Algorithms for computing indexes of neurological gait abnormalities in patients after DBS surgery for Parkinson Disease based on motion capture data

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Abstract:

Motion capture (MOCAP) technology becomes very useful in medical applications, such as orthopedics, neurology and physical therapy. In the literature there are already studies of using MOCAP measurements for diagnosis of gait abnormalities. In this paper we present an algorithm for computation of important indexes defining abnormalities of the gait, for a unified MOCAP data standard, namely for the ASF/AMC MOCAP data recording and storage system. We also present preliminary experimental results concerning examination of Parkinson's disease with bilateral subthalamic nucleus stimulation (PD) patient in the MOCAP laboratory.

1. Introduction

Multi-modal measurement and analysis of human gait, also called motion capture (MOCAP) technology, has recently undergone significant developments, which (among other contributions) has created many new possibilities for improving medical diagnostics and therapy. Fields of medical diagnostics and therapy particularly benefiting from advances in MOCAP technology are orthopedics, neurology, physical therapy and may be in a future in neurosurgery. Thanks to the fact that MOCAP systems allow for precise measurements of geometric and kinematic features of consecutive stages of human gait, as well as synchronizing multimodal measurements of gait and matching these with a whole range of clinical data, clinicians and physical therapists have at their disposal new tools for improving diagnostics and therapies.

Interesting studies concerning using MOCAP measurements for diagnosis of human gait abnormalities related to neurological diseases were presented in references [1-4]. In these papers several indexes were proposed and, on the basis of experiments with neurological patients, these indices were verified to be useful in diagnosis of neurological gait abnormalities. However, different studies were based on different MOCAP measurement platforms and different algorithms for processing MOCAP data. Proposed gait abnormality indices were also targeted to patients with different neurological disorders.

In this paper we overview some of indices introduced in [1-4] and we present an algorithm for their computation for a unified MOCAP data standard, namely for the ASF/AMC MOCAP data recording and storage system [9, 14]. Thanks to implementing several indexes in one MOCAP based system, multi-featured analysis of neurological gait abnormalities is possible. We also compare and demonstrate possibilities of the developed multi – featured MOCAP measurement system on medical examination data of the Parkinson Disease (PD) patient who has undergone the surgery based on implanting Deep Brain Stimulator (DBS) for improving his motoric skills. The patient’s taking part in this research were operated on in the Department of Neurosurgery Medical University of Silesia in Katowice. They were qualified for surgery and observed postoperatively in the Department of Neurology Medical University of Silesia [10,11,12]. Both mentioned above medical departments as well as Polish-Japanese Institute of Information Technology in Bytom are collaborating, as the group of Silesian Interdisciplinary Centre for Parkinson's Disease Treatment. Examination scenario of PD patient involved performing normal walking under four experimental conditions defined by pharmacological medication and subthalamic nucleus (STN) electrical stimulation: S1 OFF/OFF, S2 OFF/ON, S3 ON/OF, S4 ON/ON.

2. Methods

In this section we first present a rationale for defining some of indices of gait abnormalities proposed in the literature. Then we describe our algorithm for computing these indices on the basis of data files from the ASF/AMC MOCAP data recording and storage system.

2.1 Indexes for neurological gait abnormalities

Kinematic data collected by MOCAP systems can be used to calculate many different indexes that can characterize human gait. However, indexes for measuring gait abnormality must be defined in a reasonable manner, such that they can capture important properties of gait. Therefore, defining gait indices by experts in clinical neurology and biomechanics is an important element in system development for analysis of the gait. These gait indices allow reduction of the massive amounts of data obtained in MOCAP systems, retaining the most relevant features of the gait. Up to date there exist a lot of published papers which proposed indexes, less and more complex, describing gait specific features. Generally, different collections of gait indices may be used to analyze differences between people various ways of walking. Here we present some of indices that we have found functional for describing abnormalities related to neurological disorders.

Arm Swing Asymmetry (ASA)

An index called ASA (Arm Swing Asymmetry) was proposed by Zifchock et al. [1] in the form of the following expression

$$ASA = \frac{45° - \arctan\left(\frac{WD_{more}}{WD_{less}}\right)}{90°} \times 100\%. \qquad (1)$$

In the above equation, variable named WDmore refers to larger distance travelled by the wrist, while WDless refer to smaller distance traveled by the wrist of the examined subject. Wrist distances used in the expression for ASA are defined as the lengths of spatial trajectories given by positions of wrists. Generally, WD distances should be computed by (numerical) integration. When ASA is calculated Wrist distance (WD) is averaged across strides and across left and right side. The larger value of ASA, the larger difference between arms.

Zifchock et al. [1] have proven that ASA index (1) is a well scaled measure for asymmetry of gait of the analyzed subject, normalized to the range 0 – 100, robust with respect to parameters of gait and not affected by the choice of the reference values. Lewek et al. [4] used ASA index in the study of diagnosis of early stages of Parkinson Disease (PD).

Arm Swing Size Symetry (ASSS)

Another index, aimed at reflecting symmetry between upper limbs was proposed in [2]. This index is called Arm Swing Size Symmetry (ASSS) and is defined as follows:

$$ASSS = \frac{LASS}{SASS} * 100\% \qquad (2)$$

Variable LASS and SASS refer to larger and smaller Arm Swing Sizes (ASS). Arm Swing Size is defined as the maximal difference between shoulder flexion and extension angles. Both indexes, Arm Swing Size index and Arm Swing Size Symmetry index, are averaged across each stride and then again across left and right sides.

Decomposition index (DI)

Decomposition index, proposed in [2], can be defined as the percentage of stride when one joint is moving, i.e. when angular velocity is more than 5 [deg/s], while the other is not i.e. velocity is less than [5 deg/s], the residual value is average of all cycles and then is averaged across left and right sides. Decomposition index is therefore defined by the following expression:

$$DI = \frac{DI_{left} + DI_{right}}{2} \quad (3)$$

Decomposition index pertains to pairs of skeleton joints, and therefore this index can be defined and calculated in several variants, depending on which pairs of skeleton joints are used. In this paper (see result section) we use three pairs of skeleton joints, hip-knee, hip-ankle, and knee-ankle, previously demonstrated to be most meaningful for determining gait abnormalities. DI index pertains to one stride, a value representative for an examined subject can again be obtained by averaging across strides.

Stride Length (SL)

Stride Length (SL) [cm] is defined as the distance between positions of ankle marker at the moment of the start and the moment of the end of a stride. Moments of start and end of a stride are defined and moments where distance between two ankle markers assume the largest value. There are two types of strides, left type - in which at the moment of start left leg is in frontal position, and right type, where, conversely, right leg is at front at the moment of start. Each stride consists of two steps. In references [1-4] SL index was considered as an important measure of gait abnormality. Analogously to indexes above, SL index is averaged across strides.

2.2 MOCAP file formats, c3d and Acclaim.

A basic standard for recording MOCAP data is NIH MOCAP file format c3d [14]. C3d file is a binary file containing spatial positions of all body markers and all additional signals collected during a MOCAP session. There are many programs and algorithms for reading c3d files and, if necessary, converting its contents to text formats [15]. However, information included in the c3d file obtained in the MOPCAP experiment is not sufficient for computing gait abnormality indexes described above since they depend on parameters (angles, velocities, orientations) of the skeletal model. In order to obtain these parameters c3d file must be further processed to a format, which includes parameters of the skeletal model. One of such formats is the Acclaim MOCAP data standard [16]. Algorithms presented in further subsections start from the preprocessing step of transforming c3d MOCAP file to Acclaim MOCAP files.

MOCAP data stored in the Acclaim format is divided into two files, Acclaim Skeleton File with skeleton specification (file extension is .asf) and Acclaim Motion Capture with a record of animation frames (file extension is .amc). Such separation of data from specification allows the use of a single skeleton to multiple motion capture data files that have been developed on the basis of the same skeleton specification. We have developed an algorithm and program for converting c3d files to Acclaim format and we use Acclaim format for computing gait abnormality indexes. Below we present structure of the Acclaim files and our algorithms for computing gait abnormality indices.

Acclaim Skeleton File (ASF)

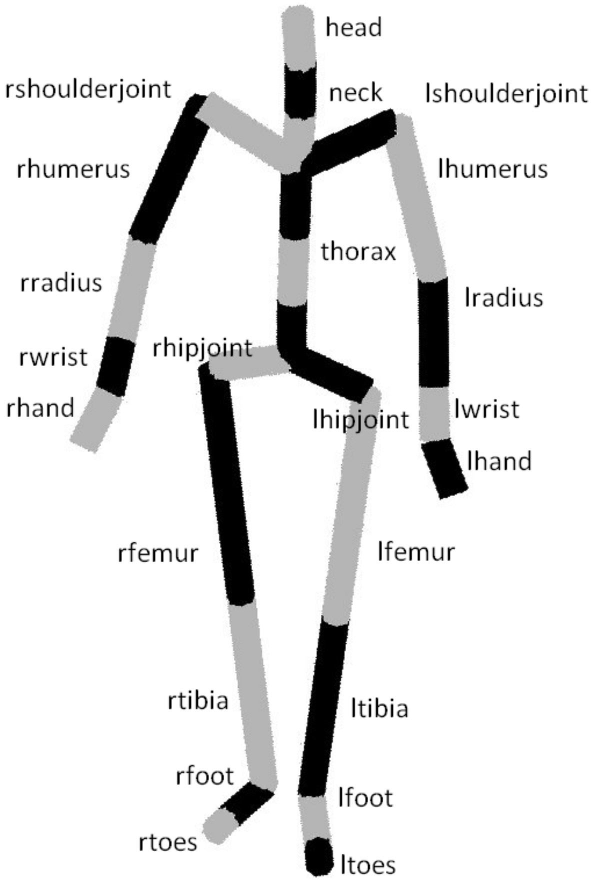

Fig.1 ASF skeleton with bone names.

File .asf is divided into segments. Each new segment is separated by the separator ":". A fragment of an ASF file is presented below.

```
# AST/ASF file generated using VICON BodyLanguage
# -----------------------------------------------
:version 1.10
:name VICON
:units
  mass 1.0
  length 0.1
  angle deg
:documentation
   .ast/.asf automatically generated from VICON data using
   VICON BodyBuilder and BodyLanguage model FULLBODY5.MOD
:root
   order TX TY TZ RZ RY RX
   axis XYZ
   position 0 0 0
   orientation 0 0 0

:bonedata
  begin
     id 1
     name lhipjoint
```

```
    direction 0.293696 0.937787 -0.185198
    length 0.643771
    axis 0 0 0  XYZ
  end
  begin
    id 2
    name lfemur
    direction 0 0.173648 -0.984808
    length 1.7263
    axis 10 0 0  XYZ
   dof rx ry rz
   limits (-180.0 180.0)
          (-180.0 180.0)
          (-180.0 180.0)
  end
```

% description of bonedata from id = 3 to id = 25

```
  begin
    id 26
    name rhand
    direction -0.136113 -0.480318 -0.866469
    length 0.364163
    axis 29 2.49423e-009 180   XYZ
   dof rx ry rz
   limits (-180.0 180.0)
          (-180.0 180.0)
          (-180.0 180.0)
  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 lshoulderjoint rshoulderjoint
    lowerneck upperneck
    upperneck head
    lshoulderjoint lhumerus
    lhumerus lradius
    lradius lwrist
    lwrist lhand
    rshoulderjoint rhumerus
    rhumerus rradius
    rradius rwrist
    rwrist rhand
 end
```

Individual sections are described below:

a) **:version –** version of the file.

b) **:name –** unique name related to name of skeleton file (.asf)

c) **:units –** Contains information about the measures that define the skeleton:

1. **mass 1.0** - the unit of mass is the kilogram
2. **length 0.1** - the unit of length is the decymeter
3. **radius:** information about the angles can be written in angular degree (deg) or arc (rad)).

d) **:documentation –** additional information about file
e) **:root –** Description of root which is the base bone in the skeleton.

1. **axis** and **order –** information about the order of the axis (eg. xyz) and the sequence of degrees. This order is also preserved on all other information about the bones.

2. **position –** determine the root translation (i.e. absolute position). Three numbers define the location of the initial values.

3. **orientation –** determines the orientation of the bone. The three numbers that follow this field defines the rotation axis relative to each according to the sequence described in the order.

f) **:bonedata –** information about the other bones of the skeleton. Description of a single bone is present between the keywords begin and end

1. **Id** - unique identification number of the bones
2. **Name –** bone name
3. **Direction –** direction of the bones resting position
4. **Length –** bone length.
5. **Axis –** rotation of the hip in the local coordinate system

   1. **DOF –** description of the degrees of freedom. Number of degrees of freedom which has a Joint depends on the number of numeric fields behind the word DOF. If there is no data after the keyword DOF, the pond does not participate in motion - has no degrees of freedom. This bone is called a "dummy" and its purpose is to be a link between the other ponds.

   2. **Limits –** defines the range for a given degree of freedom. The value (-inf, inf) means that the Joint does not have any limits for the selected DOF.

g) **:hierarchy –** It contains a hierarchy of bones in the skeleton. In each line of the first keyword is the name of the parent bone in a given node, the other keywords are the names of the bones which are children.

Acclaim Motion Capture file (AMC)

In the AMC file, motion data for skeleton defined by ASF file are written. These data are recorded for each sample time (frame) separately. Each sample of animation is specified using a single line containing the frame number. In each frame of the bone names are the same as those defined in the file .asf. The numbers following the names of the bones determine the rotation of local coordinate system of the bone. In the file .amc are all necessary data motion, allowing to display the animation [9]. Below a fragment of AMC file for the first frame is presented.

```
#!OML:ASF \\vicon1\EXTRA\BAZA NEXUS\Parkinson\Patient1\Session
4\Patient1.asf
:FULLY-SPECIFIED
:DEGREES
1
root -0.710279 7.79563 3.86089 -87.5031 6.08693 11.8787
lowerback 1.79895 -3.30051 0.297072
upperback 2.265 -2.92587 0.326628
thorax 1.32409 -1.15006 0.157878
lowerneck -7.78238 -4.42073 -2.89305
upperneck 10.8626 10.8533 -3.34283
head 4.31469 4.30008 -2.15259
rshoulderjoint -31.2625 0.83849 4.31805
rhumerus -47.1201 28.4621 22.84
rradius -1.38441e-014 4.94436 -4.68836e-013
rwrist -1.13592e-013 -7.33979e-014 7.51832
rhand 30.7408 10.638 -1.25305
lshoulderjoint 25.6942 0.700585 -3.60676
lhumerus 24.2883 47.9019 -56.5669
lradius 2.80356e-015 5.002e-014 2.71137e-013
lwrist -1.16211e-014 6.69557e-014 -11.9189
lhand -37.3497 13.2648 1.98648
rfemur 21.4446 -6.77683 2.13519
rtibia 1.87758e-014 -5.75078e-015 -1.26594e-014
rfoot -9.67908 19.7226 70.1537
rtoes -1.43537e-013 2.09591e-013 -8.18993e-014
lfemur -6.77886 -5.68302 3.24659
ltibia 3.54697e-015 3.09514e-014 -1.39804e-014
lfoot 15.1718 15.1325 -38.716
ltoes 1.90346e-013 1.54882e-013 6.2451e-014
```

2.3 Algorithms for computing gait abnormality indices (ASA, ASSS, DI, SL) from Acclaim amc/asf files

Investigations were carried out on PD patients who underwent bilateral STN DBS surgery performed at the Department of Neurosurgery Medical University of Silesia in Katowice. The our team experience with stereotactic brain surgical procedure’s equals over a 500 surgeries, performed during the period of 2000–2012. DBS surgeries were performed under local anesthesia using a Brain-Lab stereotactic positioning and treatment system: PatXfer, Target 1.19 and CT/MR Automatic Image Fusion software (until May 2011) and from June 2011with Leksell G stereotactic frame (Stereotactic Instruments, Elekta, Stokholm, Sweden) configured with stereotactic software (Framelink, Medtronic, Mineapollis). After the stereotactic frame on patients head placement, a CT was performed using Hi Speed NX/iPROBE GE device, with the scan width of 2 mm. The images were sent to the stereotactic planning station. Then the images were converted and superimposed on the previously made MR images (SIGNA MRI/Echospeed 1,5T GE Ax 3D T1+C IR – PREP acquisitio, Ax-O T2 + gadolinium acquisition). In the previously published papers we described methodology of our stereotactic procedures as well as results ad complicatios [17,18,19,20]. The STN stereotactic coordinates were obtained both: indirectly according to the midcommissural point (mid AC-PC) and directly on the basis of STN visualization in MR T2. The target and entry point were proved on the basis of Schaltenbrand-Warren electronic stereotactic atlas of the brain. During surgery electrophysiological micro-recording and macro-stimulation were provided obligatory. DBS electrode (Model 3389, Medtronic, Mineapollis) and internal pulse generators (Soletra, Medtronic, Mineapollis) were implanted in those patients [11,12,13].

In order to analyze gait of PD patient's underwent DBS surgery accorded to the surgical protocol described above, an algorithm for calculating the coefficients such as: Decomposition Index (DI), Arm Swing Size (SAS and LAS), Arm Swing Size Symmetry (ASSS), Arm Swing Asymmetry (ASA), Stride Length (SL) was implemented in Matlab, the source code of the elaborated program is freely available on request from the first author of this paper. Indices were computed based on data in asf/amc file format. All indices were calculated for each stride separately. Stride was defined as a interval between consecutive ipsilateral foot strikes - two consecutive steps. Step was defined as a maximal distance between left and right foot. First and last three steps were excluded from analysis, to avoid acceleration/deceleration effect during gait. Below we present consecutive steps of the algorithms for computing gait indices..

Smoothing the data

In order to smooth the data the Savitzky-Golay filter [5] was applied for all time – course data in the AMC files. This is a low-pass filter which performs a local polynomial regression (of degree k) on a series of values (of at least k+1 points which are treated as being equally spaced in the series) to determine the smoothed value for each point. This algorithm has been already implemented in Matlab Signal Processing toolbox, parameters k = 3 (degree of a polynomial) and f = 41 (frame size) were assumed.

Determination of 3D space position and orientation of each segment of the skeleton in each frame of the amc/asf file

In the next step data were parsed from ASF and (smoothed) AMC files and were put in a suitable data structure. The elaborated parser uses the following facts. The number of bones in the skeleton is defined in the 'bonedata' section of ASF file plus. Each bone in the 'bonedata' section of the ASF file is defined by the following attributes: name, direction from parent, length, and global – to – local coordinates system transformation expressed by using Euler angles. A special element of the skeleton is the Root. Root has the following attributes: position which describes initial translation in laboratory frame, orientation which describes initial orientation in laboratory frame defined by using Euler angles, axis defines Euler angle order for subject initial orientation, and order which defines order for translation and rotation in each frame for AMC data file. AMC file contains data which describe transformation of each bone of the skeleton with respect to its initial (reference) position defined in the ASF file. Root of the skeleton has three additional values which describe its translation with respect to the reference frame.

In our algorithm, on the basis of the ASF and AMC file we define an auxiliary data storage format, where each bone of the skeleton has the following attributes: name, length, 3d direction vector, and a unit quaternion which contains local coordinates system offset. The unit quaternion in the data structure is equivalent to three Euler angles in the AMC file [7]. Each element of the skeleton contains also a link to its children according to skeleton hierarchy parsed from the ASF file.

The notation for elements of the skeleton is $\{A_{1,\dots}A_{w\dots,}A_N\}$, where A_1 is a root element and N is the number of elements in the skeleton. For kinematic chain structure we use the following notation: $\{A_{k_1}, \dots., A_{k_C}\}$ is the set of children of the bone A_k. The parent – child relations between elements of the skeleton are used in the algorithm for computing positions and orientations of elements of the skeleton necessary for computing gait abnormality indices.

Let us assume that A_w is an element of the skeleton whose position and/or orientation in the laboratory frame is necessary for computing one of the gait abnormality indexes defined above. In order to find position and orientation of A_w, recursive transformations for all elements placed higher in kinematic chain need to be performed. Transformation to temporal position is always obtained from the initial position, therefore the algorithm described below refers to single frame of the MOCAP file. Root does not have parent so the steps for root element differ from steps for any other bone element. Transformation for positions is as follows: $V_f = V_{ti} + V_d$, where V_f is the spatial position of the element A_w of the skeleton, V_d is the direction from parent (for root temporal translation of the skeleton), V_p is parent's position, V_{ti} is subject's initial translation. Transformation for orientations is defined by using unit quaternions and has the following form: $Q_f = Q_o * Q_a$ where " $*$ " is quaternion multiplication, Q_o is local coordinate system offset (for root subject's initial orientation), Q_a is a rotation in particular frame (for root subject temporal rotation), Q_f is the orientation of element A_w. After that, the following procedure for root children need to be performed until we get to A_w: $Q_t = Q_p * Q_o * Q_a * Q_o^{-1}$, where Q_o^{-1} is a conjugate of quaternion Q_o, Q_t is element transformation in the laboratory frame, Q_p is parent orientation.

The above sequence of rotations along the kinematic chain leads to rotation of the element A_w in the local coordinate frame. In order to find position and orientation of element A_w in the laboratory frame, the transformation between local and laboratory coordinate frames must be performed. For transforming orientation, we again use quaternion multiplication $Q_f = Q_t * V_d * Q_t^{-1}$, where 3D vector V_d is treated as a quaternion without scalar. In order to find position of A_w in the laboratory frame we use the formula: $V_f = V_p + Q_f L$, where L is bone length.

Algorithm for Computing ASA

Let us denote: $P_i = (x_i, y_i, z_i)$ – position of a joint in 3D space in the i – th frame and by ΔP_i - distance between two positions in consecutive frames, P_i and P_{i+1}. Then ΔP_i is given by:

$$\Delta P_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2} \quad (4)$$

In order to compute ASS index, distance traveled by both wrists of the examined subject (WD) should be measured (estimated). In order to pursue the procedure of integration over the stream of motion frames we determine 3D position of each frame in AMC file for right and left wrists and calculate distance traveled by both wrists as sum of offsets from the center of the coordinate system. Consequently, the operation of numerical integration, based on distances ΔP_i computed in equation (4), has the following form.

$$WD = \int f\big(P(t)\big)dt \cong \sum_{i=1}^{n} \Delta P_i \quad (5)$$

Using the above formula distances traveled by both wrists are computed and then ASS is found by using equation (1).

Algorithm for computing ASSS

Larger and smaller arm swing size (LAS and SAS, LAS ≥ SAS) are calculated as the difference between maximal and minimal shoulder flexion/extension angle from AMC file, during one gait cycle for left and right side separately.

$$\text{ArmSwingSize} = \text{MaxShoulderAngle} - \text{MinShoulderAngle} \quad (6)$$

Based on equation (6) and (2) arm swing size symmetry (ASSS) is calculated. Time plots of shoulder swing angles for left and right shoulder for the examined PD patient are presented in figure 3. Strong asymmetry is seen, the larger swing size (LAS) is the one defined by the left arm and the smaller swing size (SAS) is the one defined by the right arm.

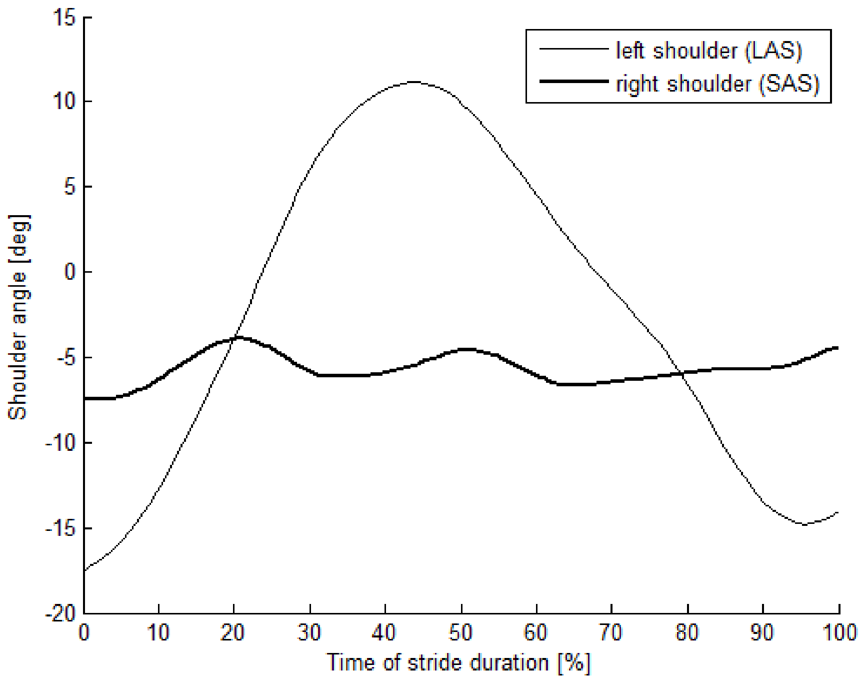

Fig.3 The shoulder angle changes during stride for left and right side. Time scale was normalized to 100%.

Algorithm for computing DI

Based on the definition of decomposition index DI, to obtain its value in the first step an angular velocity W defined as a three dimensional vector quantity (w_x, w_y, w_z) has to be obtained. The elements w_x, w_y and w_z of vector W do not depend on each other and can be respectively defined as rates of change of rotation angle about the x, y and z axis. If, again we represent rotation by using unit quaternion Q and treat quaternion Q as representing rotation relative to the neutral position of frames, angular velocity $W(t)$ can be calculated as: [6,7,8]

$$W(t) = \frac{2}{Q(t)} * \frac{dQ}{dt} \quad (7)$$

Based on equation (7) angular velocity W(t) was calculated for left and right knee, hip and ankle based on equation (6). The plot of angular velocities of right knee and right ankle, for the examined PD patient performing normal walk, is presented in figure 2. Stride time was normalized to 100%. On the basis of time functions of angular velocities, percentages of stride when only one from two joints is moving were calculated, which led to computing values of the decomposition index DI.

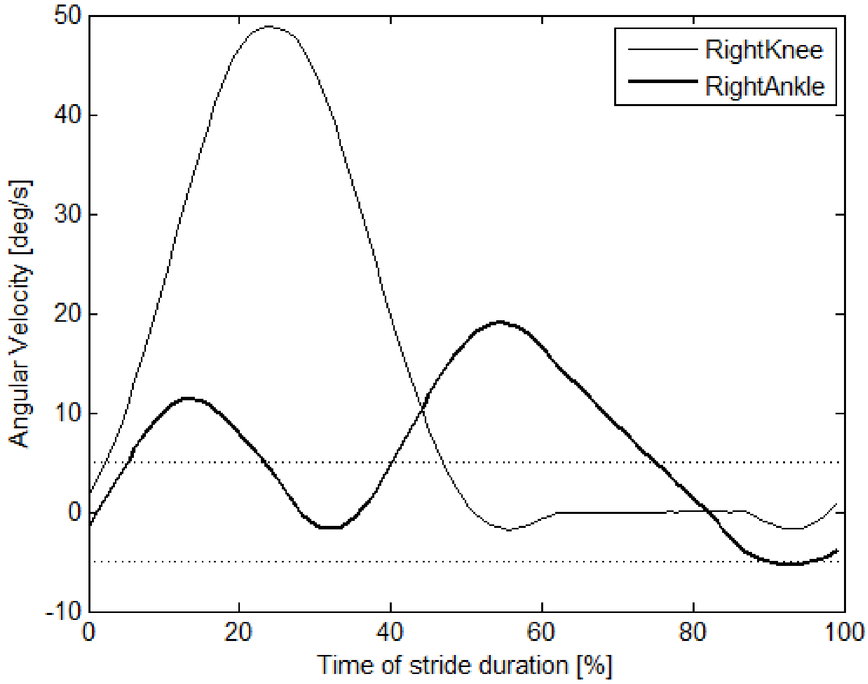

Fig. 2 The course of the angular velocity in time for right knee and right ankle.

Computing SL

Similarly to distances traveled by wrists, stride length (SL) was estimated based on equation (4).

3. Results

All measurements were made in the Human Motion Laboratory located in Polish Japanese Institute of Information Technology in Bytom, Poland. In our kinematic movement recording set-up 10-camera, with the 3D motion capture system (Vicon) have been used. The 3D position of the patient was analyzed based on 39 reflective markers (tracked at 100 FPS) placed on major body segments: 4 on Head, 5 on Torso, 14 on left and right side of upper limbs and 16 on left and right side of lower body.

Data were collected from PD patient's during normal walking. Those patient's were treated both by substitute L-Dopa drug medication and STN stimulation.

The patient performed four sessions of the normal walking task: S1, S2, S3 and S4, corresponding to different experimental conditions as shown in Table 1.

Session	Medication	Stimulation
S1	**OFF**	**OFF**
S2	**OFF**	ON
S3	ON	**OFF**
S4	ON	ON

Tab.1 Presents conditions during each session.

For all walking sessions, computations according to the algorithms presented in the Methods section were performed. Computed indexes were averaged across strides. In figure 4 we present mean values and standard errors for DI indexes for Knee – Ankle, Knee – Hip and Hip – Ankle joints, distances traveled by wrists, arm swing sizes and stride lengths. These indices are computed separately for left and right part of the examined patient's body.

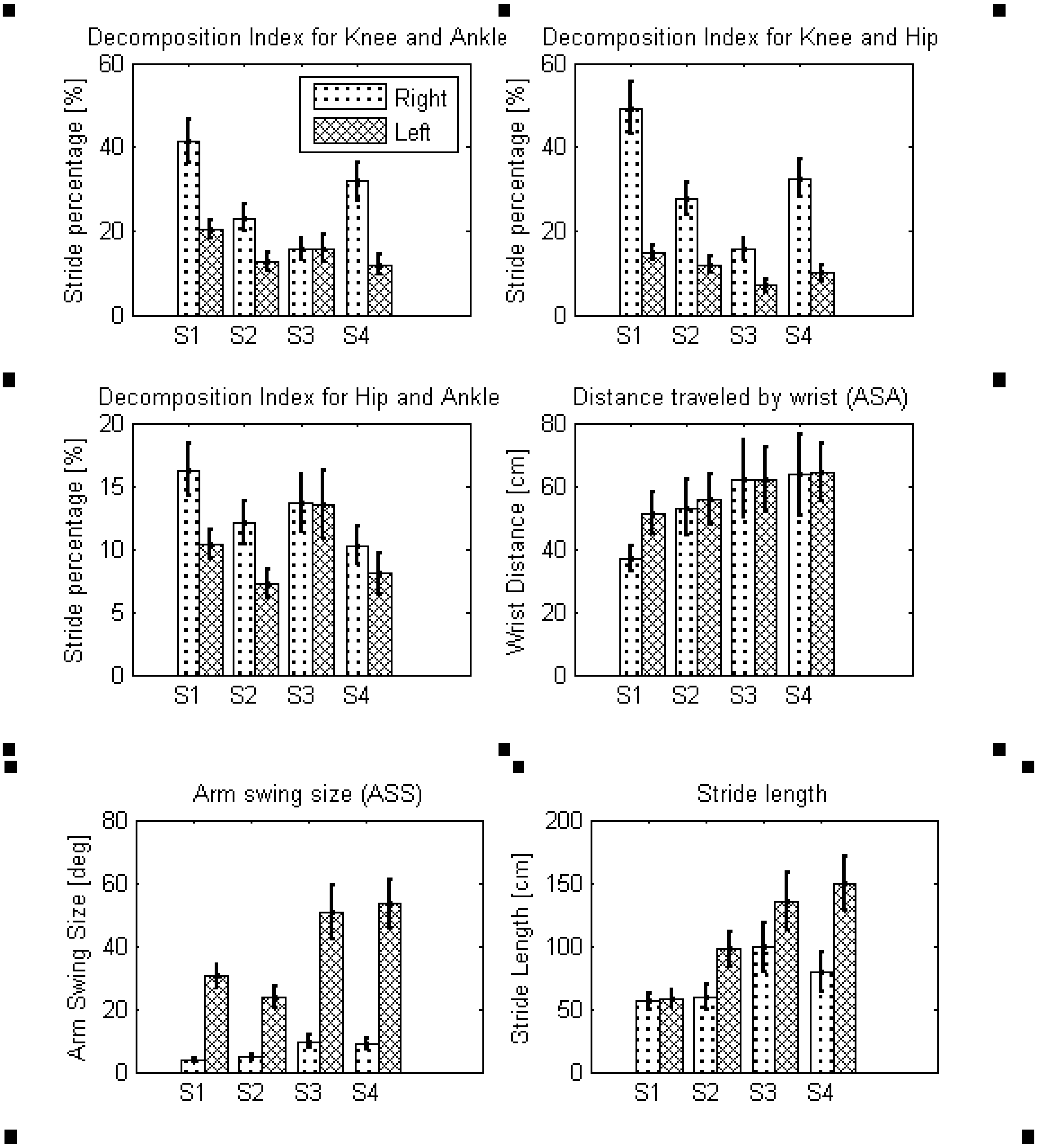

Fig. 4 Presents mean values and SE for six indicies for one patient durig normal walking for right and left side separately.

On the basis of values of indexes shown in figure 4, we finally compute gait abnormality indexes DI, ASSS, ASA and SL, and we present their values in the table 2.

Coefficient	S1	S2	S3	S4
DI (Decomposition Index) for knee and ankle [%]	30.71	17.91	16.94	22.28
DI (Decomposition Index) for knee and hip [%]	31.99	20.1	10.705	21.12
DI (Decomposition Index) for hip and ankle [%]	13.41	9.92	13.80	9.11
ASSS (Arm Swing Size Symmetry)	18.03	20.18	17.78	18.03
ASA (Arm Swing Asymmetry)	10.17	1.71	0.32	0.28
SL Stride Length [cm]	57.29	78.76	119.17	114.96

Tab.2 Gait abnormality indexes computed for the PD patient during normal walk task, for four experiments conditions, S1, S2, S3 and S4. Indexes are averaged across strides, sides and trials.

4. Conclusions

In this paper an algorithm for computing gait abnormality indices: ASA, ASSS, DI, SL defined in the literature [1-4] was developed and specialized to Acclaim gait data format [9]. The developed algorithm was also verified for experimental data related to the PD patient normal walk. Abnormality indices: ASA, ASSS, DI, SL were decomposed into components (WDR, WDL, DIR, DIL, LAS, SAS, SLL, SLR) corresponding to separate motions of the right and left body parts of the examined subject as shown in figure 4. In the case of examination of PD patients left and right components have some additional diagnostic value, they allow for detecting which body side is more affected by the disease.

Examination of time plots of acclaim format angles registered during examination session and values of the computing abnormality indices confirm their usefulness in studies of gait neurological disorders. Values of abnormality indexes exhibit significant differences between different experimental conditions, S1, S2, S3 and S4 (table 2).

Acknowlednments

This work was supported by the European Union from the European Social Fund (UDA-POKL.04.01.01-00-106/09-00 M. Stawarz and Ł. Janik), by The National Science Center (NN518289240 A. Polański; NN516475740 K. Wojciechowski.)

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