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IDENTIFIERS FOR HUMAN MOTION ANALYSIS

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Abstract: *This paper proposes a series of identifiers that show the fact that the human motion is specific to each person. In order to find these parameters, a simple system based on video analysis was used to capture and analyze the human motion. Measurements were conducted on seven different subjects that were filmed during normal walking. Experimental data were processed with dedicated software and specific software programs developed by the authors. In the end, a combination of five identifiers that demonstrate the uniqueness of human motion was proposed.*
Key words: *human motion analysis, gait identifiers, markers, video processing, inverse kinematics*

1. INTRODUCTION

The study of human motion was of interest to researchers since ancient times, the results being relevant to areas such as sports, medicine and forensics [1-4]. The main purpose of the studies in these fields was to improve performances of athletes, to offer new solutions and also to improve the methods used in medicine (mainly rehabilitation medicine for orthopedics) and to offer alternatives to the usual human identification methods used in forensics.

Based on experimental observations and pattern analysis, different mathematical models were proposed [5-8] and multiple approaches were considered. Some of the approaches were based on gait cycle analysis [9-11], some of them on inverse kinematics, following the idea of obtaining motion parameters like velocity or acceleration starting from the position of body parts during motion [12].

In this paper the authors focus on finding a series of motion identifiers extracted from video materials of human walking in normal conditions. The goal is to prove that these identifiers are unique and stable for every individual. This is consistent with the needs in the above described fields: sports, rehabilitation medicine and forensics.

2. MATERIALS AND METHODS

When choosing a gait analysis system, there are lots of variants to be considered: video analysis methods, image analysis only methods, methods based on GPS and different other radio technologies etc. [13-14].

Aiming for low costs and wide availability, the plan was to use simple systems and methods so that the results can be easily obtained, verified and replicated. Also, it was very important that the system used did not influence in any way the human motion during walking.

Considering the possible practical applications in domains like sports and medicine, it was mandatory that the system is non-intrusive, so the choices were limited to gait analysis systems that carry almost no weight on the subject's joints and any solutions that include any form of electrical / electronic systems installed directly on the joint were also rejected from the start. Also, the ease of installation and ease of use are important factors in choosing a suitable gait analysis system.

For this research, the authors used a simple gait analysis system that extracts the data from the main joints of the human leg during walking: the hip, knee and ankle joints were considered. Markers (consisting of coloured paper) were installed on these leg joints and a frame-by-frame temporal evolution of these joints in motion, specific for every person who was video recorded using the system, was obtained. The motion was considered to be plane [15-19].

A lateral video camera, perpendicular on the walking axis, was used to capture the motion of the leg for every subject who walks in front of it. In order to keep things simple, 30 frames per second were chosen for the video recordings, but tests were made also using a high-speed camera, able of providing 500 frames per second videos. The processing time of high frames per second videos is significantly higher. Considering the goal of this research, 30 frames per second were enough, but for professional applications in sports or medicine a higher frame rate is advised.

Adobe After Effects was used as software to extract the data from the video materials. The extracted data was then transferred to Microsoft Excel tables, processed and analyzed using software programs which the authors developed in MATLAB [20]. The process of gathering the experimental data from video materials, using Adobe After Effects, can be seen in Figure 1.

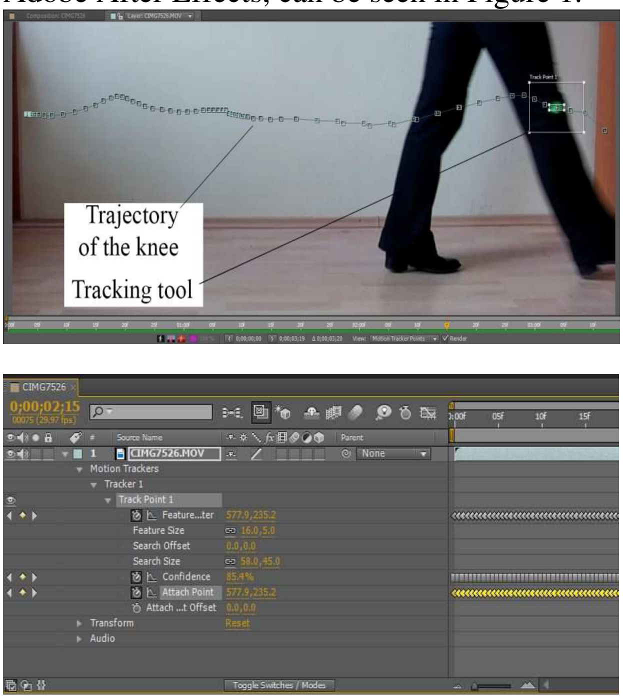


Fig. 1. Extracting the data from video materials

Extracting the coordinates is done using Adobe After Effects. The software offers a tracking tool which will follow the motion of the selected leg joint. The tool looks like two overlapping squares and a „+” in the middle.

Adobe After Effects automatically processes the video material frame by frame, and for each frame it analyzes the outer square versus the inner square (considering colour, luminance or saturation) to determine the correct position of the moving object. In the end, a list of (X,Y) coordinates for the selected leg joint was obtained [21-22]. That list was stored in an Excel table. This repeats 10 times for each subject, so, in the end, for each subject we have 10 tables for each leg joint, 30 tables of experimental data in total for each subject.

The data was then imported into MATLAB and a set of programs was developed by the authors in order to obtain the identifiers presented in Chapter 3 of this paper, Gait Identifiers.

Using inverse kinematics, the authors were able to determine values for velocity and acceleration for human walking, and these parameters were taken into consideration for the analysis.

3. GAIT IDENTIFIERS

In order to be considered useful for the purpose of this work, a Gait identifier has to have two primary characteristics: stability and uniqueness. Stability means that, for the same subject, a Gait identifier does not change drastically (remains between some boundaries) every time the subject walks normally. Uniqueness means that, for two or more subjects, the same Gait identifier is sufficiently different in value to be able to be used as a criterion to differentiate the different subjects considered.

In order to reduce error when working with a large number of subjects, the recommendation is that combinations of those gait identifiers are preferred to be used instead of using single identifiers alone.

In Figure 2, the authors present the ankle and knee’s marker representation in time for the same subject, while Fig. 3 shows the motion of the ankle, in comparison for two different subjects. It is important to note that Adobe After Effects considers the origin of the system of coordinates (0,0) to be the top-left corner and not the usual bottom left corner; the authors did not want to alter the data in any way and used the values as they were given by the application. In order to visually re-create the trajectory of the joints, these images should be viewed upside down. Again, this has only a visual effect, the math behind the identifiers is not affected in any way.

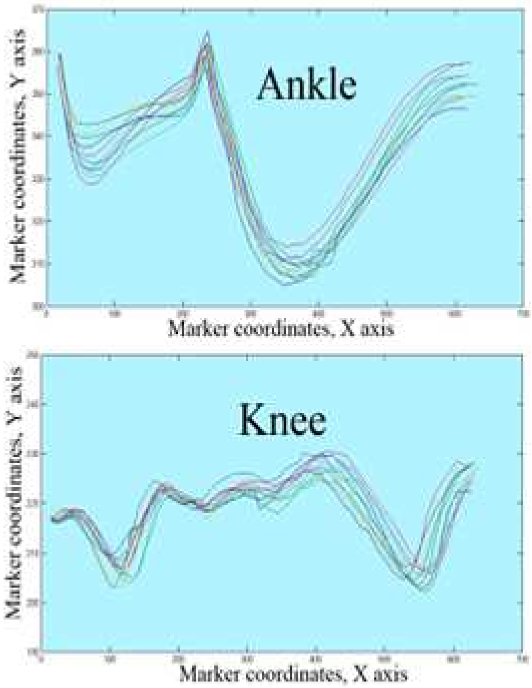


Fig. 2. Temporal evolution for the Ankle and Knee markers: same subject, 10 different recording sessions

By looking at the graphical representation of the temporal evolution of markers, it can be seen that the trajectories of the joints, for each subject, present both stability (Fig. 2) and uniqueness (Fig. 3). The idea is to extract some mathematical parameters which can be used to define these characteristics of motion (uniqueness and stability).

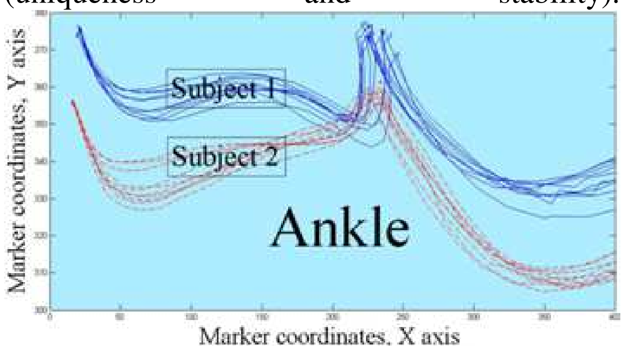


Fig. 3. Temporal evolution of the Ankle marker: two different subjects, 10 different recording sessions

The gait parameters which the authors found useful were directly computed using the coordinates obtained from the experimental data. The authors focused on their distribution during motion, these parameters being the main ones which they used in order to uniquely define the motion of the leg of an individual. These parameters were:

- The *variance to the mean, on the y axis*:

$$\sigma_y^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2 \quad (1)$$

- The *weighted mean velocity moment*:

$$\overline{V_{1y}} = \frac{1}{n-1}\sum_{i=1}^{n-1} p_i x_i v_{iy} = \frac{1}{n-1}\sum_{i=1}^{n-1} p_i \alpha_i (i-1)\Delta t \frac{y_{i+1} - y_i}{\Delta t}$$

To ease the calculus, the authors have chosen p_i so $p_i \alpha_i = 1$ and then:

$$\overline{V_{1y}} = \frac{1}{n-1}\sum_{i=1}^{n-1}(y_{i+1} - y_i)(i-1) \quad (2)$$

- The *weighted mean acceleration moment*:

$$\overline{A_{1y}} = \frac{1}{n-2}\sum_{i=1}^{n-2} p_i x_i a_{iy} = \frac{1}{n-2}\sum_{i=1}^{n-2} p_i \alpha_i (i-1)\Delta t \frac{y_{i+2} - 2y_{i+1} + y_i}{\Delta t^2}$$

$$= \frac{1}{n-2}\sum_{i=1}^{n-2} p_i \frac{\alpha_i}{\Delta t}(i-1)(y_{i+2} - 2y_{i+1} + y_i)$$

To ease the calculus, the authors have chosen p_i so $p_i \frac{\alpha_i}{\Delta t} = 1$ and then:

$$\overline{A_{1y}} = \frac{1}{n-2}\sum_{i=1}^{n-2}(y_{i+2} - 2y_{i+1} + y_i)(i-1) \quad (3)$$

- The *mean displacement moment on the y axis*, 1st degree:

$$\overline{S_{1y}} = \frac{1}{n}\sum_{i=1}^{n} p_i x_i y_i = \frac{1}{n}\sum_{i=1}^{n} p_i \alpha_i (i-1)\Delta t\, y_i$$

and if $p_i \alpha_i \Delta t = 1$:

$$\overline{S_{1y}} = \frac{1}{n}\sum_{i=1}^{n} y_i (i-1) \quad (4)$$

- The *mean displacement moment on the y axis*, 2nd degree:

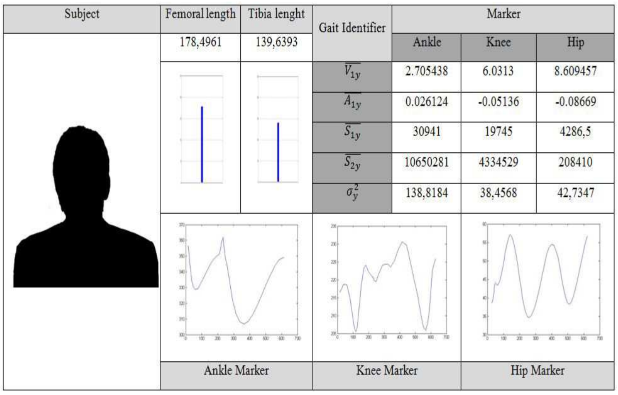
$$\overline{S_{2y}} = \frac{1}{n}\sum_{i=1}^{n} p_i x_i y_i^2 = \frac{1}{n}\sum_{i=1}^{n} p_i \alpha_i (i-1)\Delta t\, y_i^2$$

and if $p_i \alpha_i \Delta t = 1$:

$$\overline{S_{2y}} = \frac{1}{n}\sum_{i=1}^{n} y_i^2 (i-1) \quad (5)$$

In these expressions, Δt represents the time element for a frame of the walking session (the video recording was made at a number of 30 frames per second, so the time frame is 1/30 seconds), y_i represents the vertical coordinate corresponding to the *i* frame, *n* is the number of frames and $t_i = \Delta t * i$.

In the end, a file can be assigned for each subject, containing all the important data for the respective subject (Fig. 4).



Subject	Femoral length	Tibia lenght	Gait Identifier	Marker		
	178,4961	139,6393		Ankle	Knee	Hip
			$\overline{V_{1y}}$	2.705438	6.0313	8.609457
			$\overline{A_{1y}}$	0.026124	-0.05136	-0.08669
			$\overline{S_{1y}}$	30941	19745	4286,5
			$\overline{S_{2y}}$	10650281	4334529	208410
			σ_y^2	138,8184	38,4568	42,7347
	Ankle Marker		Knee Marker		Hip Marker	

Fig. 4. The file of a subject, for one walking session

4. RESULTS

To prove the stability and uniqueness of the chosen motion parameters, the following analysis was done:

- a combination of 3 of the 5 Gait identifiers was considered for a 3D graphical representation of the motion for the 7 considered subjects (for the presentation of the results shown in this paper, just one combination of parameters is shown, but, during the experiment, many other combinations were tested, all proving consistent with the facts presented in this work)
- the authors used those Gait identifiers as axis for a 3-dimensional graphic
- the authors drew the graphics for the values of these Gait identifiers, for all the 7 subjects and all the 10 walking sessions
- the above steps were repeated 3 times, one time for each leg joint: ankle, knee and hip; in the end, each joint had its own 3D graphical representation for the 7 subjects

It was expected that the values for each subject (the points determined by the combination of the 3 parameters) would group together, each group of points being at a significant distance from the points belonging to other subjects.

The authors present the analysis for a knee marker, for the 7 subjects x 10 walking sessions, having as axis the Variance, the Mean Displacement Moment of 1st degree and the Mean Displacement Moment of 2nd degree (on the y axis). These three identifiers have been chosen for presentation based on their variance, but any combination of the above identifiers can be considered. This method was chosen because it also offers a good visual representation for the results, which might be useful in fields where fast interpretations of results are needed (like athletics, where sports motions can be both recorded and analyzed on the sports field).

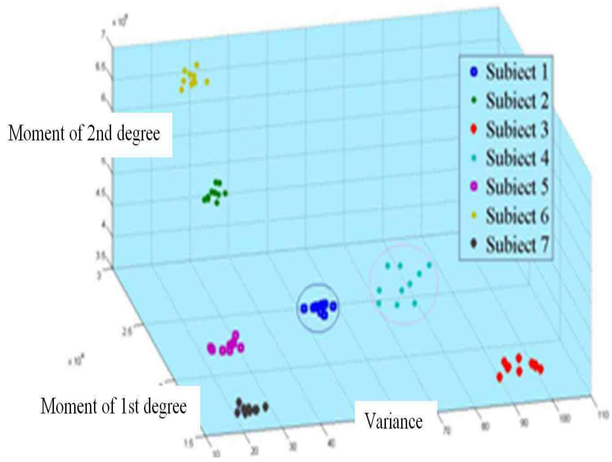


Fig. 5. Knee representation for the 7 subjects over 10 walking sessions, having as axis: the Variance, the Mean Displacement Moment of 1st degree and the Mean Displacement Moment of 2nd degree

In Fig. 5 it can be seen that the combination of identifiers for each subject groups together and, at the same time, at a reasonable distance from the combination of identifiers which corresponds to the other subjects. The authors consider that, on this sample, this proves the stability and uniqueness of the combination of parameters which they have chosen for the analysis.

5. LIMITATIONS AND FUTURE WORK

The solution to the problem given in this paper is based on a small sample and things might be different when considering databases of thousands of people. Also, the identifiers presented should be taken as combinations, as their uniqueness is not that consistent when considered each on their own.

For future research, the authors aim to find correlations between these gait identifiers and the physical characteristics of subjects (things like weight, height, gender and age are to be considered), a mathematical model for human walking being their ultimate goal in this field.

It is expected that the number of identifiers will increase after future research, and plans are that the Principal Component Analysis method to be used in order to statistically analyze the data.

6. CONCLUSION

The authors proposed and presented a simple gait analysis system which can successfully be used to capture process and analyze the human motion data in order to extract gait parameters which can be used to prove the uniqueness of human motion.

A simple solution for obtaining the gait data, from video capture to actual coordinates of a few human joints was presented. The authors aimed to find a series of statistical elements that make the human gait unique. They obtained five identifiers which, used in combination with each other, offer representations that are both stable and unique.

As practical applications, the authors consider these parameters to be useful in domains like medicine (especially rehabilitation medicine), sports (with the aim of improving athletic performances by identifying good / bad patterns for athletes) and, usually with the help of other tools from those fields, forensics and security, to help identify people from databases based on gait. The gait analysis system and the methods used in this work were carefully chosen so that eventual practical applications would be suitable for institutions on a limited budget, such as junior sports clubs, old foster care etc.

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Identificatori pentru mișcarea umană

Lucrarea propune găsirea unei serii de identificatori care arată faptul că mișcarea umană este specifică fiecărei persoane. În scopul de a găsi acești parametri, a fost utilizat un sistem simplu bazat pe analiza video pentru a înregistra și analiza mișcarea umană. Măsurătorile au fost efectuate pe șapte subiecți diferite, care au fost filmați în timpul mersul normal. Datele experimentale au fost prelucrate cu software dedicat și programe software specifice, elaborate de autori. În final, a fost propusă o combinație de cinci identificatori care demonstrează unicitatea mișcării umane.

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