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[1.] Miriam ANDREJIOVÁ, [2.] Zlatica DOLNÁ, [3.] Dušan ŠIMŠÍK, [4.] Zuzana KIMÁKOVÁ

AN ANALYSIS OF TEMPORAL AND SPATIAL PARAMETERS OF HUMAN GAIT

[1,4.] TECHNICAL UNIVERSITY OF KOSICE, FACULTY OF MECHANICAL ENGINEERING, DEPARTMENT OF APPLIED MATHEMATICS AND INFORMATICS, KOSICE, SLOVAKIA
[2,3.] TECHNICAL UNIVERSITY OF KOSICE, FACULTY OF MECHANICAL ENGINEERING, DEPARTMENT OF AUTOMATION, CONTROL AND HUMAN MACHINE INTERACTIONS, KOSICE, SLOVAKIA

ABSTRACT: *Basic manifestation of any living being is its locomotion. The locomotion of human being is based on locomotion patterns, which are formed in the process of evolution of every person. We assume it is an original feature of dynamic systems that human body is. Therefore, the pattern one moves and follows subconsciously, can describe an individuality of each of us. The most common prototype of locomotion is human gait. It is not only a way of bipedal motion for transport used daily; it also accompanies everyday human activities. The assumption that gait is a unique motion activity is relatively stable statement that allows us to examine human gait variability. The scope of the paper aims to analyze the basic gait parameters (temporal and spatial) in order to investigate the differences between the individuals. It is an initial study using correlation analysis. The final aim is to create a methodology of gait parameter variability assessment applicable for person identification based on the human gait. Therefore, the target field is gait pattern characteristic for individual that can help to distinguish the differences between people. The study is the first step of data analysis methodology that we try to create.*
KEYWORDS: *human gait, temporal and spatial gait parameters, correlation analysis*

INTRODUCTION

Gait as a basic and the most important way of human locomotion is characterised by its main functions: load response, body segments coordination and body locomotion in space.

Qualitative analysis *of gait starts with general gait examination of the physician as one of the routine investigation method in clinical sphere of rehabilitation medicine. It serves as a diagnostic tool commonly used worldwide. It assists to assess the features of the posture and postural functions during motion or movements that are performed during daily life activities. The professional observes overall body posture, body segments' posture and their movement related to the entire body movement. One of the important features to observe is to focus on the symmetry in frontal view. It detects the imbalance, predicts the linked indisposition of the spine, pelvis and joints of the lower extremities caused by the unequal loading. Smoothness, speed, coordination of the movement, cooperation of the upper and lower extremities together with the trunk movements can also provide an insight to the person's condition. The entire diagnostic system is based on the subjective assessment of the function, stability (standing stability and gait stability) and some of the gait parameters that are observed. Therefore, some authors use a term observational analysis. Even though this type of analysis is an important part of the clinical investigation, it strongly depends on many conditions, mainly on the experiences of investigator. This approach is often as an input source of information.*

Quantitative description *of human movement aims to quantitatively describe a particular movement, record it, analyze and process in order to determine them numerically. We can analyze gait and its temporal and spatial parameters, kinematic and kinetic parameters. From the technical requirements point of view, the temporal and spatial gait parameters are the easiest to measure, e.g. to estimate step length, step width, walking speed, stride time and other, only stopwatch and the meter is necessary. However, more advanced methods and techniques are preferred because of higher precision, robustness and repeatability of measurements. Nowadays, the systems installed in the motion laboratories are designed for detailed and complex provide all three types of the parameters. Kinematic parameters include mainly angles and rotations of anatomic joints and body segments that are analysed. Kinetic parameters give us information about the dynamics of the movement. They enable us to count with mass influence, with acceleration of the body or its segments, provide load response, position of centre of mass and show us the forces acting in the muscles during the movement determined from the electrical activity of muscles (EMG).*

Temporal and spatial gait parameters *as step length [m], step width [m], stride length [m], stride time [s], walking speed [m/s], cadence [step/min], gait cycle phases – stance and swing phase [%] can be defined as following:*

Gait cycle *is a basic unit of a human walking. It is a part of human gait measured from the initial contact of the heel of one foot with the ground until another contact of the heel of the same foot. Gait cycle is divided into two main phases - stance and swing phases. One gait cycle takes about one second. It normally consists of approximately 60% of stance phase and 40% of swing phase. Stance phase is characterized by contact of foot with the ground. The swing phase is described by swinging of the foot* *at the moment of take off the ground until the contact of foot of the same leg. During gait both phases partly overlap.*

Step length l *is measured in the same axis that the gait is performed. It is a distance from the place of the initial heel cont of one foot with the ground till the place of the contact of the heel of another foot. This distance depends to some extent also on the height of the subject as well as the other influences, e.g. metal state, motion pattern, age, stability disorders.*

Step width *is defined as a medium-lateral distance between feet during the double stance (in the moment of heel strike of one foot while the other foot is also in contact with the ground). It reaches usually only few centimetres.*

Stride length *represents the distance which the subject passes during one gait cycle. It is a distance from one heel strike of one foot to the place of the heel strike of the same foot. The period of one stride = one gait cycle is called a* ***stride time****.*

Cadence r *is a number of steps per one minute.*

Walking speed *can be calculated as it is seen in the equation (1):*

$$v = \frac{l.r}{120}. \quad (1)$$

Gait can be assessed by several systems, differing with the methods used, principle and data processing. Modern methods use systems based on various physical principles (optical, electromagnetic, ultrasound, others). Their initial application is in the medicine, in rehabilitation. From the clinical sphere, sports, industry it was already applied in the forensic science and criminalistics using IT for data acquisition, movement tracking and for gait variability assessment.

Gait analysis used for identification purposes in biometrics has been introduced as a tool for person identification in the past decade. There are already several methods and algorithms developed worldwide. Most of them lead to a database of the gait records and date processed in various ways, mathematical modelling, image processing, etc. There is even the real life success story documented from the Southampton. It was a case of the child kidnapping. A surveillance camera record was the only proof of the crime. However, the person that committed crime was masked and did not leave any physical tracks that could show his identity. The camera record and gait analysis using image processing have served as the proof and method to find a suspect that matched the criminal who was caught upon the positive identification. The most known databases devoted to the research of human gait as a tool for identification purposes are the results of the institutes: MIT Georgia Institute of Technology (GaTECh), National Institute of Standards in Technology (NIST), University of Maryland (UMD), University of Southampton (Soton), Carnegie Mellon University (CMU), University of South Florida (USF), University of California San Diego (UCSD) and Centre for Biometrics and Security Research that created CASIA database with Chinese biometrics.

The novelty of the approach described in the paper is based on the demographic background in our geographic area, using the biometric data of young healthy people. We have focused on the original algorithm in the methodology design for project we cooperated on with the Institute of Institute of Forensic Science and Criminology in Carlsbad, Czech Republic.

MATERIAL AND METHODS

The temporal and spatial parameters belong to basic parameters of human gait analysis. For their determination a length measuring instrument and a stopwatch are sufficient. However, for more precise approach we have used optical system for the movement analysis based on the optical system.

Human gait analysis requires complex approach. Therefore, a specialised Laboratory of motion analysis was established at the Department of Automation, Control and Human Machine Interactions at the Faculty of Mechanical Engineering at the Technical University of Kosice. To measure gait parameters a system of optical-electronic recording of movement, SMART from the company BTS Engineering, was used. It was applied not only to capture the motion data, also it conveyed the 3D reconstruction, graphical outputs were displayed and the date were plotted and processed for further conversion and analysis. The system is designed for clinical applications in orthopaedics and rehabilitation.

In the study we build our assumptions on the fact that gait is a typical feature characteristic for each individual. The method applied for analysis of the gait parameters' variability belongs to the model oriented methods. This method is based on the movement capture of the individual that is represented with a stick figure, model consisting of 25 reflective markers. Based on the knowledge of human biomechanics we have selected anatomical landmarks for the marker model and attached markers on her/his body (also indoor and outdoor clothing applied). All the measurements were conducted within the same conditions acting. However, as the data processing is time-consuming process, only the data from measurements in sportswear were analyzed.

10 volunteers (5 women and 5 men) participated on the measurements. These volunteers, aged 24 to 32 years, did not claim to have any pathology, injury or any posttraumatic history in their musculoskeletal system prior to measurements. Basic characteristics and biometric data of the subjects are shown in Table 1.

Table 1. Descriptive statistics (10 subjects)

Descriptive statistics	Age	Weight	Height	BMI
Mean	26,80	69,00	1,75	23,05
Maximum (Max)	32,00	91,00	1,92	26,49
Minimum (Min)	24,00	53,00	1,60	18,56
Standard deviation (S.D.)	2,35	12,98	0,12	2,59

Figure 1. Measurements in the Laboratory of motion analysis

The visualisation of the motion captured by software of the SMART system that is after the 3D motion reconstruction can be seen in Figure 2. It displays the body movement that can be assessed qualitatively as well as quantitatively (right part of the screen shows the graphs of the kinematic data – displacement, velocity and acceleration).

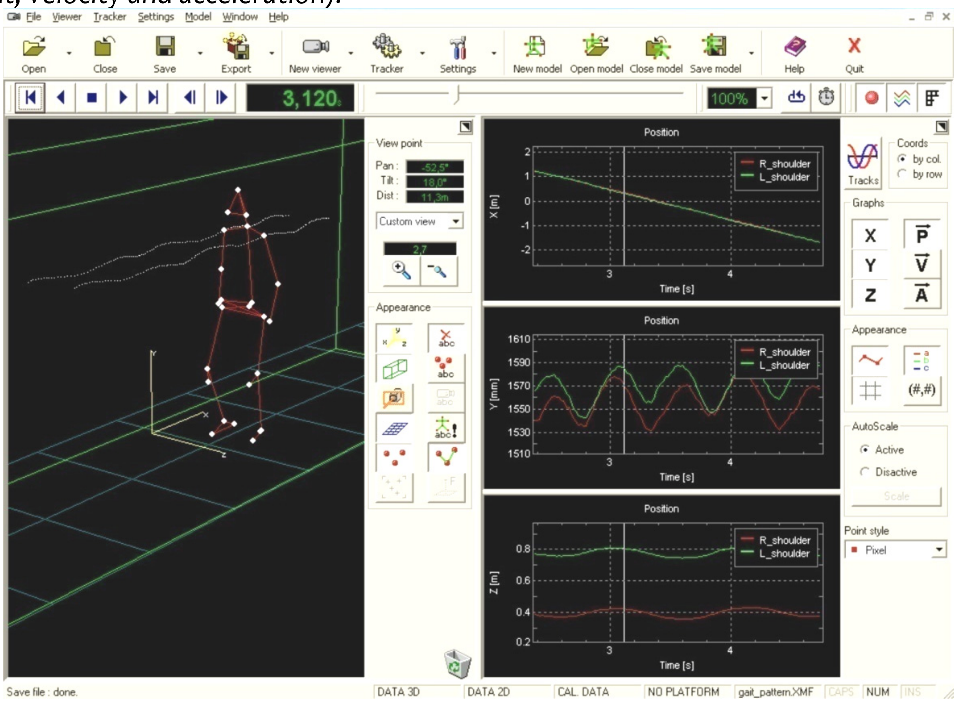

Figure 2.Recording of the movement of the measured subject

ANALYSIS OF THE GAIT PARAMETERS

Each measurement of human gait in 3D – three planes (frontal, sagital and transversal) of the whole body consisted of recordings 10 repeated measurements per subject in self-selected speed of walking. The reason to use the voluntary speed was to simulate the natural conditions and subjects were asked to walk without they knew when the recording has started or finished. A wide range of gait parameters were recorded. However, for our initial study, the spatial and temporal parameters we have assessed. All of them we considered separately for left and right hand side. This is the best way to quantify the symmetry of movement that is performed by human body.

RESULTS

The basic descriptive statistics was the first part of the data evaluation. We calculated: arithmetic mean (Mean), maximum (Max), minimum (Min), standard deviation (S.D.) and variation coefficient (CV).

Table 2. Step length for the right and left foot [m]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	0,647	0,579	0,517	0,564	0,564	0,578	0,622	0,664	0,584	0,535
Max	0,693	0,596	0,530	0,613	0,602	0,642	0,657	0,724	0,644	0,552
Min	0,592	0,550	0,492	0,525	0,507	0,499	0,591	0,547	0,527	0,508
S.D.	0,030	0,016	0,010	0,027	0,032	0,046	0,025	0,060	0,034	0,017
CV	4,581	2,847	2,029	4,773	5,735	7,917	4,006	8,990	5,865	3,157
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	0,672	0,539	0,513	0,561	0,556	0,513	0,598	0,654	0,595	0,556
Max	0,710	0,572	0,535	0,607	0,592	0,545	0,686	0,719	0,636	0,572
Min	0,633	0,502	0,488	0,531	0,515	0,493	0,512	0,420	0,540	0,519
S.D.	0,021	0,024	0,016	0,025	0,025	0,016	0,044	0,084	0,029	0,018
CV	3,156	4,404	3,137	4,406	4,413	3,180	7,406	12,885	4,924	3,249

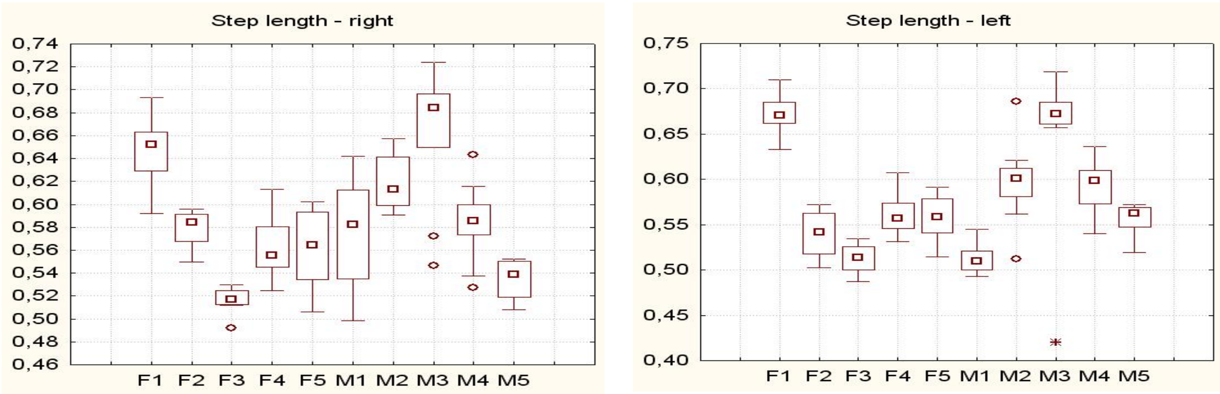

Figure 3:Box plot – Step length (right, left)

Table 3. Step width for the right and left foot [m]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	0,048	0,047	0,065	0,068	0,125	0,058	0,029	0,111	0,123	0,038
Max	0,087	0,076	0,083	0,129	0,152	0,065	0,058	0,190	0,149	0,117
Min	0,015	0,007	0,042	0,027	0,095	0,050	0,014	0,034	0,088	0,006
S.D.	0,026	0,020	0,015	0,036	0,018	0,005	0,018	0,047	0,024	0,033
CV	53,57	42,37	22,37	52,91	14,09	7,83	60,76	42,23	19,20	87,28
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	0,039	0,024	0,080	0,055	0,108	0,032	0,054	0,099	0,109	0,047
Max	0,084	0,063	0,099	0,106	0,133	0,055	0,091	0,117	0,141	0,081
Min	0,018	0,004	0,028	0,025	0,093	0,015	0,021	0,075	0,076	0,025
S.D.	0,021	0,018	0,021	0,026	0,015	0,011	0,020	0,014	0,020	0,019
CV	52,71	74,73	25,72	46,71	14,23	36,36	36,88	14,49	18,67	40,25

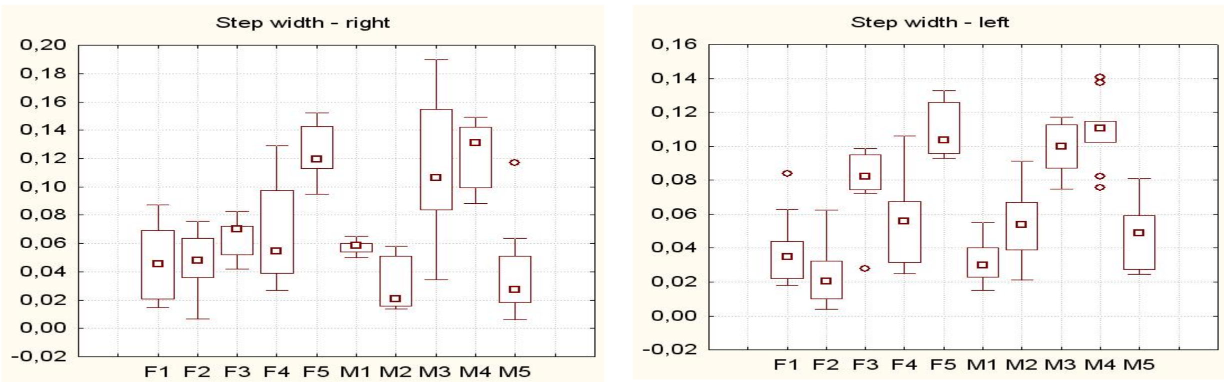

Figure 4. Box plot – Step width (right, left)

Table 4. Stride length for the right and left foot [m]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	1,366	1,121	1,073	1,206	1,148	1,346	1,200	1,314	1,217	1,136
Max	1,448	1,243	1,117	1,287	1,267	1,548	1,400	1,490	1,312	1,198
Min	1,244	0,976	1,003	1,140	1,000	1,194	1,114	1,120	1,130	1,011
S.D.	0,054	0,083	0,032	0,052	0,086	0,135	0,086	0,146	0,062	0,053
CV	3,927	7,404	2,956	4,277	7,472	10,023	7,148	11,122	5,068	4,640
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	1,361	1,115	1,083	1,208	1,194	1,307	1,298	1,348	1,230	1,157
Max	1,407	1,198	1,132	1,273	1,260	1,495	1,398	1,437	1,442	1,185
Min	1,272	0,911	1,048	1,131	1,114	1,122	1,143	1,108	1,119	1,094
S.D.	0,043	0,084	0,026	0,049	0,045	0,145	0,093	0,118	0,091	0,033
CV	3,147	7,500	2,394	4,067	3,798	11,074	7,162	8,766	7,395	2,890

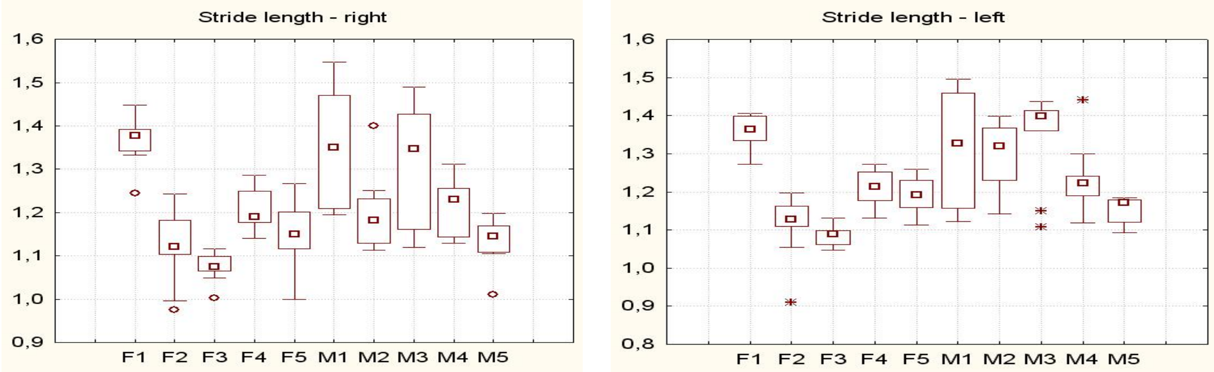

Figure 5. Box plot – Stride length (right, left)

Table 5. Stride time for the right and left foot [s]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	1,076	1,127	1,236	1,120	1,308	1,114	1,096	1,220	1,288	1,098
Max	1,160	1,180	1,320	1,140	1,520	1,240	1,140	1,240	1,600	1,160
Min	1,020	1,080	1,160	1,060	1,140	1,060	1,040	1,160	1,160	1,060
S.D.	0,039	0,035	0,050	0,028	0,108	0,056	0,036	0,027	0,124	0,032
CV	3,591	3,075	4,022	2,525	8,288	5,011	3,309	2,186	9,661	2,906
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	1,044	1,128	1,242	1,118	1,262	1,132	1,100	1,226	1,258	1,096
Max	1,200	1,200	1,320	1,160	1,360	1,260	1,160	1,280	1,560	1,220
Min	0,900	1,080	1,180	1,060	1,160	1,040	1,040	1,140	1,100	1,060
S.D.	0,091	0,037	0,049	0,029	0,060	0,073	0,037	0,038	0,135	0,048
CV	8,700	3,259	3,977	2,592	4,751	6,458	3,320	3,081	10,716	4,369

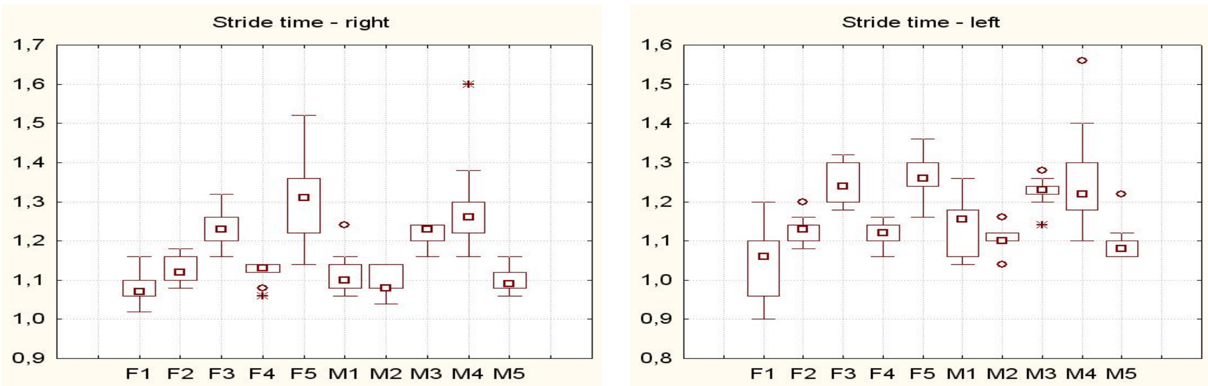

Figure 6. Box plot – Stride time (right, left)

Table 6. Walking speed for the right and left lower extremity [m/s]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	1,270	0,995	0,869	1,078	0,872	1,208	1,096	1,078	0,951	1,035
Max	1,368	1,110	0,931	1,208	1,104	1,387	1,228	1,242	1,058	1,109
Min	1,196	0,879	0,808	1,000	0,602	1,053	0,977	0,918	0,777	0,919
S.D.	0,048	0,077	0,033	0,064	0,138	0,106	0,087	0,128	0,084	0,056
CV	3,772	7,707	3,824	5,952	15,888	8,776	7,895	11,889	8,854	5,447
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	1,312	0,990	0,874	1,082	0,949	1,156	1,182	1,100	0,986	1,057
Max	1,471	1,106	0,930	1,194	1,071	1,278	1,279	1,198	1,104	1,113
Min	1,166	0,799	0,809	0,988	0,852	0,959	1,020	0,880	0,762	0,962
S.D.	0,111	0,087	0,044	0,065	0,073	0,120	0,102	0,094	0,108	0,050
CV	8,452	8,740	5,080	6,008	7,739	10,397	8,663	8,511	10,987	4,763

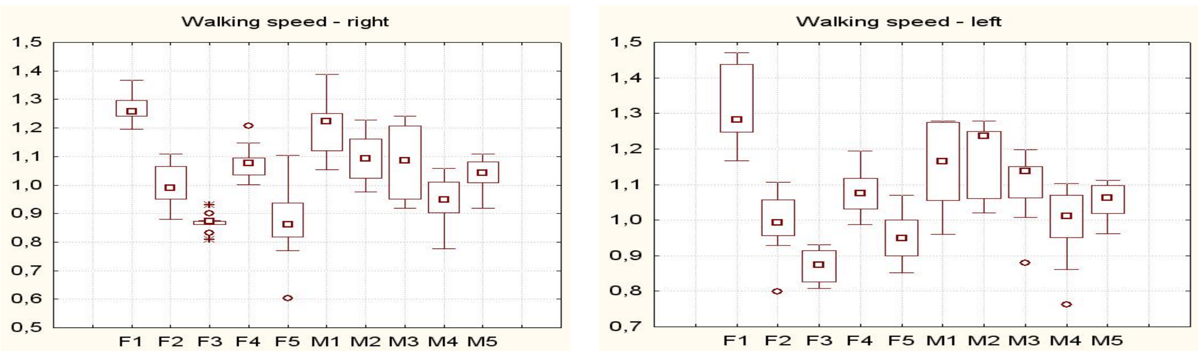

Figure 7. Box plot – Walking speed (right, left)

Table 7. Cadence for the right and left lower extremity [step/min]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	111,7	106,6	97,7	107,2	90,9	108,0	109,6	98,4	93,9	109,4
Max	117,6	111,1	103,4	113,2	105,3	113,2	115,4	103,4	103,4	113,2
Min	103,4	101,7	90,9	105,3	64,8	96,8	105,3	96,8	75,0	103,4
S.D.	3,9	3,2	3,5	2,8	10,9	5,2	3,6	2,2	8,0	3,1
CV	3,5	3,0	3,6	2,6	12,0	4,8	3,3	2,2	8,5	2,9
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	115,7	106,5	97,3	107,4	95,3	106,4	109,2	98,0	96,3	109,7
Max	133,3	111,1	101,7	113,2	103,4	115,4	115,4	105,3	109,1	113,2
Min	100,0	100,0	92,3	103,4	88,2	95,2	103,4	93,8	76,9	98,4
S.D.	10,2	3,4	3,2	2,8	4,6	6,8	3,7	3,1	9,4	4,5
CV	8,8	3,2	3,3	2,6	4,8	6,4	3,4	3,2	9,7	4,1

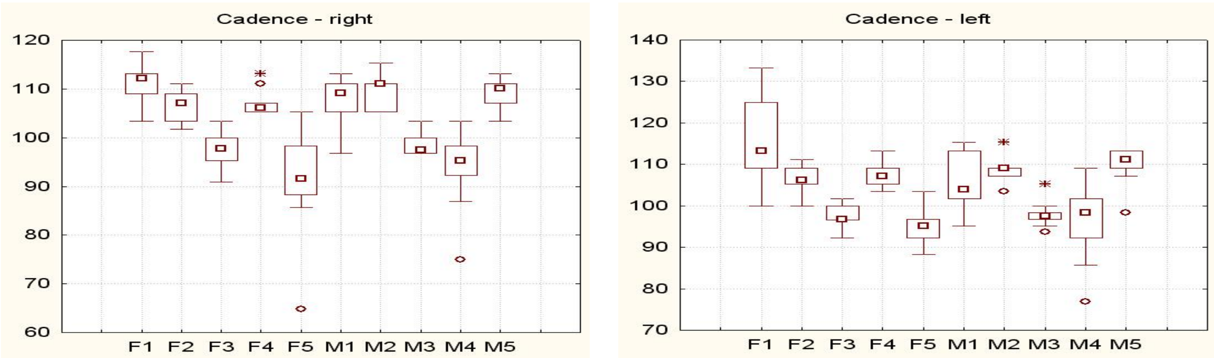

Figure 8. Box plot – Cadence (right, left)

Table 8. Stance phase for the right and left extremity [%]

Right	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5
Mean	58,7	53,9	58,5	59,8	59,3	51,3	55,3	62,5	59,8	60,7
Max	65,4	60,7	61,9	63,2	62,9	58,9	58,9	65,0	63,8	62,5
Min	53,7	36,4	51,7	55,6	44,3	35,5	50,9	61,3	54,8	58,5
S.D.	4,2	7,3	3,2	2,0	5,4	9,0	2,5	1,2	2,9	1,4
CV	7,2	13,6	5,4	3,3	9,2	17,5	4,5	2,0	4,8	2,3
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	57,7	55,3	58,6	59,4	61,8	53,8	53,4	59,4	61,0	59,8
Max	75,6	61,7	63,1	62,5	64,6	61,5	58,2	61,3	67,3	63,0
Min	45,8	48,3	49,2	56,6	58,7	39,2	50,0	56,1	57,7	56,6
S.D.	8,4	4,2	4,0	1,7	1,9	6,5	2,7	1,5	2,7	1,9
CV	14,6	7,6	6,7	2,9	3,1	12,1	5,1	2,6	4,3	3,2

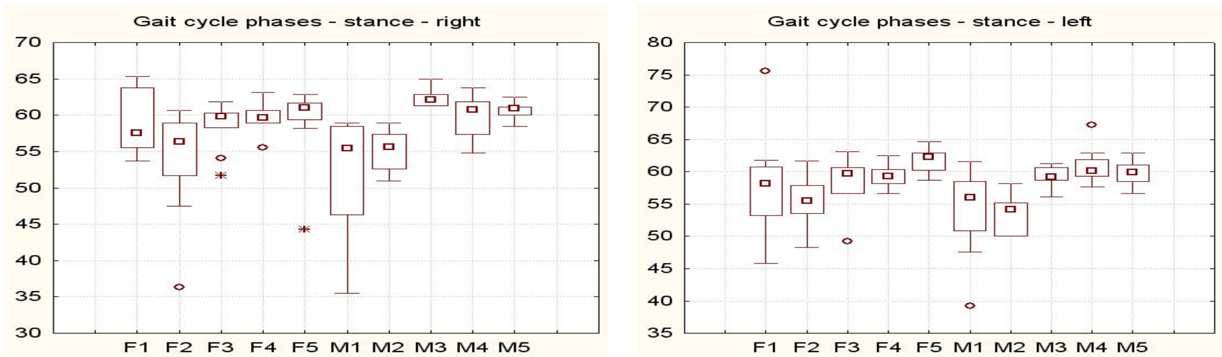

Figure 9. Box plot –Stance phase of gait cycle (right, left)

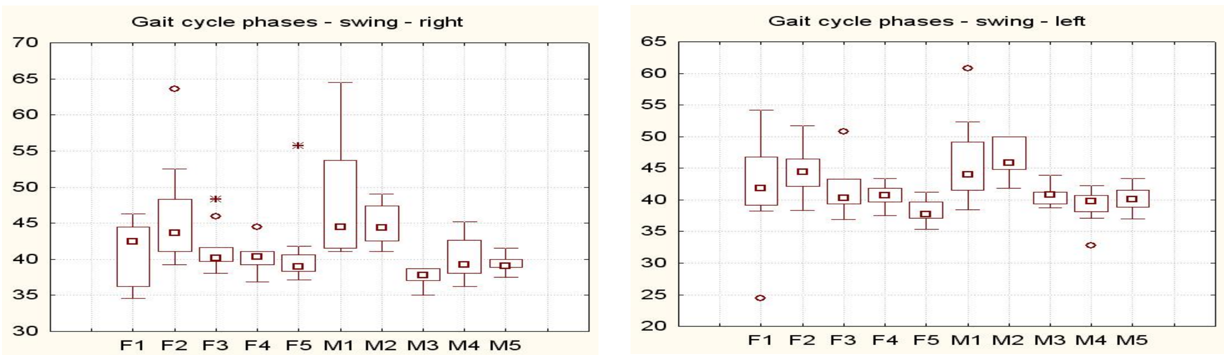

Figure 10. Box plot – Swing phase of gait cycle (right, left)

Table 9. Swing phase for the right and left lower extremity [%]

Right	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	41,3	46,1	41,5	40,2	40,7	48,7	44,7	37,5	40,2	39,3
Max	46,3	63,6	48,3	44,4	55,7	64,5	49,1	38,7	45,2	41,5
Min	34,6	39,3	38,1	36,8	37,1	41,1	41,1	35,0	36,2	37,5
S.D.	4,2	7,3	3,2	2,0	5,4	9,0	2,5	1,2	2,9	1,4
CV	10,2	15,9	7,7	4,9	13,3	18,5	5,6	3,3	7,1	3,5
Left	**F1**	**F2**	**F3**	**F4**	**F5**	**M1**	**M2**	**M3**	**M4**	**M5**
Mean	42,3	44,7	41,4	40,6	38,2	46,2	46,6	40,6	39,0	40,2
Max	54,2	51,7	50,8	43,4	41,3	60,8	50,0	43,9	42,3	43,4
Min	24,4	38,3	36,9	37,5	35,4	38,5	41,8	38,7	32,7	37,0
S.D.	8,4	4,2	4,0	1,7	1,9	6,5	2,7	1,5	2,7	1,9
CV	19,9	9,5	9,6	4,3	5,0	14,1	5,9	3,8	6,8	4,8

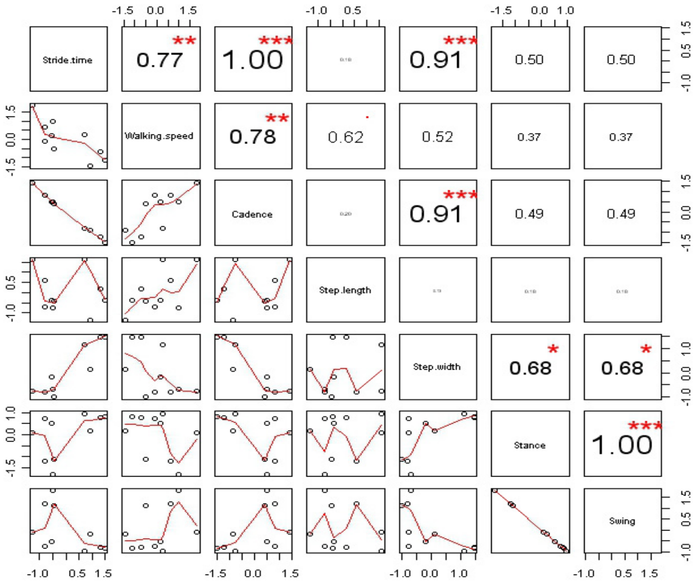

Figure 11. Graphical representation of Correlation between the gait parameters

In the next step, after the tools of the descriptive statistics were applied, we were conducting a correlation analysis. As the monitored parameters are measured in various units, for setting correlation we have used correlation coefficient and correlation matrix. The main aim was to find the relations between the gait parameters (Table 10 and Figure 11) and the influence of the biometric characteristics (age, weight, height, BMI) on the gait parameters (Table 11).

The bolt values in the tables are indicating the high level of dependence. Correlation coefficient's absolute value above 0,7 is interpreted as a very high correlation, the value ranging from 0,5 to 0,7 as a high correlation. When the correlation coefficient value is above 0,3 or 0,5, we usually conclude a moderate correlation and the value up to 0,3 a trivial, low correlation.

Table 10. Correlation Matrix – gait parameters

	Stride length	Stride time	Walking speed	Cadence	Step length	Step width	Stance	Swing
Stride length	1							
Stride time	-0,303	1						
Walk.speed	**0,840**	**-0,768**	1					
Cadence	0,316	**-0,998**	**0,779**	1				
Step length	**0,770**	-0,182	0,621	0,198	1			
Step width	-0,007	**0,914**	-0,522	**-0,907**	0,130	1		
Stance	-0,140	0,504	-0,372	-0,492	0,172	0,683	**1**	
Swing	0,140	-0,504	0,372	0,492	-0,172	-0,683	**-1**	1

CONCLUSIONS

Human gait is a prototype movement that proves its periodicity, repeatability and similarity. However, we can recognize the identity of our relatives, friends and people we know according the way of walking even from greater distance. This was already an assumption for Aristotle, when he examined a test of walking along the wall to see the motion tracks. From the point of view of gait individuality we can say that each of the subjects had its typical features and characteristics of gait. The uniqueness of human gait manifested itself in the entire body movement, motion of upper and lower extremities and also in trunk and head movement from the subjective assessment.

Table 11. Correlation Matrix

	Age	Weight	Height	BMI
Stride length	-0,435	0,326	**0,634**	-0,139
Stride time	0,213	0,021	-0,384	0,392
Walking speed	-0,414	0,162	**0,614**	-0,346
Cadence	-0,214	-0,046	0,367	-0,408
Step length	-0,271	0,091	0,495	-0,183
Step width	0,245	0,082	-0,130	0,437
Stance	**0,686**	-0,005	-0,192	0,510
Swing	**-0,686**	0,005	0,192	-0,510

From the results of the quantitative analysis we can conclude that almost all parameters investigated have shown variability. Each individual gait (10 gait measurements) proved differences in stride time, stride length, walking speed, step length and width. Highest variability was found in cadence and gait cycle phases. According to very rough rule the variation coefficient higher than 40 % is a sign of considerable inhomogenity of a statistic file. Therefore, the step width is at majority of measured subjects (except for F3, F5, M1, M4) the most variable gait parameter.

From the correlation analysis we can say that there is a very strong negative correlation between parameters Cadence and Stride time (r=-0,998), Step width and Cadence (r=-0,907). Very strong positive correlation is between parameters Step width and Stride time (r=0,914). Strong correlation is between parameters Walking speed and Stride length (r=0,840), Cadence and Walking speed (r=0,779), *and Walking speed and Stride time (r=-0,768). On the contrary, a very weak correlation was found is between Step length and Stride time (r=-0,182), Step length and Cadence (r=0,130), Step length and Stance (r=0,172), and Step width and Step length (r=0,130). A very negligible correlation is between Step width and Stride length (r=-0,007).*

Stride length and Walking speed proved the dependence on the height of the subject (r=0,634, r=0,614). Strong correlation was demonstrated also between gait cycle phases (stance and swing phase) and the age of the subject (r=0,686, or r=-0,686).

These results gave us important information the correlations between the parameters and also the influence of age and height on the gait parameters. From the initial study we can conclude that the spatial and temporal data are differing within the subjects and that there is high correlation between age and phases of gait cycle. This is supported by the results of the similar scope from the field of gait analysis of children and elderly people. Our result proved that there is influence of age also when we have group of people with 10 years difference.

The research of the gait parameters variability continues. We plan to extend the measurements to make the group of data wider (we have another 10 subjects measured and need to process their gait data), use more advanced statistic methods to evaluate the variability (apply analysis of variance, PCS, cluster analysis) and verify our approach with comparison of the results from the marker free measurements of the same subjects's gait. This algorithm uses a commercial camera to record movement and image processing that can be used in real life for comparing a suspect with the record form crime scene. These steps will lead us to design of a methodology. At the moment the study provided us first information and it will go on from the pilot methodology to the improved one that might be useful for the practical application in the field of human identification.

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