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Models and methods for biometric motion identification

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Abstract

Human motion is a complex signal with many different properties depending on various factors: age, gender, physical condition, emotions etc. Nevertheless there is a hypothesis which claims that human motion can be a source for biometric analysis and person identification. In the paper some methods to analyze and compare different motions are presented. Methods are examined for usefulness in motion identification. We distinguish time-series and frequency analysis for rotational signals describing mainly the motion of legs. The results of experiments are presented taking into consideration different motion representations.

1. Introduction

Nowadays the biometry is becoming a very important field. Application of biometric methods is very important especially for security systems. There are many different well established methods like fingerprint analysis, voice comparison, retina matching. New concepts base on keyboard typing analysis and motion analysis. The latter idea has a lot of possibilities and could be very helpful for security issues and human identification at distance. It is possible to analyze a motion of any person without the necessity to take special examinations (as it is common for example during fingerprint analysis). The comparison could also be performed for many people independently (e.g. for crowd analysis in order to determine a suspicious behavior). The first step of any motion analysis system is to collect motion data.

1.1. Motion recording systems

There are two major types of motion recording: video recording (the standard way based on video stream) and motion capture. The first is very popular because of low costs of the equipment. The second requires more specialized systems, but offers great accuracy.

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Video recording is very popular for many security applications. Usually the possibilities of such systems are constrained only to detection. Systems which could analyze the observed behavior are still under development. The main problem is to transform two dimensional image (or video stream) into three dimensional data which describes the actual motion. Moreover, the technique is very sensible of any image distortions which can lead to data inconsistency.

Image processing algorithms are one of the most rapidly developing areas. There is much research attempting to obtain algorithms that could identify the person on the image and extract motion from the stream. It will be probably possible in the following years, especially that processing power of common processor is still increasing. Note that some of the algorithms presented in this paper can be used also for the analysis of video recorded motion.

Alternative systems are based on the *Motion Capture* technique. The method was firstly developed and used for movies production. In those systems a real actor performs some actions recorded in a three-dimensional space. The recording is carried out using a few cameras (at least three) and markers which are attached to the actor's body. The positions of markers are recorded in every frame (moment of time). Consequently, it is possible to recreate the actor's positions in the whole sequence, which leads to animation of the figure.

The technique records only a limited number of points from the body. Usually markers are placed on joints, because bones between the joints cannot normally move. The most natural way to represent data are rotations, although some other representations have also been proposed (some of them will be presented later).

The main advantage of *MC* systems is the accuracy of recorded data. Captured motion contains a lot of subtle details because its source is the real actor. Motion can be subsequently processed and used in the animation system to render a completely new figure. The technique is widely used in many movies which require the creation of special characters. Motion capturing can also be very helpful for medical analysis (e.g. for examination of bone system disorders). There are some attepts to apply the *MC* system for runners training.

1.2. Related works concerning biometric motion analysis

In every biometric problem it is crucial to distinguish basic properties of the examined object. In the considered problem, motion is the object which is taken into account. The basic approach is to treat motion as a multi-dimensional time-series of rotations (or positions) of each bone in the skeleton. It is also possible to compute accelerations or velocities of different parts of the body. The question is whether all parts have to be taken into account.

Murray [1] suggested that the motion of hips and legs differs significantly among different people. In paper [2] rotations of shanks, hips and neck are considered. The approach has similar problems to the previous one – those parts of the body are usually hidden under the clothes. On the contrary, another part which could be analyzed are legs. The approach is presented in papers [3-7]. The main advantage is the possibility to determine the position of these parts of the body also in the image. Legs usually move in a more regular way compared to other parts of the body (like hands). The motion is more periodical, which is not interfered with other behaviors like carrying or gesticulations.

Taking those conditions into consideration, we decided to examine the motion of legs, especially two bones: hips and shanks. We use the motion capture data obtained from the commercial system to check the performance of the presented methods. In all experiments presented in this paper we use the *LifeForms* motion library, which contains different action sequences played by real actors and processed using the *motion capture* technique[1].

2. Data representation

The natural way to represent data of human motion is to describe rotations of each bone. Rotations can be expressed as the vector of three variables

$$\vec{r}_k(t) = \begin{bmatrix} r_{xk}(t) \\ r_{yk}(t) \\ r_{zk}(t) \end{bmatrix}, \tag{1}$$

where k denotes a bone in the skeleton and t denotes time moment (e.g. frame number) in the sequence. Complete rotation is described as a rotation around three axes independently. This type of representation is called *Euler's rotations*.

The main disadvantage of Euler's rotations is the necessity to preserve the same order of the axes. Moreover there is a possibility to get *gimbal lock* effect, where one degree of freedom is lost.

The simplification of the approach is to analyze the motion performed into the perpendicular direction to the camera. This is the situation which takes place during the video recording analysis (using the Hough transform it is fairly easy to distinguish moving legs of the person). The simplification was proposed in [6] and we base our experiments on that approach. The novelty presented in our paper is using a similar approach for both frequency and time-series analysis of motion capture data. Moreover, we propose to use also different data representation.

We base our experiments on three dimensional motion capture data. One of the most convenient alternative representations for rotations are unit quaternions. Quaternions are generalization of complex numbers proposed by Hamilton. The most important feature is that the unit quaternion (quaternion of the length 1) can represent rotations. More detailed application of quaternions for three-

[1] *LifeForms* software is produced by *Credo Interactive Inc.* http://www.credo-interactive.com/

dimensional transformations can be found in [8]. Single quaternion can be represented as

$$\vec{q} = w + x\vec{i} + y\vec{j} + z\vec{k} = [w \quad x \quad y \quad z] = (s, \vec{v}), \tag{2}$$

where w (or s) is a scalar part and v denotes the vector part. The representation used for coding rotations is formulated as

$$\vec{q} = (s, \vec{v}) = \left(\cos\frac{\theta}{2}, \vec{u}\sin\frac{\theta}{2}\right), \tag{3}$$

where u is a singular vector along which a rotation of angle θ is defined.

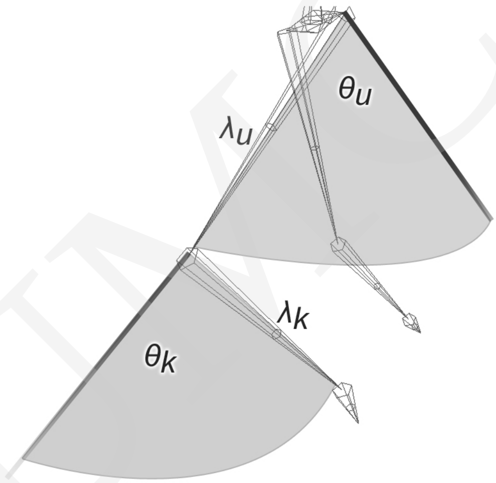

Fig. 1 The modified motion model of limbs

Using quaternions we can take into consideration the actual angle of the rotation instead of rotation along one axis. It can be useful for motion capture data analysis. We can also define a specific measure of similarity between rotations described by quaternions. The measure takes into consideration a scalar part of the quaternion and has some interesting features as presented in [9].

We use the model of motion of legs based on [7] which was adapted for the representations used in our experiments. In some experiments we take into the rotations along different axes into consideration. For the comparison we also consider considerations quaternion based model which uses adjusted information from all axes converted into a scalar part of the quaternion. The motion model is briefly presented in Figure 1. Rotations are measured against the initial position of bones for a skeleton of a standing person.

3. Time-series analysis

We propose to use the *Dynamic Time Warping (DTW)* method to compare motion sequences. The method is based on dynamic programming and is widely used for different time-series comparison applications (like voice recognition [10]). The application for motion processing was presented in different papers [9,11]. The proposal of database structure based on DTW was proposed in [12].

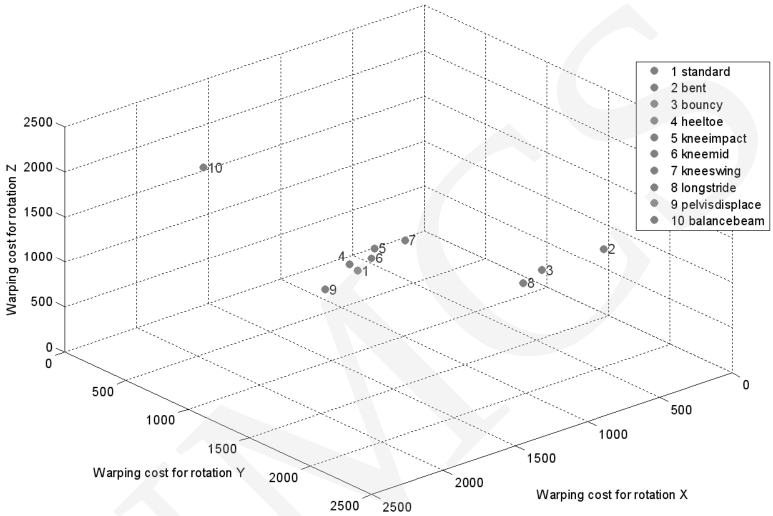

Fig. 2. The results of *DTW* comparison for hip rotations along 3 axes

Two experiments were prepared. In each we selected one motion capture sequence called *armout.bvh* as a template sequence (it is one of the most standard motions representing walking along a straight line). Each motion from the group of sequences was compared to the template. The warping cost represents a measure of similarity between sequences. The properties of comparison algorithm allow to process signals with different lengths.

In the first experiment warping costs for rotations of a hip along three axes were computed. The results are presented in Figure 2. Warping costs for different rotations are placed on different axes. This method of data visualization is based on paper [7]. The novelty is to use it for the *DTW* analysis of motion capture data. The closer points are placed on the graph, the more similar ones are analyzed sequences.

Similar experiment was carried out using different parameters. This time we analyzed only *X* rotations, but taking into consideration different parts of the body: left hip, right hip and left shank. Due to the asymmetrical nature of such comparison, it is possible to detect any disorders in motion disturbing symmetrical character of normal gait. The results are presented in Figure 3.

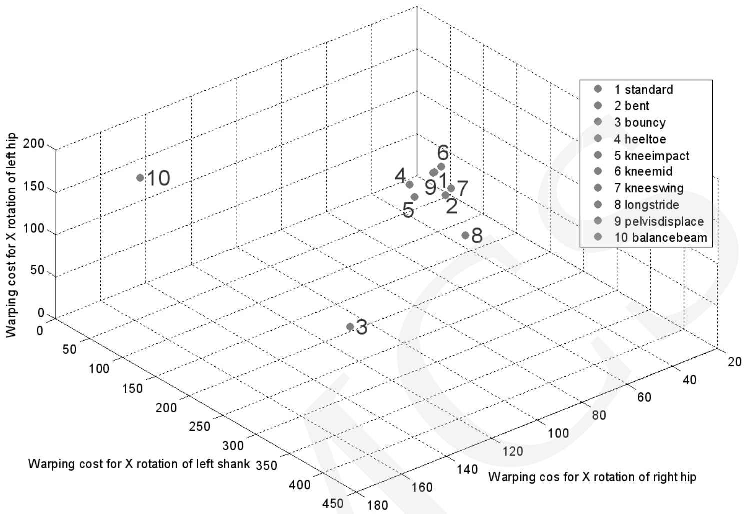

Fig. 3. The results of *DTW* comparison for X rotations of left hip, right hip and left shank

4. Spectrum analysis

Some research indicates that the spectrum analysis of the motion signal can lead to interesting results concerning person identification [3-7]. We wanted to verify if the method is suitable also for the motion capture data represented either by Euler's angles or by quaternions.

Spectrum of the signal can be computed using the Fourier transform defined as:

$$f(t) = \sum_{k=-\infty}^{\infty} \underline{F_k} e^{ikw_0 t} , \tag{4}$$

$$\underline{F_k} = \frac{1}{T} \int_{t_0}^{t_0+T} f(t) e^{-ikw_0 t} dt = \left|\underline{F_k}\right| e^{i\varphi_k} , \tag{5}$$

which in the discrete form becomes

$$H_n = \sum_{k=0}^{N-1} h_k e^{2\pi ikn/N} . \tag{6}$$

The spectrum computed in this way can be afterwards analyzed and be the source of interesting biometric information. Kuan [13] showed that the spectrum parameters differ significantly for different persons. In [6,7] the approach was extended with the application of phase-weighted magnitude. We use similar data visualization in order to compare the results with other research. The example of frequency analysis for two different sequences is presented in Figure 4. Both spectra were computed for the rotational signals along the X axis of the right hip. As one can observe, the result of spectrum analysis differs significantly for two sequences, but only in some details (*Sprint* and *Walk* represent motions of the same type).

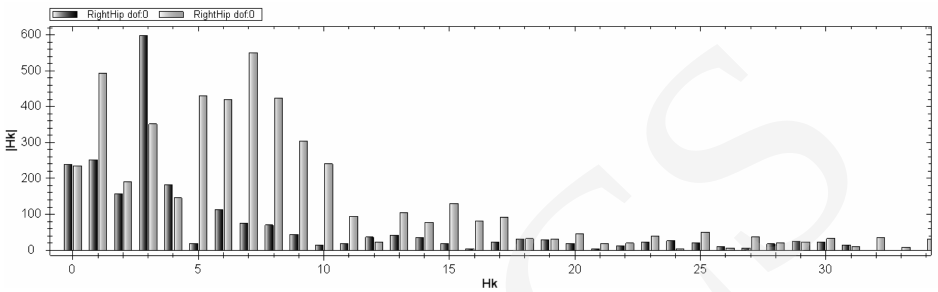

Fig. 4. The example of spectrum analysis for the sequences *SprintToWalk* and *RunToWalk*

4.1. Experiment: signal energy comparison

The initial experiment consists of the comparison of the energy accumulated in the most important part of the signal spectrum. We compared the first few spectrum amplitude coefficients in the signals of rotations along 3 axes. The first 30 coefficients were taken into account, because one can notice it is the main band, where the majority of the energy is accumulated. The results are presented in Figure 5.

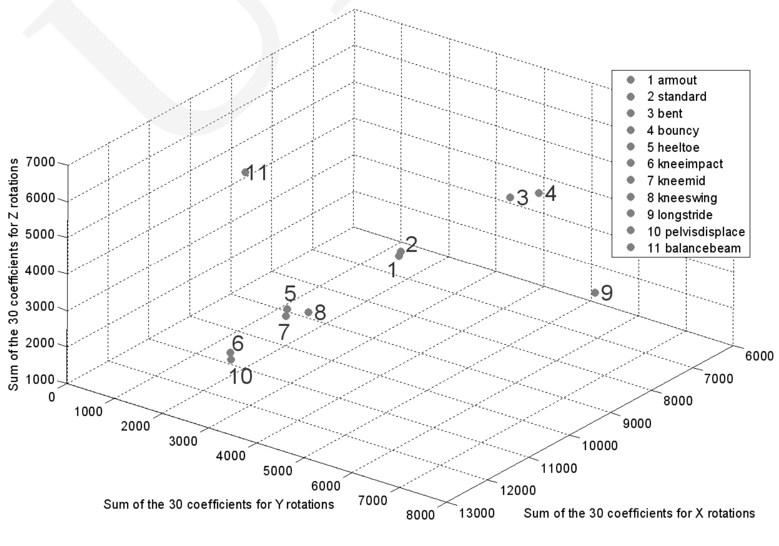

Fig. 5. The results of spectrum analysis taking into account the sum of first coefficients of rotational signals

Compared with figure 3 it is noticeable that the sequences which are different can be distinguished more reliably. It is evident especially for the sequences number 6, 7, 8, 9, 10, 11 – the actor in those figures moves not so clearly (the motion was influenced by some kind of bones disorder) as for the standard sequences number 1 and 2. The advantage over the results presented in figure 1 is even more visible. We can conclude that taking into consideration different parts of the body (as shown in figure 3) gives more information than analyzing rotations of the same part along different axes. That is the reason why we used the quaternion representation in the next experiment (using scalar comparison method we do not have to consider different axes).

It is difficult to determine clearly the performance of the comparison method because of the lack of data. We have only a limited number of motions in the database, and moreover, we do not have information about its origin (whether motions were carried out by the same or different persons). To overcome this problem, it is possible to use a motion generator. The idea is to build a group of motions which are similar in general character but differ in subtle details. Having a large group of generated motions we can check whether the comparison algorithm is able to distinguish the generated groups properly. The detailed description of different motion generators can be found in [14].

Four groups of motions were generated for the experiment: *1 – RunToWalk, 2 – RunToWalk noised* (an extra randomized quaternion noise was added), 3 – *JogToWalk, 4 – Sprint*. There are 200 motions in each group, where motions differ slightly within a group. The spectrum analysis was performed in a similar way to that in previous experiments. In Figure 6 a three dimensional graph is presented. Each axis represents the value of amplitude coefficient (first or second) of a different part of the body. Elements of groups are marked with different symbols.

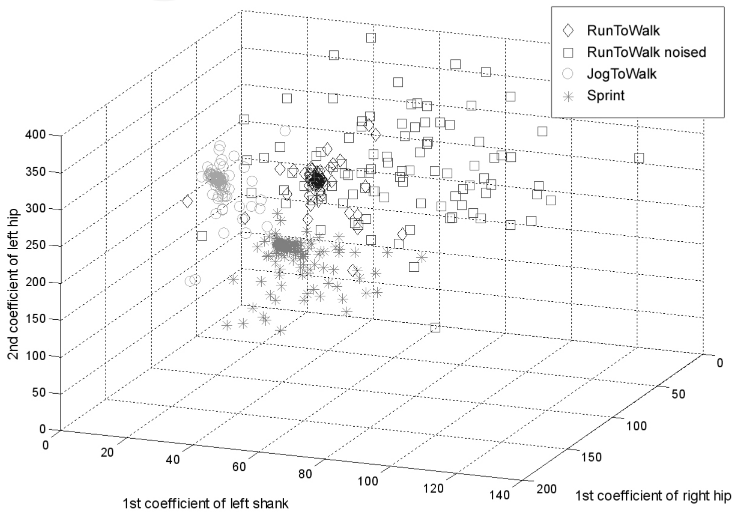

Fig. 6. The results of spectrum analysis for the generated groups of motions (800 motions were computed in total)

4.2. Experiment: multidimensional spectrum analysis

As it is noticeable, the most difficult is to distinguish a noised group of motions. Also some elements of other groups do not form a clearly defined cluster. It is possible to check indirectly the performance of the comparison method. The idea is to run clustering algorithm and to check how well clustered groups we can obtain. It is possible to apply this idea, because we know the origin of each element before clustering. Generated groups of motions act as test sequences (normally we do not know how clustered elements should be placed).

There are many clustering algorithms. We propose to use hierarchical agglomerative clustering of complete-link type. Different clustering algorithms in application for the motion analysis are described in [15].

Clustering algorithm was run for each pair of previously generated groups. We computed a coefficient of quality of clustering which measures whether all elements are properly divided between groups. Its range is from 0 (no elements belong to a proper group, which means that elements are divided between groups equally) to 1 (all elements belong to a proper group, none is faulty clustered).

The experiment was carried out for different algorithms of motion analysis. The standard algorithm taking into consideration only 3 parameters is called *3D*. Extended algorithms compute distance between the clustered elements taking into account more spectrum amplitude coefficients (from 1 to 10). Clustering was carried out for each algorithm independently. The results are presented in Table 1.

Table 1. Clustering quality for different pairs of groups and variable number of spectrum amplitude coefficients

		Extended method					
Pairs of groups	3D method	1 coeff.	2 coeff.	3 coeff.	5 coeff.	8 coeff.	10 coeff.
1-2	0.010	0.02	0.63	0.82	0.78	0.92	1.00
3-4	0.935	0.99	0.945	0.95	1.00	1.00	1.00
2-3	0.340	0.82	0.52	0.66	0.80	0.99	1.00
1-3	0.340	0.22	0.35	0.36	0.36	0.36	0.36
1-4	0.900	0.95	0.96	0.96	0.96	0.96	0.96
2-4	0.940	0.99	1.00	1.00	1.00	1.00	1.00

The standard 3D method has serious problems during clustering, especially when noised elements are considered. The extended method provides generally better performance and mostly leads to perfectly clustered groups (quality coefficient = 1). We can conclude that taking into consideration only three parameters from the spectrum analysis is not always satisfactory. Using the quaternion representation (as it was done in the extended method) and a few more amplitude coefficients can give much better results. Note that in most cases it was enough to use 5 coefficients to obtain satisfactory results (except the pair 1-3, which represents very similar groups of motions difficult to distinguish).

The next step is to find a method which could deal also with very similar motions like *RunToWalk* and *JogToWalk*. Those motions are so similar that even taking into account many amplitude coefficients would not give satisfactory recognition. One of the ideas is to use the combined time-spectrum analysis. It could join the results obtained from the *Dynamic Time Warping* comparison and the spectrum analysis.

5. Conclusions

Biometry is becoming one of the most important fields connected closely with surveillance systems. Nowadays, when security is the priority issue for many governments, it is very important to obtain methods to identify humans at distance or to track a person in more complex situations (like crowded street). Motion analysis is necessary for tracking or recognition systems. Currently much research is carried out concerning both video streaming and motion capture analysis.

In the paper the most important approaches concerning possibilities of biometry motion identification are presented. The presented works mainly concern motion capture data, but after slight modifications it can be also used for video recording processing. Different motion data representations are presented and briefly described against application for analysis.

Two major approaches are presented – the time series and frequency domain analysis. The first is based on the *Dynamic Time Warping* algorithm and is widely used in many applications to deform, compare or normalize signals. The method can also be used for person identification. Although its performance is still questionable and requires further investigations.

The second group of methods is based on the spectrum analysis. Some ideas concerning the spectrum amplitude coefficients are adopted, compared and examined. We show that spectrum analysis can be also carried out for motion represented by quaternion matrices. Detailed investigations show that taking into consideration higher coefficients can be helpful to distinguish similar motions. Proper experiments are carried out using the motion generator. The performance of different methods is measured using the clustering algorithm.

We propose to construct a combined method which would take into consideration the results from spectrum analysis and time-series comparison. For example, one could determine a measure of similarity using *DTW* and use a similar measure in the spectrum domain (considering a number of coefficients). The combination should increase accuracy of results leading to better quality of clustering. This would be very helpful for further biometric analysis.

Biometric motion identification is under intensive development. The presented analysis of possibilities and some modifications are the base of much more complex identification system. Such a system always requires well defined human motion model, comparison algorithms and properly constructed motion database. The results obtained from the system will greatly depend on analysis methods. The results presented in the paper can be helpful to determine kinds of methods to be used and in what circumstances.

References

[1] Murray M. P., *Gait as a total pattern of movement*. Amer. J. Phys. Med. 46(1) (1967).
[2] Murray M.P., Drought A.B., Kory R.C., *Walking patterns of normal men*. J. Bone Joint Surg. 46-A(2) (1996) 335.
[3] Cunado D., Nixon M.S., Carter J.N., *Automatic extraction and description of human gait models for recognition purposes*. Computer Vision and Image Understanding, 90(1) (2003).
[4] Cunado D., Nixon M.S., Carter J.N., *Using Gait as a Biometric, via Phase-Weighted Magnitude Spectra*. Proc. of 1st Int. Conf. on Audio- and Video-Based Biometric Person Authentication, (2003).
[5] Mowbray S.D, Nixon M.S, *Automatic Gait Recognition via Fourier Descriptors of Deformable Objects*. Proc. of Audio Visual Biometric Person Authentication, (2003).
[6] Yam C.Y., *Automated person recognition by walking and running via model-based approaches*. Pattern Recognition 37(5), Elsevier Science, (2003).
[7] Yam C.Y., Nixon M.S., Carter J.N. *Extended Model-Based Automatic Gait Recognition of Walking and Running*. In Proc. of 3rd Int. Conf. on Audio- and Video-Based Biometric Person Authentication, AVBPA 2001, (2001) 278.
[8] Maillot P., *Using quaternions for coding 3d transformations*. In Graphics Gems I, Academic Press Inc., Boston, (1990) 498.
[9] Kulbacki M., Jablonski B., Klempous R., Segen R., *Learning from Examples and Comparing Models of Human Motion*. Journal of Advanced Computational Intelligence and Intelligent Informatics, Fuji Technology Press, 8(5) (2004) 477.
[10] Myers C.S, Rabiner L.R., *A comparative study of several dynamic time-warping algorithms for connected word recognition*. The Bell System Technical Journal, 60(7) (1981) 1389.
[11] Witkin A., Popović Z., *Motion Warping*. Proc. of SIGGRAPH 1995, USA, (1995).
[12] Bąk A. *Organizacja bazy danych ruchów elementarnych animowanych postaci ludzkich*. M.Sc. Thesis, Wroclaw University of Technology, Wroclaw (2001), in Polish.
[13] Kuan E.L., *Investigating gait as a biometric*. Technical report, Departament of Electronics and Computer Science, University of Sothampton, (1995).
[14] Jablonski B., Kulbacki M., Klempous R., Segen J., *Methods for Comparison of Animated Motion Generators*. Proc. IEEE International Conference on Computational Cybernetics, Hungary, (2003).
[15] Rawicki J., *Metody grupowania ruchów danych motion capture*, in *Diversitas Cybernetica*, Wydawnictwa Komunikacji i Łączności, Warszawa, (2005) 63, in Polish