlaceStartAir2StepsRStart	14	3	3	2	3	3		
jogOnPlaceStartAir4StepsLStart	14	3	3	2	3	3		
jogOnPlaceStartFloor2StepsRStart	14	3	3	2	3	3		
jogOnPlaceStartFloor4StepsRStart	14	3	3	2	3	3		
jogRightCircle4StepsLstart	2	2	0	0	0	0		
jogRightCircle4StepsRstart	17	2	5	3	3	4		
jogRightCircle6StepsLstart	2	2	0	0	0	0		
jogRightCircle6StepsRstart	12	2	5	2	3	0		
jumpDown	14	4	3	3	1	3		
jumpingJack1Reps	52	12	12	12	4	12		
jumpingJack3Reps	13	3	3	3	1	3		
kickLFront1Reps	29	6	6	6	6	5		
kickLFront2Reps	14	3	3	3	3	2		
kickLSide1Reps	26	6	4	6	4	6		

MotionClass	#	bd	bk	dg	mm	tr	Class Description	Comments
kickLSide2Reps	13	3	2	3	2	3		
kickRFront1Reps	30	6	6	6	6	6		
kickRFront2Reps	15	3	3	3	3	3		
kickRSide1Reps	30	6	6	6	6	6		
kickRSide2Reps	15	3	3	3	3	3		
lieDownFloor	20	4	6	4	4	2		
punchLFront1Reps	30	6	6	6	6	6		
punchLFront2Reps	15	3	3	3	3	3		
punchLSide1Reps	30	6	6	6	6	6		
punchLSide2Reps	15	3	3	3	3	3		
punchRFront1Reps	30	6	6	6	6	6		
punchRFront2Reps	15	3	3	3	3	3		
punchRSide1Reps	28	6	6	4	6	6		
punchRSide2Reps	14	3	3	2	3	3		
rotateArmsBothBackward1Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsBothBackward3Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsBothForward1Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsBothForward3Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsLBackward1Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsLBackward3Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsLForward1Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsLForward3Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsRBackward1Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsRBackward3Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsRForward1Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
rotateArmsRForward3Reps	16	4	4	2	3	3		AMC dg...010 does not fit C3D
runOnPlaceStartAir2StepsLStart	15	3	3	3	3	3		
runOnPlaceStartAir2StepsRStart	15	3	3	3	3	3		
runOnPlaceStartAir4StepsLStart	14	2	3	3	3	3		
runOnPlaceStartFloor2StepsRStart	15	3	3	3	3	3		
runOnPlaceStartFloor4StepsRStart	15	3	3	3	3	3		
shuffle2StepsLStart	13	3	0	4	3	3		
shuffle2StepsRStart	13	3	0	4	3	3		
shuffle4StepsLStart	13	3	0	4	3	3		
shuffle4StepsRStart	12	3	0	3	3	3		
sitDownChair	20	4	6	4	4	2		
sitDownFloor	20	4	6	4	4	2		
sitDownKneelTieShoes	17	3	6	3	2	3		AMC shoes strong artifact at rknee
sitDownTable	20	4	6	4	4	2		
skier1RepsLstart	30	9	8	9	4	0		
skier3RepsLstart	10	3	3	3	1	0		
sneak2StepsLStart	16	3	3	4	3	3		
sneak2StepsRStart	16	3	3	4	3	3		
sneak4StepsLStart	15	3	3	3	3	3		
sneak4StepsRStart	16	3	3	4	3	3		
squat1Reps	52	12	12	12	4	12		
squat3Reps	13	3	3	3	1	3		
staircaseDown3Rstart	15	3	3	3	3	3		
staircaseUp3Rstart	28	7	5	6	4	6		
standUpKneelToStand	17	3	6	3	2	3		
standUpLieFloor	20	4	6	4	4	2		
standUpSitChair	20	4	6	4	4	2		
standUpSitFloor	20	4	6	4	4	2		
standUpSitTable	20	4	6	4	4	2		
throwBasketball	14	3	3	3	2	3		
throwFarR	14	3	3	3	2	3		
throwSittingHighR	14	3	3	3	2	3		
throwSittingLowR	14	3	3	3	2	3		
throwStandingHighR	14	3	3	3	2	3		
throwStandingLowR	14	3	3	3	2	3		
turnLeft	30	1	3	12	12	2		
turnRight	30	14	6	3	0	7		

MotionClass	#	bd	bk	dg	mm	tr	Class Description	Comments
walk2StepsLstart	31	6	6	8	6	5		
walk2StepsRstart	31	6	6	8	6	5		
walk4StepsLstart	16	3	3	4	3	3		
walk4StepsRstart	16	3	3	4	3	3		
walkBackwards2StepsRstart	15	3	3	4	3	2		
walkBackwards4StepsRstart	15	3	3	4	3	2		
walkLeft2Steps	16	3	3	4	3	3		
walkLeft3Steps	16	3	3	4	3	3		
walkLeftCircle4StepsLstart	2	2	0	0	0	0		
walkLeftCircle4StepsRstart	18	3	6	3	2	4		
walkLeftCircle6StepsLstart	2	2	0	0	0	0		
walkLeftCircle6StepsRstart	15	3	3	3	2	4		
walkOnPlace2StepsLStart	15	3	3	3	3	3		
walkOnPlace2StepsRStart	15	3	3	3	3	3		
walkOnPlace4StepsLStart	15	3	3	3	3	3		
walkOnPlace4StepsRStart	15	3	3	3	3	3		
walkRightCircle4StepsLstart	1	1	0	0	0	0		
walkRightCircle4StepsRstart	15	1	4	3	3	4		
walkRightCircle6StepsLstart	1	1	0	0	0	0		
walkRightCircle6StepsRstart	10	0	1	3	3	3		
walkRightCrossFront2Steps	16	3	3	4	3	3		
walkRightCrossFront3Steps	13	3	3	3	1	3		

2.4 Videos

For some of the motions, additional AVI movie clips are available, which have been recorded with a customary digital camcorder. Each movie clip has been manually trimmed to correspond to an explicitly given fragment of a mocap file. In the following table, one finds a list of all video clips indicating the respective video filename (first column), the filename of the the corresponding mocap file (second column), as well as the start and the end frames within this mocap file matching the video clip (third and fourth column). The total length of the whole MoCap-take is denoted in the column *eof*.

Videofilename	corr.mocapfile	start	end	eof	Comments
HDM_bd_01-01_01_25.avi	HDM_bd_01-01_01	560	9841	9841	
HDM_bk_03-03_01_25.avi	HDM_bk_03-03_01	1	4411	4411	
HDM_dg_03-02_02_25.avi	HDM_dg_03-02_02	450	5750	5860	
HDM_dg_03-05_01_25.avi	HDM_dg_03-05_01	1	3838	3838	
HDM_mm_01-05_01_25.avi	HDM_mm_01-05_01	1	4672	4672	
HDM_mm_03-05_01_25.avi	HDM_mm_03-05_01	1	1993	1993	
HDM_mm_03-05_02_25.avi	HDM_mm_03-05_02	350	4289	4289	
HDM_mm_03-05_03_25.avi	HDM_mm_03-05_03	220	3400	3484	
HDM_mm_04-01_01_25.avi	HDM_mm_04-01_01	1	12848	12848	
HDM_mm_05-03_01_25.avi	HDM_mm_05-03_01	1	4169	4169	
HDM_mm_05-03_02_25.avi	HDM_mm_05-03_02	1	4166	4166	
HDM_mm_05-03_03_25.avi	HDM_mm_05-03_03	1	4327	4327	
HDM_tr_01-03_03_25.avi	HDM_tr_01-03_03	430	3689	3689	
HDM_tr_03-05_01_25.avi	HDM_tr_03-05_01	1	4998	4998	
HDM_tr_03-05_02_25.avi	HDM_tr_03-05_02	1	4400	4499	
HDM_tr_03-05_03_25.avi	HDM_tr_03-05_03	1	4356	4356	
HDM_tr_04-01_01_25.avi	HDM_tr_04-01_01	1	11000	11201	
HDM_tr_05-03_01_25.avi	HDM_tr_05-03_01	1	3223	3223	
HDM_tr_05-03_02_25.avi	HDM_tr_05-03_02	1	3550	3633	
HDM_tr_05-03_03_25.avi	HDM_tr_05-03_03	1	3250	3337	
HDM_tr_05-03_04_25.avi	HDM_tr_05-03_04	1	6452	6452	

Remark: Videos-files have been edited by hand and frame numbers may vary a bit.

In addition to these clips, that each show a whole take, there are also clips available for some of the cut files. The naming conventions directly correspond to those of the cut files described in section 2.3, the only difference is the frame rate which is 25 Hz instead of the usual 120 Hz that are provided by the MoCap-System.

Videofilename	corr.mocapfile	start	end	Comments
HDM_mm_cartwheelLHandStart1Reps_008_25.avi	HDM_mm_05-03_01_120	3072	3572	
HDM_mm_cartwheelLHandStart1Reps_009_25.avi	HDM_mm_05-03_02_120	3156	3676	
HDM_mm_cartwheelLHandStart1Reps_010_25.avi	HDM_mm_05-03_03_120	3318	3808	
HDM_tr_cartwheelLHandStart1Reps_011_25.avi	HDM_tr_05-03_01_120	2464	3004	
HDM_tr_cartwheelLHandStart1Reps_012_25.avi	HDM_tr_05-03_02_120	2520	2860	
HDM_tr_cartwheelLHandStart1Reps_013_25.avi	HDM_tr_05-03_02_120	2860	3156	
HDM_tr_cartwheelLHandStart1Reps_014_25.avi	HDM_tr_05-03_03_120	2566	3006	
HDM_tr_cartwheelLHandStart1Reps_015_25.avi	HDM_tr_05-03_04_120	2391	2774	
HDM_tr_cartwheelLHandStart1Reps_016_25.avi	HDM_tr_05-03_04_120	2774	3109	
HDM_tr_cartwheelLHandStart2Reps_001_25.avi	HDM_tr_05-03_02_120	2496	3156	
HDM_dg_elbowToKnee3RepsLelbowStart_007_25.avi	HDM_dg_03-05_01_120	2072	2416	
HDM_mm_elbowToKnee3RepsLelbowStart_010_25.avi	HDM_mm_03-05_02_120	2475	2908	
HDM_dg_elbowToKnee3RepsRelbowStart_007_25.avi	HDM_dg_03-05_01_120	1912	2296	
HDM_mm_elbowToKnee3RepsRelbowStart_010_25.avi	HDM_mm_03-05_02_120	2315	2752	
HDM_tr_jogLeftCircle4StepsRstart_016_25.avi	HDM_tr_01-03_03_120	2368	2612	
HDM_tr_jogLeftCircle6StepsRstart_014_25.avi	HDM_tr_01-03_03_120	2368	2709	
HDM_tr_jogRightCircle4StepsRstart_016_25.avi	HDM_tr_01-03_03_120	2849	3109	
HDM_dg_jumpingJack3Reps_007_25.avi	HDM_dg_03-05_01_120	341	731	
HDM_mm_jumpingJack3Reps_010_25.avi	HDM_mm_03-05_02_120	495	960	
HDM_dg_kickLFront2Reps_008_25.avi	HDM_dg_03-02_02_120	2069	2569	
HDM_dg_kickLSide2Reps_007_25.avi	HDM_dg_03-02_02_120	2675	3001	
HDM_dg_kickRFront2Reps_008_25.avi	HDM_dg_03-02_02_120	467	789	
HDM_dg_kickRSide2Reps_008_25.avi	HDM_dg_03-02_02_120	1440	1788	
HDM_mm_lieDownFloor_015_25.avi	HDM_mm_04-01_01_120	9355	10095	
HDM_mm_lieDownFloor_016_25.avi	HDM_mm_04-01_01_120	11315	11995	
HDM_tr_lieDownFloor_019_25.avi	HDM_tr_04-01_01_120	8290	8910	
HDM_tr_lieDownFloor_020_25.avi	HDM_tr_04-01_01_120	9896	10476	
HDM_dg_punchLFront2Reps_008_25.avi	HDM_dg_03-02_02_120	4539	4841	
HDM_dg_punchLSide2Reps_008_25.avi	HDM_dg_03-02_02_120	5039	5353	
HDM_dg_punchRFront2Reps_008_25.avi	HDM_dg_03-02_02_120	3375	3708	
HDM_bd_shuffle4StepsLStart_001_25.avi	HDM_bd_01-01_01_120	8486	8893	
HDM_bd_shuffle4StepsRStart_001_25.avi	HDM_bd_01-01_01_120	8624	9003	
HDM_mm_sitDownChair_015_25.avi	HDM_mm_04-01_01_120	1001	1381	
HDM_mm_sitDownChair_016_25.avi	HDM_mm_04-01_01_120	2641	2981	
HDM_mm_sitDownFloor_015_25.avi	HDM_mm_04-01_01_120	6475	6955	
HDM_mm_sitDownFloor_016_25.avi	HDM_mm_04-01_01_120	7975	8435	
HDM_dg_skier3RepsLstart_007_25.avi	HDM_dg_03-05_01_120	1307	1610	
HDM_mm_skier3RepsLstart_010_25.avi	HDM_mm_03-05_02_120	1615	2073	
HDM_bd_sneak4StepsLStart_001_25.avi	HDM_bd_01-01_01_120	7623	8123	
HDM_bd_sneak4StepsRStart_001_25.avi	HDM_bd_01-01_01_120	7787	8266	
HDM_mm_squat1Reps_037_25.avi	HDM_mm_03-05_02_120	3222	3410	
HDM_mm_squat1Reps_038_25.avi	HDM_mm_03-05_02_120	3410	3615	
HDM_mm_squat1Reps_039_25.avi	HDM_mm_03-05_02_120	3615	3820	
HDM_mm_squat1Reps_040_25.avi	HDM_mm_03-05_02_120	3820	4024	
HDM_tr_squat1Reps_041_25.avi	HDM_tr_03-05_01_120	3294	3484	
HDM_tr_squat1Reps_042_25.avi	HDM_tr_03-05_01_120	3484	3763	
HDM_tr_squat1Reps_043_25.avi	HDM_tr_03-05_01_120	3763	4074	
HDM_tr_squat1Reps_044_25.avi	HDM_tr_03-05_01_120	4074	4259	
HDM_tr_squat1Reps_045_25.avi	HDM_tr_03-05_02_120	3059	3274	
HDM_tr_squat1Reps_046_25.avi	HDM_tr_03-05_02_120	3274	3525	
HDM_tr_squat1Reps_047_25.avi	HDM_tr_03-05_02_120	3525	3821	
HDM_tr_squat1Reps_048_25.avi	HDM_tr_03-05_02_120	3821	4077	
HDM_tr_squat1Reps_049_25.avi	HDM_tr_03-05_03_120	3012	3236	
HDM_tr_squat1Reps_050_25.avi	HDM_tr_03-05_03_120	3236	3527	
HDM_tr_squat1Reps_051_25.avi	HDM_tr_03-05_03_120	3527	3805	
HDM_tr_squat1Reps_052_25.avi	HDM_tr_03-05_03_120	3805	4099	
HDM_dg_squat3Reps_007_25.avi	HDM_dg_03-05_01_120	2950	3550	
HDM_mm_squat3Reps_010_25.avi	HDM_mm_03-05_02_120	3399	4024	
HDM_tr_squat3Reps_011_25.avi	HDM_tr_03-05_01_120	3528	4259	
HDM_tr_squat3Reps_012_25.avi	HDM_tr_03-05_02_120	3288	4077	
HDM_tr_squat3Reps_013_25.avi	HDM_tr_03-05_03_120	3277	4099	
HDM_mm_standUpSitChair_015_25.avi	HDM_mm_04-01_01_120	1321	1641	
HDM_mm_standUpSitChair_016_25.avi	HDM_mm_04-01_01_120	2941	3341	
HDM_mm_standUpSitFloor_015_25.avi	HDM_mm_04-01_01_120	6895	7215	

Videofilename	corr.mocapfile	start	end	Comments
HDM_mm_standUpSitFloor_016_25.avi	HDM_mm_04-01_01_120	8355	8755	
HDM_bk_throwBasketball_004_25.avi	HDM_bk_03-03_01_120	2825	3305	
HDM_bk_throwFarR_004_25.avi	HDM_bk_03-03_01_120	3525	4124	
HDM_bk_throwSittingHighR_004_25.avi	HDM_bk_03-03_01_120	761	1161	
HDM_bk_throwSittingLowR_004_25.avi	HDM_bk_03-03_01_120	1161	1445	
HDM_bk_throwStandingHighR_004_25.avi	HDM_bk_03-03_01_120	1925	2405	
HDM_bk_throwStandingLowR_004_25.avi	HDM_bk_03-03_01_120	2405	2825	
HDM_bd_turnLeft_001_25.avi	HDM_bd_01-01_01_120	2374	2636	
HDM_bd_turnRight_002_25.avi	HDM_bd_01-01_01_120	1136	1356	
HDM_bd_walk4StepsLstart_001_25.avi	HDM_bd_01-01_01_120	676	1016	
HDM_bd_walk4StepsRstart_001_25.avi	HDM_bd_01-01_01_120	787	1109	
HDM_bd_walkBackwards4StepsRstart_001_25.avi	HDM_bd_01-01_01_120	2629	2998	
HDM_bd_walkLeft3Steps_001_25.avi	HDM_bd_01-01_01_120	4422	4926	
HDM_tr_walkLeftCircle4StepsRstart_017_25.avi	HDM_tr_01-03_03_120	601	901	
HDM_tr_walkLeftCircle6StepsRstart_014_25.avi	HDM_tr_01-03_03_120	601	1034	
HDM_tr_walkRightCircle4StepsRstart_014_25.avi	HDM_tr_01-03_03_120	1174	1503	
HDM_tr_walkRightCircle6StepsRstart_009_25.avi	HDM_tr_01-03_03_120	1174	1628	
HDM_bd_walkRightCrossFront3Steps_001	HDM_bd_01-01_01_120	5041	5741	

Remark: Videos-files have been edited by hand and frame numbers may vary a bit.

3 MATLAB Tools

In our mocap files, all lengths are measured in centimeters. Angles are usually measured in degrees.

3.1 MATLAB Parser

We provide a MATLAB parser both for ASF/AMC and C3D data, which is located in the `tools\parser` directory. Before the parser can be used in a MATLAB session, one has to ensure that the M-files belonging to the parser are available in MATLAB's PATH. This can be easily done by executing `tools\addDirsToPath.m` (once per MATLAB session).

Reading an ASF/AMC file works as follows (for a complete description of all possible parameters type "readMocap" in MATLAB):

```
skelfile = 'HDM_mm.asf';
motfile = 'HDM_mm_cartwheelLHandStart1Reps_001_120.amc';
[skel,mot] = readMocap(skelfile,motfile);
```

Reading a C3D file works as follows:

```
motfile = 'HDM_mm_cartwheelLHandStart1Reps_001_120.c3d';
[skel,mot] = readMocap(motfile);
```

The parser is strongly based on the C3D-Parser available at `www.c3d.org`, but has been modified for our purposes to supply more suitable MATLAB structures (see explanation below). Besides, we strongly enhanced the performance by avoiding to read 12- and 4-byte chunks in a loop (as done by the original parser), but rather read the whole data at once and then decompose it by matrix operations. The performance gain for long MoCap files with thousands of frames lies in the range of 100-500.

The variables `skel` and `mot` that are returned by the parser are MATLAB `structs` containing the following fields:

```
skel =

                  njoints: 31               % number of joints
rootRotationalOffsetEuler: [3x1 double]     % rotational offset of root, XYZ Euler angles
 rootRotationalOffsetQuat: [4x1 double]     % rotational offset of root, quaternion
                    nodes: [31x1 struct]    % contains hierarchy information, explained below
                    paths: {7x1 cell}       % cell array encoding decomposition of kinematic chain tree into paths
               jointNames: {31x1 cell}      % names of joints
                boneNames: {31x1 cell}      % names of bones
                  nameMap: {24x3 cell}      % mapping to standard skeleton, explained below
                 animated: [29x1 double]    % indices into "nodes" denoting bones with associated DOFs
               unanimated: [2x1 double]     % indices into "nodes" denoting bones without associated DOFs
                 filename: 'HDM_tr.asf'
                  version: '1.10'
                     name: 'VICON'
                 massUnit: 1
               lengthUnit: 0.4500           % division factor for lengths to arrive at centimeters
                angleUnit: 'deg'            % can be either "rad" for radians or "deg" for degrees
            documentation: {2x1 cell}       % one cell array entry for each line of documentation
                 fileType: 'ASF'
                     skin: []               % unused
```

```
mot =

          njoints: 31                      % number of joints
          nframes: 441                     % number of frames in motion
        frameTime: 0.0083                  % inverse of sampling rate
     samplingRate: 120                     % sampling rate
jointTrajectories: {31x1 cell}             % cell array of (3 x nframes) matrices encoding 3D joint trajectories
  rootTranslation: [3x441 double]          % (3 x nframes) matrix encoding absolute position of root
    rotationEuler: {31x1 cell}             % Euler angles as (1 x nframes), (2 x nframes), or (3 x nframes) matrices
     rotationQuat: {31x1 cell}             % quaternions as (4 x nframes) matrices for each joint
       jointNames: {31x1 cell}             % names of joints
        boneNames: {31x1 cell}             % names of bones
          nameMap: {24x3 cell}             % mapping to standard skeleton, explained below
         animated: [29x1 double]           % indices into "nodes" denoting bones with associated DOFs
       unanimated: [2x1 double]            % indices into "nodes" denoting bones without associated DOFs
      boundingBox: [6x1 double]            % minimum bounding rectangle of motion
         filename: 'HDM_mm_cartwheelLHandStart1Reps_001_120.amc'
    documentation: ''                      % one cell array entry for each line of documentation
        angleUnit: 'deg'                   % can be either "rad" for radians or "deg" for degrees
```

The entry `skel.nodes` encodes the underlying kinematic chain. The kinematic chain tree consists of abstract *nodes*, which can be though of as both joints and bones (which are pairs of joints). This dualism between joints and bones can be established by associating each bone with its distal joint, where the root forms a special case. See also Sect. 4.1

```
skel.nodes(14) =                           % node number 14 stands for the neck joint

         children: [3x1 double]            % 3 child nodes (neck, 2 claviculae), represented as indices into skel.nodes
        jointName: 'upperback_@_thorax'    % name of node if viewed as a joint
         boneName: 'thorax'                % name of node if viewed as a bone
               ID: 14                      % index of this node within skel.nodes
         parentID: 13                      % index of parent node within skel.nodes
           offset: [3x1 double]            % 3D vector: translation from parent to current node in parent system
        direction: [3x1 double]            % unit-length version of offset vector
           length: 14.5763                 % length of offset vector
             axis: [3x1 double]            % XYZ Euler angles encoding offset of local coord sys against world sys
              DOF: {3x1 cell}              % cell array with possible entries RX, RY, RZ, TX, TY, TZ
    rotationOrder: 'XYZ'                   % XYZ Euler convention, right-to-left multiplication order
           limits: [3x2 double]            % optional field describing angle range limits for rotational DOFs
```

A further interesting field is `skel.nameMap` (`mot.nameMap` is simply a duplicate). This field describes a mapping between the joints of our standard skeleton (see Fig. 2) and the actual joints of the skeleton taken from the mocap file, see also Sect. 4.2. A typical `nameMap` is a 24×3 cell array and looks like this:

```
skel.nameMap =

    'root'          [ 1]    [ 1]
    'lhip'          [ 3]    [ 2]
    'lknee'         [ 4]    [ 3]
    'lankle'        [ 5]    [ 4]
    'ltoes'         [ 0]    [ 6]
    'rhip'          [ 8]    [ 7]
    'rknee'         [ 9]    [ 8]
    'rankle'        [10]    [ 9]
    'rtoes'         [ 0]    [11]
    'belly'         [13]    [12]
    'chest'         [14]    [13]
    'neck'          [15]    [14]
    'head'          [17]    [16]
    'headtop'       [ 0]    [17]
    'lclavicle'     [18]    [14]
    'lshoulder'     [19]    [18]
    'lelbow'        [20]    [19]
    'lwrist'        [22]    [21]
    'lfingers'      [ 0]    [23]
    'rclavicle'     [25]    [14]
    'rshoulder'     [26]    [25]
    'relbow'        [27]    [26]
    'rwrist'        [29]    [28]
    'rfingers'      [ 0]    [30]
```

The first column specifies the joint names of the standard skeleton. The second column contains indices into the cell array `mot.rotationEuler` and `mot.rotationQuat`, specifying which of the entries of those cell arrays holds the rotational DOFs for the respective joint. For example, the quaternions for the joint ‘lelbow’ are found in `mot.rotationQuat{20}`. Zero entries in the second column appear for joints that have no associated DOFs, typically the end effectors.

The third column provides indices into the cell array `mot.jointTrajectories`. For example, the 3D trajectory of the ‘lelbow’ joint is `mot.jointTrajectories{19}`.

The helper functions `DOFID` and `trajectoryID` can be used to perform lookups in the name map. For example, the Euler angles and the joint trajectory for the left elbow can be accessed via

```
eulers = mot.rotationEuler{DOFID(mot,'lelbow')};
  traj = mot.jointTrajectories{trajectoryID(mot,'lelbow')};
```

3.2 MATLAB Animation Tool

In this section, we describe how mocap data can be animated using the `animate` command provided in the `tools\animate` directory. Currently, this animation only works with MATLAB 6.5.

Due to an incompatibility in MATLAB’s timer concept that was introduced in the version change from 6.5 to 7, MATLAB 7 will not be able to properly render the animation.

After the appropriate directory has been added to MATLAB’s path (by executing `tools\addDirsToPath.m`; necessary only once per session), animations can be started as follows:

```
animate(skel,mot,num_repeats,time_scale_factor,range,show_frame_counter);
animate([skel1 skel2 skelN], [mot1 mot2 motN], ...
        num_repeats, time_scale_factor, ...
        {[1:100] [50:200] []}, ...
        [true true false]);
```

The latter command can animate several skeletons in parallel. Note that some of the options have to be specified separately for each of the skeletons.

The camera tool of MATLAB’s figure window can be used to change the view settings. Particularly useful is the “orbit” function, for which the principal axis should be set to “Y” since the Y axis points upwards for our mocap data.

3.3 Cutting Tool

The tools for generating the MoCap-clips described in section 2.3 can be found in the `tools\cutTool` directory. Using the cut-program and some cut-files describing which cuts to perform, one can easily create their own clips.

Format of the Cut Files

Each line of the cut files used by the cutting tool has to comply with the following format:

"relative filename" frameNrStart frameNrEnd outputFilename

Comment lines should start with the symbol %, but in fact all lines not starting with quotes (ASCII 34) are ignored by this version of the cutting tool.

Example of a cut file:

```
% motion class staircaseUp3Rstart
"HDM05\HDM05_amc\bd\HDM_bd_01-05_02_120.amc"    3506    3907    HDM_bd_staircaseUp3Rstart_001_120
"HDM05\HDM05_amc\bd\HDM_bd_01-05_03_120.amc"    3673    4116    HDM_bd_staircaseUp3Rstart_002_120
"HDM05\HDM05_amc\bd\HDM_bd_01-05_04_120.amc"    3573    3953    HDM_bd_staircaseUp3Rstart_003_120
"HDM05\HDM05_amc\bd\HDM_bd_01-05_05_120.amc"    3558    3913    HDM_bd_staircaseUp3Rstart_004_120
"HDM05\HDM05_amc\bd\HDM_bd_01-06_01_120.amc"     781    1085    HDM_bd_staircaseUp3Rstart_005_120
"HDM05\HDM05_amc\bd\HDM_bd_01-06_02_120.amc"     781     971    HDM_bd_staircaseUp3Rstart_006_120
```

Applying Cut Files to Mocap Data

Performing the cuts and generating the cut-out MoCap-files is straight forward - just call the cutting tool with the following parameters:

```
applyCutMapping( cutMappingInputPathOrFile, inputPath, outputPath, fileType )
```

`cutMappingInputPathOrFile` can be either a single file or a directory. In the latter case, all *.txt files will be processed. The `inputPath` specifies the absolute path of the input files and will be completed by the relative part of the path found in the cut-file(s). `fileType` can be used to determines which type of files will be processed. It can be either 'c3d', 'amc' or left empty. The default behaviour (if left empty) generates both AMC and C3D versions of the clips.

The cutting tool creates all clips in one directory. Please note that there is an additional tool to sort the clips into directories named by the motion classes. It can also be found in `tools\cutTool` and has the following parameters:

```
sortCutFiles( inputPath, substringStart, substringDelimiter )
```

Please type *help sortCutFiles* for further explanation.

4 Mocap File Formats

4.1 ASF/AMC

ASF/AMC is a skeleton-based mocap file format that was developed by the computer game producer Acclaim. With the demise of Acclaim in 2004, usage of this format seems to have been discontinued, and it is not being developed any further. Furthermore, the format is very poorly documented, the only sources are web pages such as [1]. Yet there is a large corpus of ASF/AMC mocap data available to the public, for example the CMU mocap database [4]. Commercial mocap software such as Vicon BodyBuilder offers export options to the ASF/AMC format.

Mocap data in ASF/AMC format is described by two separate ASCII-coded files: an ASF file contains the fixed skeleton information, while an AMC file encodes the free parameters. Typically, there will be a single ASF file for each actor, which can be used with multiple AMC files recorded by that actor. ASF files are bone-based in contrast to the joint-based BVH files, which are also widely used. The Euler conventions for ASF and AMC files are always based on a right-to-left multiplication order, corresponding to a fixed reference frame.

The following excerpt from an ASF file was taken from the CMU database [4]. Individual sections within ASF files are delimited by keywords preceded by a colon (`:`), for example `:name`. An ASF file is divided into three blocks: a header, the bone data, and the skeletal hierarchy.

```
# Example of an ASF file.
# Comments are denoted by a hash sign.
:version            1.10
:name               MY_SKELETON
:units
    mass            1.0
    length          0.45
    angle           deg
:documentation
This is an ASF test file. Documentation can have
an arbitrary number of lines.
#######################################################
:root
    order           TX TY TZ  RX RY RZ
    axis            XYZ
    position        0         0        0
    orientation     0         0        0
:bonedata
    begin
        id          1
        name        lhipjoint
        direction   0.603808 -0.713975 0.35448
        length      2.2025
        axis        0         0        0        XYZ
    end
    begin
        id          2
        name        lfemur
        direction   0.34202 -0.939693  0
        length      6.55877
        axis        0         0        20       XYZ
        dof         RX        RY       RZ
```

```
        limits     (-160.0  20.0)
                   ( -70.0  70.0)
                   ( -60.0  70.0)
    end
    begin
        id         3
        name       ltibia
        direction  0.34202 -0.939693  0
        length     6.80302
        axis       0        0         20       XYZ
        dof        RX
        limits     (-10.0  170.0)
    end
    begin
        id         4
        name       lfoot
        direction  0.09185 -0.25235   0.963267
        length     2.03446
        axis      -90       0         20       XYZ
        dof        RX                 RZ
        limits     (-45.0   90.0)
                   (-70.0   20.0)
    end
. . .
    begin
        id         30
        name       rthumb
        direction -0.707107 0         0.707107
        length     0.691594
        axis      -90      -45        0        XYZ
        dof        RX                 RZ
        limits     (-45.0   45.0)
                   (-45.0   45.0)
    end
#########################################################
:hierarchy
    begin
        root lhipjoint rhipjoint lowerback
        lhipjoint lfemur
        lfemur ltibia
        ltibia lfoot
        lfoot ltoes
        rhipjoint rfemur
        rfemur rtibia
        rtibia rfoot
        rfoot rtoes
        lowerback upperback
        upperback thorax
        thorax lowerneck lclavicle rclavicle
        lowerneck upperneck
        upperneck head
        lclavicle lhumerus
        lhumerus lradius
        lradius lwrist
        lwrist lhand lthumb
        lhand lfingers
        rclavicle rhumerus
        rhumerus rradius
        rradius rwrist
        rwrist rhand rthumb
        rhand rfingers
    end
```

In the following, we explain some of the important sections of an ASF file.

`:units` — `length` specifies a constant by which all coordinates and lengths appearing in ASF and AMC files have to be *divided* to obtain inches. This is the situation for CMU data. Other variants have been encountered where the data has to be multiplied by the constant to obtain centimeters.

`angle` can be either `deg` or `rad`, standing for degree or radians.

`:root` — The root node is treated separately in ASF files since it is not a proper bone consisting of both a proximal and a distal joint, but rather a single joint. However, those bones that are directly incident to the root are not necessarily rigidly connected to the root but can move by means of their proximal joint.

`order` specifies the order in which the root's degrees of freedom appear in associated AMC files. For example, "`TX`" stands for translation in x direction, while "`RY`" stands for rotation about the y axis.

`axis` defines the Euler convention for the root coordinate system, which is independent of the order of appearance in the AMC file as specified by `order`. A value of "`XYZ`" stands for the Euler convention $\overleftarrow{xyz}$.

`position` is a coordinate triplet describing a translational offset for the root. This can be used to change the starting position of the skeleton without altering the AMC data.

`orientation` is an Euler angle triplet in the convention given by `axis`, which describes a rotational offset for the root. This can be used to change the starting orientation of the skeleton without altering the AMC data.

`:bonedata` — A list of bones, each of which is delimited by `begin`/`end` pairs.

`id` is an optional numeric identifier for the bone.

`name` is supposed to contain no whitespace characters and provides a unique textual description for the bone.

`direction` is a coordinate triplet specifying a vector in the world coordinate system, which indicates the direction of the bone in the skeleton's neutral pose.

`length` is the bone's length. Multiplying a normalized version of the `direction` vector by `length`, one obtains the offset vector to the bone's distal joint.

`axis` is a triplet of Euler angles referring to the skeleton's neutral pose. It specifies the rotational offset of the bone's local coordinate system against the world coordinate system, always using the $\overleftarrow{xyz}$ convention. Confusingly, the Euler convention that is given behind the `axis` Euler triplet has nothing to do with this rotational offset. Instead, it specifies the Euler convention that is used for the rotational degrees of freedom of this bone.

`dof` is an optional field declaring the bone's degrees of freedom and their sequence of appearance in associated AMC files, as for the case of the root's `order` field. Note that the Euler convention for the bone's local coordinate system is independent of their order of appearance in the AMC file. The Euler convention is specified by the `axis` field (see above). Usually, only rotational DOFs are specified for the bones. If less than three rotational DOFs are given, the unspecified Euler angles must be set to be zero.

`limits` is an optional field declaring a valid interval for each DOF, given in the same sequence as the DOFs. The intervals are specified by a start and end value and are enclosed in parentheses. This information is intended for motion editing applications only and does not imply that the data in associated AMC files is actually clipped to the specified range.

`:hierarchy` Enclosed in a `begin`/`end` pair, this section describes the tree structure of the kinematic chain. Each line specifies a parent (first entry) and its children (following entries), where parents must be either the `root` or must have been previously referenced as a child. All references are in terms of the bones' `name` fields.

The AMC file format is as simple as it is impractical to parse. Neither does it contain a field for the sampling rate, nor does its header specify the total number of frames, nor does it give the name of the associated ASF file. Some AMC files contain that information in non-standard comment fields, but we decided to encode the sampling rate and the ASF file in the AMC filename.

After the two header lines, an AMC file gives a list of frames, where each frame is delimited by its frame number. The following lines specify the degrees of freedom for all bones that have associated `dof` fields. The first entry in a line is the bone name, the following entries are the corresponding values for the DOFs, where the sequence is specified by the `order` and `dof` fields, respectively.

The sequence of bones could be different for every frame. In practice, however, one can assume that all frames specify the bones in the same order, which can be exploited to notably speed up the parsing. Generally, AMC data takes rather long to parse due to the high redundancy and the text-based representation, opposed to a binary format. Readability by a human, not speed, was an issue for the designers of the ASF/AMC format.

Here is an example of a one-frame AMC file associated to the above ASF file.

```
:FULLY-SPECIFIED
:DEGREES
1
root         8.25657  15.4288     6.98449   6.82839   -8.42357   1.70701
lowerback  -12.2602   -2.18333   -5.50437
upperback   -0.70081  -2.30222    2.4283
thorax       6.47028  -1.33088    5.28671
```

```
lowerneck     2.07852  -15.724   -16.5646
upperneck     4.67254  -21.8828   12.1131
head          4.19382  -10.9818    4.95799
rclavicle     0          0
rhumerus    -35.355     15.7653  -90.7264
rradius      37.2218
rwrist       -7.61225
rhand       -19.101     20.8962
rfingers      7.12502
rthumb        7.20768   -8.9611
lclavicle     0          0
lhumerus    -35.7523   -10.6979   92.1621
lradius      38.1065
lwrist       22.5441
lhand        -8.19849   44.3013
lfingers      7.12502
lthumb       17.7178    73.5141
rfemur      -20.0494    10.5411   21.064
rtibia       41.0307
rfoot       -30.5875   -12.6663
rtoes        -6.70629
lfemur      -20.5304     2.9253  -26.2642
ltibia       42.4012
lfoot       -13.1633    22.5873
ltoes       -13.3539
```

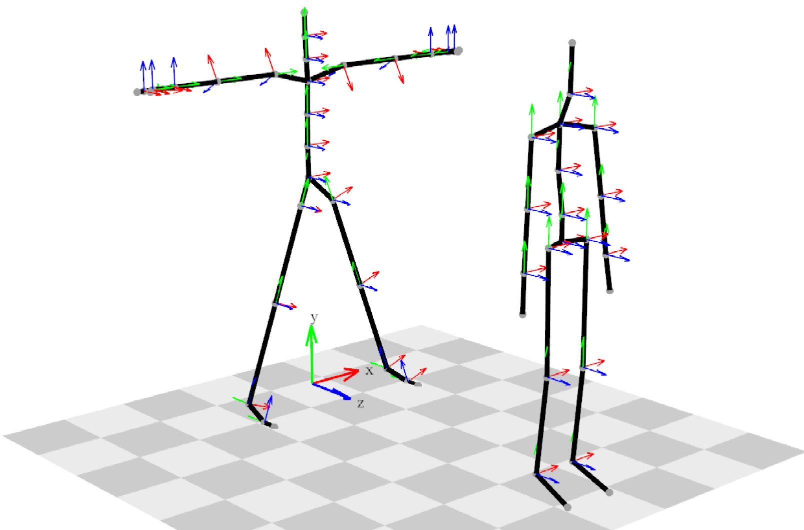

Figure 5. Neutral poses of the ASF skeleton (left) and the BVH skeleton (right). The respective local coordinate systems are shown at each bone's proximal joint. For the BVH skeleton, the local coordinate systems are aligned with the world system. The axes are color-coded as red, green, and blue arrows, standing for the x, y, and z axis, respectively.

4.2 Mapping ASF/AMC Mocap Data to the Standard Skeleton

As a smallest common denominator for different mocap data formats, we use the joint-based standard skeleton of Fig. 2. Table 6 explains how the joints of the standard skeleton correspond to the joints of typical ASF and BVH skeletons.

Joint of standard skeleton	Distal joint of ASF bone
root	root
lhip	lhipjoint
lknee	lfemur
lankle	ltibia
ltoes	ltoes
rhip	rhipjoint
rknee	rfemur
rankle	rtibia
rtoes	rtoes
belly	lowerback
chest	upperback
neck	thorax
head	upperneck
headtop	head
lclavicle	thorax
lshoulder	lclavicle
lelbow	lhumerus
lwrist	lwrist
lfingers	lfingers
rclavicle	thorax
rshoulder	rclavicle
relbow	rhumerus
rwrist	rwrist
rfingers	rfingers

Table 6. Mapping ASF skeletons to the joints of the standard skeleton of Fig. 2.

4.3 The C3D Format

The C3D format is used by many suppliers of mocap hard- and software to export and exchange raw motion capture data. It is a binary format that is not skeleton-based but instead specifies the 3D trajectories of all markers. A documentation is available at [3], and parsers for MATLAB and other programming languages can be found at [4]. One important characteristic of the C3D format is that it allows for additional data streams to be synchronized and stored together with the mocap data. As an example of a typical application, digitized force data from a force plate could be recorded in parallel with the mocap data.

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