

A method for human gait comparison

Abstract. This paper presents a method for comparing two different human gaits recorded in a motion capture laboratory. The comparison consists in comparing how joint angles change. The test data was read from C3D files. In order to obtain presented results a piece of software is created in C++ language. The software allows for reading acquisition files and calculating the angles between chosen body parts.

Streszczenie. Artykuł przedstawia metodę porównania dwóch różnych nagrań ruchu człowieka. Porównanie dotyczy wybranych kończyn i polega na badaniu zmienności kątów poszczególnych stawów. Wykorzystano dane o trajektoriach markerów odczytane z plików C3D. Do uzyskania wyników wykorzystano program opracowany w języku C++ służący do odczytywania nagrań i obliczania wspomnianych kątów. (Metoda porównania różnych nagrań chodu człowieka)

Keywords: human gait, motion capture, comparison

Słowa kluczowe: chód człowieka, akwizycja ruchu, porównanie

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Introduction

Professional motion capture laboratories that allow us to record actors' movements differ not only in the equipment they possess but also in the environment for motion acquisition. Motion recorded in such laboratories can be exported to special motion capture formats that allow the data to be processed and analysed further. This has spawned an area of computational motion analysis. This kind of research is relevant to various fields such as: sports, medicine, orthopaedics.

This paper presents a method of comparing two gaits of the same actor. An actor's motion was recorded using a marker based motion capture system and saved in C3D files. Each time the actor walked slowly. The comparison presents how the angles between selected body parts change while the actor is walking. This article focuses on three angles: (1) the angle between chest and thigh, (2) the angle between thigh and shin and (3) the angle between shin and foot.

The comparison was created in a self-written piece of software. The computer program was developed in C++ language. It depends upon two libraries that allow for reading acquisition files, (C3D files for instance) and for performing calculations in 3D space. The first library is b-tk (biomechanical toolkit) [1] while the second is Eigen [2].

The experiment's results are shown in graphs and tables. The ultimate goal of the presented research is to create a method for fine-tuning an artificial human model by comparing it to real motion capture data.

Motion acquisition

Creating realistic human motion is not an easy task. Methods used for creating animations, such as kinematics, inverse kinematics and the key frames method, do not always give satisfactory results. Sometimes even minor changes in motion parameters can cause the resulting motion to look artificial. That is why it is frequently more convenient to acquire the real object's motion (e.g. an actor) and then tie it to the animated artificial object (e.g. human model) [3]. Motion capture systems are widely used in computer games and the movie industry for creating animations. These systems acquire the three dimensional motion of people or other objects and transfer the received data to a computer. Usually, the data is transferred in real time. There are four types of motion capture systems: (1) optical systems utilizing markers, (2) systems based on electromagnetic sensors, (3) system builds using several video cameras, (4) systems using electromechanical suits. Each type has some advantages and disadvantages.

Most common are optical, marker based systems [4]. The actor, whose moves are recorded, wears a special suit with reflective markers. The markers' movements are frequently recorded with high-speed infrared cameras. These systems are frequently combined with video recording equipment in order to make data post-processing easier. Angles that describe the limbs' positions relative to each other are not computed directly. They are computed based on the position of marker groups' places on or near joints that are of interest. The motion acquisition process needs to be conducted in an environment with controlled lighting.

Also popular are systems that use electromagnetic sensors. The sensors transmit information about their orientation/position to some central unit collecting all the data. These systems must work in an environment without distortions from the magnetic field [3]. The sensors use either cables or wireless connections for data transmission. Both solutions may be uncomfortable for the actor. Cables may limit freedom of movement while wireless sensors require some sort of power source such as a battery pack. The advantage of these systems is that they are able to acquire both positions and angles from each sensor. Also the number of sensors is fewer than the number of markers in optical systems. Their main disadvantages are: limited range and the accuracy of the magnetic field measurement.

Gaining in popularity are motion capture systems that do not use specialized, and usually expensive, cameras. Instead they use video cameras optionally combined with an infrared depth sensor [5]. These systems are inexpensive and offer the actor maximal freedom. However their accuracy is limited.

Another category is MEMS (micro electro-mechanical systems) motion trackers which may also be combined with magnetic field sensors [6]. Their advantage is that they can be used in almost any environment and that their data collection doesn't require a high performance computer (a simple notebook is fine).

Regardless of the system type, the accompanying software delivers the collected data in one of the standard motion capture file formats. These files can be additionally processed with the use of third-party software such as the software created by the authors of this paper.

Gait comparison method

The aim of this paper's research is to create a method for comparing two different gaits of the same person. More precisely, the method compares the motion of the actor's

right and left legs in two different acquisitions. A total of six joints are taken into account for the left and right sides of the body. The joints are: left hip, left knee, left ankle, right hip, right knee, and right ankle. For each joint, changing angles are calculated as the actor walks. Their values indicate the range of motion of each joint. In order to trace the positions of the above mentioned joints (three on the left and three on the right), twelve markers are needed (six on each leg). The markers cannot be placed precisely on the joints. They are put on limbs, near the proper joint. These markers are then used for computing the position of the joint. Two markers nearest to a joint are taken into account.

The method consists of three steps: (1) reading the point trajectories from two different acquisition files, (2) computing the angles between selected body parts and (3) performing an analysis of the calculated values.

Once the recorded motion is read, we can select the markers that are needed. The markers in C3D files are searched by their names. As stated above, the actor has markers placed on both sides of his legs. For the purpose of this paper, only the marker's positions on the outer side of the leg are used. After obtaining the positions of selected markers in each frame, the joint angles can be computed. As mentioned earlier, in each frame, the angles of six joints are determined. The joints are: left hip, left knee, left ankle, right hip, right knee and right ankle. Each angle is computed using a dot product of two vectors. It is presented in equation 1.

$$(1) \quad \beta = \arccos(\overline{v_1} \cdot \overline{v_2})$$

Where: β – joint angle, $\overline{v_1}$ and $\overline{v_2}$ – normalized vectors. The vectors are normalized as shown in equation 2:

$$(3) \quad \overline{v_i} = \frac{v_i}{\|v_i\|}$$

Every vector is created based on the positions of two markers: hence four markers are used for computing each angle. The following markers correspond to the joint angles enumerated above: (1) left hip, beneath left knee, left shin and left ankle, (2) left ankle, left shin, left heel and left, bottom middle part of the foot, (3) left part of the waist, the chest, left hip and left knee, (4) right knee, right hip, right shin and right ankle, (5) right ankle, right shin, right heel and right, bottom middle part of the foot, (6) right part of the waist, the chest, right hip and right knee

An example of creating vectors based on markers and computing a knee angle is presented in fig. 1.

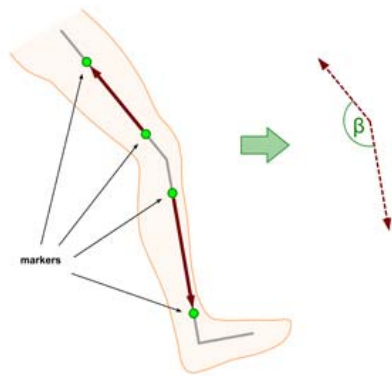


Fig. 1. The computation of a knee joint angle

In each pair the first two markers constitute the first vector (they are the beginning and the end the of the

vector). The second two markers constitute the second vector. Because each marker's positions are represented in three dimensions, the vectors are also three dimensional.

The result of the procedure described above is that six angles are computed for each frame. These angles change during as the actor walks.

The angles computed in radians are converted to degrees for easier interpretation.

In order to test the proposed method, a computer program was created in C++. It depends on the b-tk library [1] which allows for reading, writing and manipulating C3D files. Reading points from a C3D file is possible with the use of the `readAcquisition()` method [1] with the C3D file name as a parameter. This method is available in the Acquisition class. Once the recorded motion is read, we can select the markers that are needed. The markers in a C3D file are searched by their name. The `FindPoint()` method which takes a marker name as a parameter is used for this purpose [1].

Results

In order to obtain the results presented below, two files recorded in a motion capture laboratory with Vicon equipment [7] are used. The files are in C3D format, and both contain recordings of the same actor walking slowly. The first file contains 873 frames and 53 markers' trajectories. Positions in 3D space are sampled at 100 Hz. The second file contains 771 frames and also 53 markers' trajectories. The sampling frequency is the same as in the first file. The markers are placed all over the actor's body in order to create a complete recording of his motion. Each marker is identified by a unique name in the C3D file.

The results are presented in figures 1 through 5. Fig. 2 presents the angles (in degrees) computed, based on the first file. The angles are presented for three joints: the left hip, the left knee and the left ankle. The gait duration is 8.72 seconds. It is clearly visible that the gait consists of three full steps. Each step begins when the heel touches the floor. Additionally, one can see two additional phases: the preparation for gait and stopping. Fig. 3 shows the angles computed for the knee, angle and hip during a single complete step from the first file. The step's duration is 1.6 seconds. Figures 4 through 6 compare the way in which corresponding angles change, in the two recordings. The comparison is for the following joints: left knee, left ankle and left hip. Graphs are plotted for the middle of the three recorded steps. Frame durations have been calculated based on the number of frames and frame capture frequency (equation 3)

$$(3) \quad t_i = \frac{i}{f}$$

where: i - frame number, f - data capture frequency.

In the graphs we can see that the least difference is visible for hip angles and the most for ankle angles. Two gaits are recorded with the same actor. This confirms that there are differences in the way a person walks.

In tables 1 through 3 absolute differences between corresponding angles in the first and the second recording are shown. Values are presented for selected frames. The selected frames are contained in the middle step (out of a total of three steps). Each table contains data for one chosen joint. As can be seen, actor steps selected from the two files do not start in the same frame. That is, data from one file needs to be shifted for comparison. The middle step in the first file starts in the 313th frame and in the 368th frame in the second file. The duration of both is 153 frames.

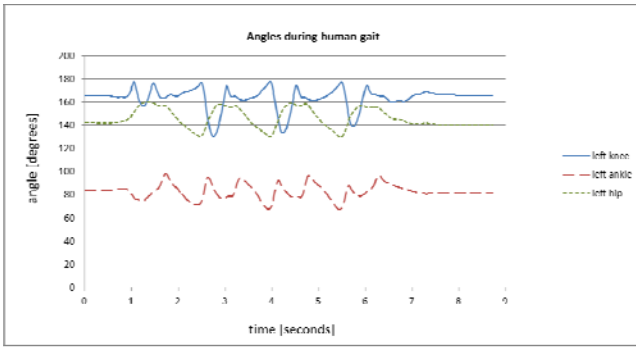


Fig.2. Joint angle changes during actor's walk

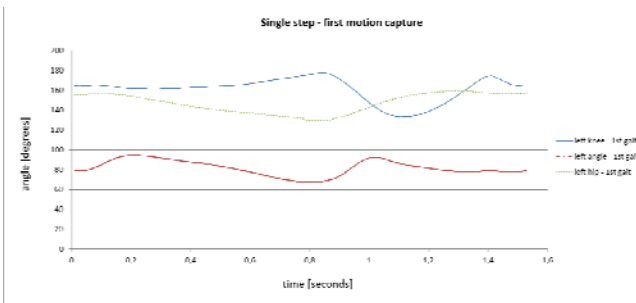


Fig.3. Joint angle changes during one step of actor's walk

A comparison of right leg motion during a single step is presented in figures 6 through 8. The step from the first file starts in the 387th frame and ends in the 543rd frame. The step from the second file starts in the 370th frame and ends in the 523rd frame. Because these steps have different duration times, the shorter step is scaled to match the duration of the longer lasting step. The formulas used for scaling are presented in equations 4 and 5.

$$(4) \quad t'_s = k \cdot t_s$$

where: t'_s – time of a sample after scaling, t_s – time of a sample prior to scaling, k - scaling coefficient computed given by equation 5:

$$(5) \quad k = \frac{t_1}{t_2}$$

where: t_1 and t_2 - duration times of the first and the second step.

The obtained results are similar to those for the left leg.

The results show that the biggest differences in joint angles are between the heel and the shin, and they manifest themselves in the second part of the step. The smallest angle difference is between the chest and the thigh. The angles are almost identical, which allows us to conclude that hip movement is the most repeatable as a person walks.

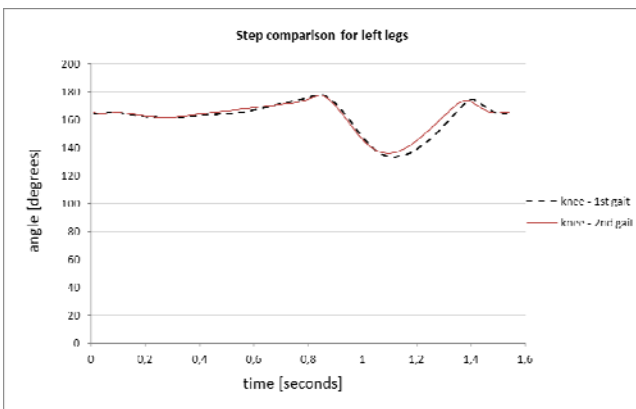


Fig.4. Comparison of left knee angle change during steps taken from two recordings of the same actor walk.

Table 1. Left knee angle differences between chosen frames in two different recordings of the same actor.

1st file		2nd file		Absolute difference
Frame number	Angle	Frame number	Angle	
313	164,515	368	165,48	0,965
343	161,714	398	161,874	0,16
373	167,13	428	168,739	1,609
413	145,222	458	167,62	22,398
443	157,623	488	146,566	11,057

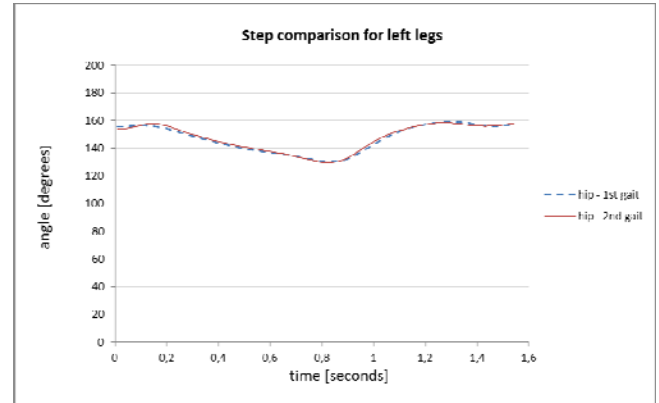


Fig.5. Comparison of left hip angle change during steps taken from two recordings of the same actor walk.

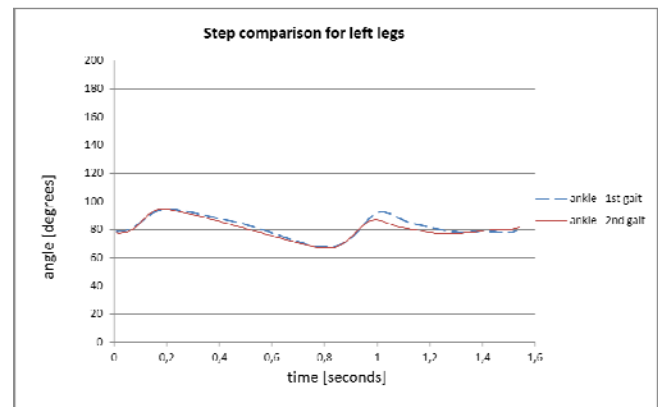


Fig.6. Comparison of left ankle angle change during steps taken from two recordings of the same actor walk.

Table 2. Left ankle angle differences between chosen frames in two different recordings of the same actor.

1st file		2nd file		Absolute difference
Frame number	Angle	Frame number	Angle	
313	78,5704	368	77,5947	0,9757
333	91,4036	398	90,0372	1,3664
373	77,0774	428	75,0881	1,9893
413	92,3449	458	76,2621	16,0828
443	78,1147	488	77,7255	0,3892

Table 3. Left hip angle differences between chosen frames two different recordings of the same actor.

1st file		2nd file		Absolute difference
Frame Number	Angle	Frame number	Angle	
313	155,502	368	154,136	1,366
343	148,31	398	149,404	1,094
373	136,6	428	137,344	0,744
413	143,981	458	134,196	9,785
443	159,209	488	157,544	1,665

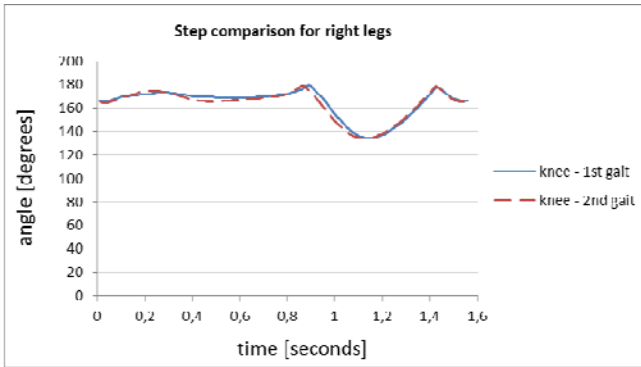


Fig.7. Comparison of right knee angle change during steps taken from two recordings of the same actor walk.

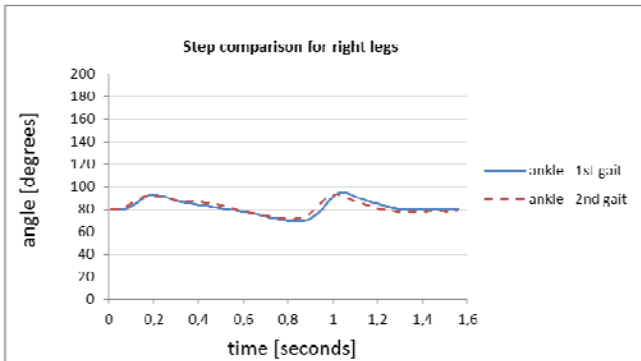


Fig.7. Comparison of right ankle angle change during steps taken from two recordings of the same actor walk.

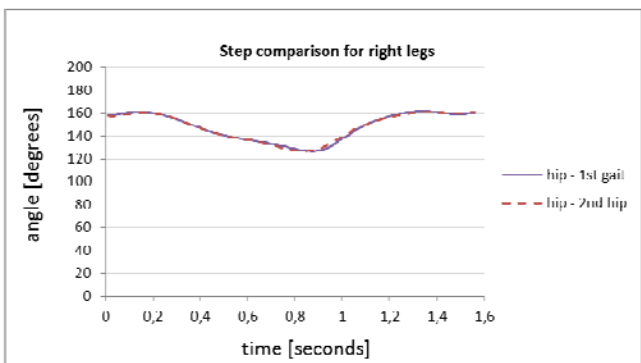


Fig.8. Comparison of right hip angle change during steps taken from two recordings of the same actor walk.

Conclusions

The paper presents a method for comparing two different motion recordings. Comparison of two different walks of the same actor is presented as an example. Motion was recorded in a motion capture laboratory using Vicon equipment. C3D files were used for data storage. The markers' positions are used to compute the angles between: chest and thigh, thigh and shin, shin and foot for both sides of the actor's body. Our research confirms that ankle and knee angles vary most from trial to trial. Hip angles vary least.

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