517. Autocorrelation function for human gait analysis

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(Received 23 July 2009; accepted 27 November 2009)

Abstract. The paper presents applying of the autocorrelation function to human gait analysis. The series of angle signals at the hip, knee and ankle joints of patients with different pathological states were analyzed. The signals were processed by means of the autocorrelation function. This approach allowed to apply the simple mathematical function for analytic description of curves. By using curve fitting, parameters of 5th order polynomial function were evaluated. Mean values and standard deviation of six parameters were observed in relation to human gait pathology. The results indicate new possibilities for applying the method to diagnose human gait using the autocorrelation function.

Keywords: autocorrelation function, human gait, curve fitting, analytic description.

Introduction

The human gait analysis is an important problem in biomechanics of human locomotion field. It is a first step in diagnostics of human movement apparatus and decision making about treatment (rehabilitation, surgery etc.). It is also used for improving the training methods in sport and in problems of ergonomics and work safety. Unfortunately, various devices used for recording human gait give a lot of information, which is extremely difficult to interpret in fast and efficient way. The detailed and complex human gait analysis takes several hours. So, many methods of fast decision making has been elaborated recently [2, 5, 6, 7].

The transition from time signals to parameters expressed in numbers can be obtained by employing curve fitting. It can be developed using analytic description of signals in time domain as well as analytic description of the autocorrelation function. In the field of technical object diagnosis, many of applications of the autocorrelation function are known [4].

The correct diagnosis is important in choosing appropriate methods for gait improvement. Therefore, analysis of parameters of the autocorrelation function for diagnosing disease of investigated subject was the main aim of the work. It allowed to get to know the relations between calculated parameters and human gait pathology.

Method and input data

The measurements were made on a group of 35 subjects by means of optoelectronic system. Obtained data presents both typical and pathological gait in saggital plane. All subjects walked barefoot at their natural cadence along pathway. They represented the following type of gait:

- typical - persons who have not reported problems with gait;
- Cerebral Palsy (CP) – Spastic Diplegia;
- Hemiplegia;
- Spina Bifida (SB) – Myelomingocele.

The movement of investigated subjects was recorded by six infrared cameras with special retro reflective markers placed on characteristic points of human body. The experiment has been repeated several time so more that 130 strides has been collected. Finally, many parameters were obtained (kinetic, kinematic, anthropometric and other) describing patient's gait. Authors took into consideration only a relative angles between main segments of a lower limb (at the hip, knee and ankle joints), because they are one of the most popular parameters in human gait analysis.

The autocorrelation function was used for describing of variance of instantaneous relative angles in main joints of a human lower limb. The autocorrelation function is a time-domain function for describing the random response of the system. It is used for searching the time connectivity between two fragments of the process which are separated in delay time τ. The autocorrelation function shows a similarity of the considered fragments of the process and is defined as [1]

$$R_{uu}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T u(t)u(t+\tau)dt, \qquad (1)$$

where T is a finite record length in sec.

The form of the mathematical function for describing all of the calculated autocorrelation functions was determined as 5th order polynomial function as follows

$$R_{uu}(\tau) = P_1 x^5 + P_2 x^4 + P_3 x^3 + P_4 x^2 + P_5 x + P_6, \qquad (2)$$

where P_1, …, P_6 are some abstract numbers.

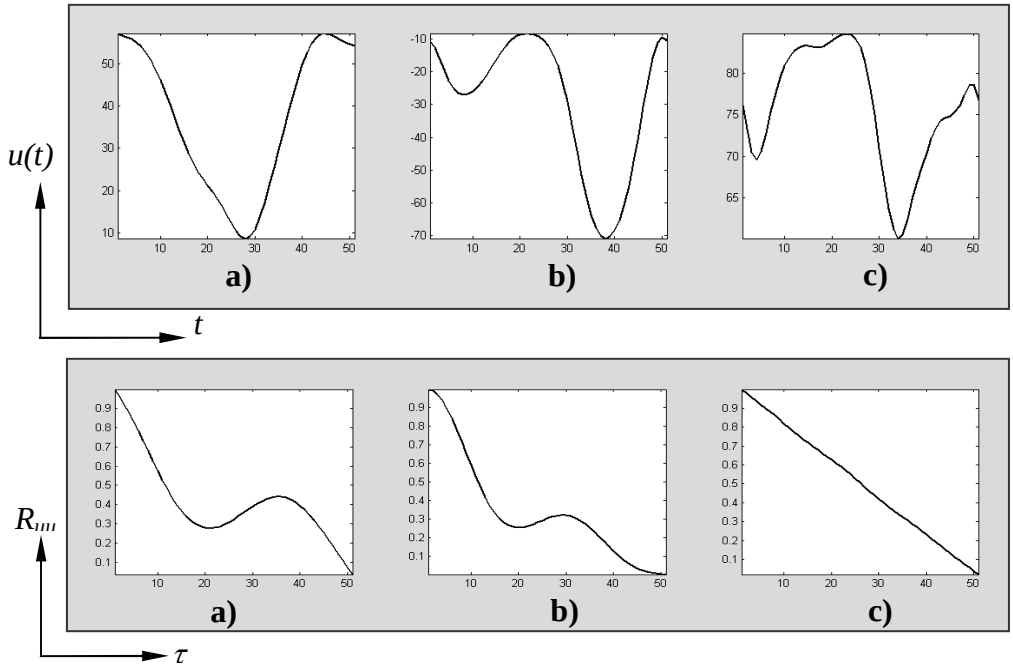

Fig. 1. Exemplary plots of joints signals (above) and corresponding autocorrelation functions (below): a) hip joint; b) knee joint; c) ankle joint

Then, parameters of analytic form of $R_{uu}(\tau)$ were calculated using the software with curve fitting tool. All of the fittings resulted a determination coefficient R^2 over a level of 95%. Exemplary plots of joints signals and the autocorrelation functions are shown in Fig. 1.

The preprocessing of P1-P6 parameters was based on Chauvenet's criterion [9]. It was made to avoid an influence of noisy signals for final results. Chauvenet's criterion is a special kind of well known three-sigma rule, which defines noisy data in dependency on number of measurements. In this paper the criterion was used for all types of subjects gait. Authors claims that rejecting noisy data should be a common procedure and sometimes is realized in human gait analysis [3, 8]. Unfortunately, a way how it was done often is not given [8]. It is important to say that rejecting any measurements is a controversial solution and it needs to be done in a very careful way [3].

The result of Chauvenet's criterion was throwing out of 14 gait strides from 8 subjects. Among them the all data as many as 5 subjects have been rejected. It is important to say that no fewer than 4 person have outliner anthropometric data (much lower than other body weight etc.). So, final set of data consists of 30 subjects and 118 strides (see Table 1).

Table 1. Material after rejecting of noisy data

	Typical	Hemiplegia	Spina Bifida	Cerebral Palsy
Number of subjects	9	9	6	6
Number of strides	51	33	16	19

Results and discussion

The average values of P1-P6 parameters have been calculated separately for each group of subjects. They are presented in Fig. 2 and in Tables 2 and 3.

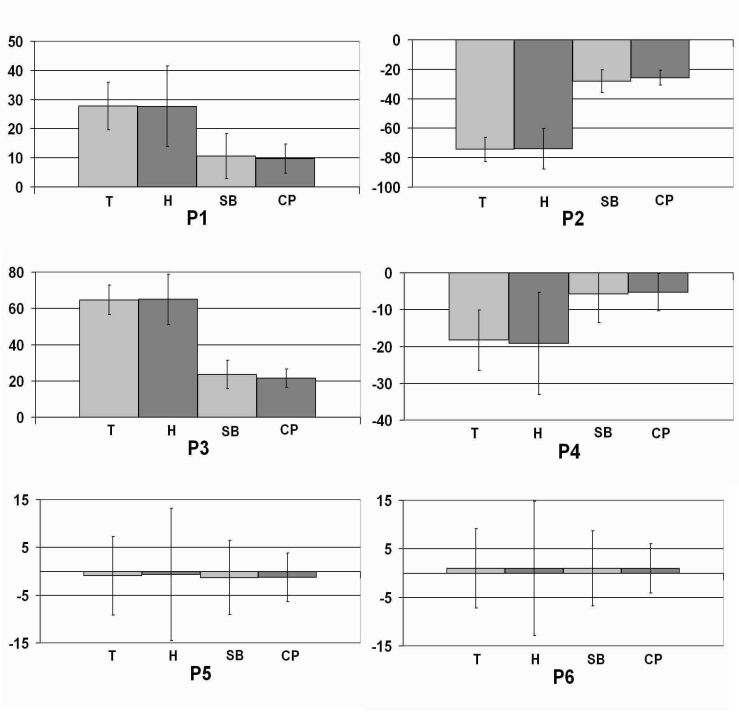

Fig. 2. Mean value and standard deviation of P1-P6 parameters of the autocorrelation function calculated from hip joint signals for typical (T), hemiplegia (H), spina bifida (SB) and cerebral palsy (CP) subjects

It is easy to notice that they are grouped into two classes: first consists of typical and hemiplegic subjects and second – subjects with Spina Bifida and Cerebral Palsy. Between those groups are really big differences, especially in parameters P1-P4.

Table 2. Parameters P1-P6 for typical and hemiplegic subjects

		Mean		Standard deviation		p-level
		Hemiplegia	**Typical**	**Hemiplegia**	**Typical**	
HIP JOINT	P1	27.7113	27.7994	13.83298	8.19510	0.974104*
	P2	-73.9469	-74.3039	37.07007	21.53477	0.960745*
	P3	65.0589	64.7408	33.70124	19.20248	0.961415*
	P4	-19.1370	-18.2431	11.04131	6.24932	0.678064*
	P5	**-0.6253**	**-0.9321**	**0.66794**	**0.48462**	**0.017702**
	P6	0.9827	0.9841	0.01119	0.00654	0.505866*
KNEE JOINT	P1	27.1900	31.6421	12.67975	4.67278	0.064495*
	P2	-71.5199	-77.3486	33.39233	11.29983	0.346668*
	P3	64.2636	63.5374	29.81483	8.99103	0.894164*
	P4	-20.8797	-18.3928	9.58404	2.40122	0.159230*
	P5	**-0.0202**	**-0.4042**	**0.54611**	**0.20607**	**0.000513***
	P6	**0.9980**	**1.0160**	**0.00936**	**0.00586**	**0.000000***
ANKLE JOINT	P1	-1.1454	-0.8681	1.11923	1.75050	0.381259*
	P2	2.8005	2.4300	2.85381	4.45623	0.645501*
	P3	-1.8160	-2.5300	2.49085	3.91569	0.312956*
	P4	**-0.0034**	**1.2148**	**0.84788**	**1.39672**	**0.000004***
	P5	**-0.8232**	**-1.2340**	**0.10072**	**0.19938**	**0.000000***
	P6	**1.0015**	**1.0056**	**0.00142**	**0.00293**	**0.000000***

* p-level for Cochran-Cox test after rejecting hypothesis (Brown-Forsythe test) of variation's homogeneity in both sets

Table 3. Parameters P1-P6 for subjects with Spina Bifida and Cerebral Palsy

		Mean		Standard deviation		p-level
		Spina Bifida	**Cerebral Palsy**	**Spina Bifida**	**Cerebral Palsy**	
HIP JOINT	P1	10.6238	9.7346	7.77040	5.04055	0.686102
	P2	-28.1525	-25.7189	20.23801	13.60772	0.674871
	P3	23.6311	21.5605	17.68551	11.92165	0.683215
	P4	-5.7606	-5.2953	5.56708	3.32544	0.771958*
	P5	-1.3058	-1.2440	0.49023	0.21048	0.643987*
	P6	0.9966	0.9957	0.00785	0.00358	0.678470
KNEE JOINT	P1	14.5816	12.8369	8.99137	10.19022	0.598222
	P2	-36.0631	-32.9676	21.89894	25.45249	0.705159
	P3	30.4523	28.7852	17.89244	21.14955	0.804940
	P4	-9.5893	-9.2671	5.23878	6.13146	0.869663
	P5	-0.3530	-0.3539	0.32480	0.28348	0.993430
	P6	**1.0005**	**0.9932**	**0.00398**	**0.00353**	**0.000002**
ANKLE JOINT	**P1**	**-2.1416**	**-0.3271**	**1.08214**	**1.45168**	**0.000237**
	P2	**5.4339**	**0.7856**	**2.72552**	**3.66318**	**0.000196**
	P3	**-4.4679**	**-0.4855**	**2.30807**	**3.11576**	**0.000177**
	P4	**1.2220**	**-0.0198**	**0.78661**	**1.04177**	**0.000426**
	P5	-1.0334	-0.9395	0.12696	0.14858	0.055059
	P6	1.0029	1.0020	0.00194	0.00218	0.181551

* p-level for Cochran-Cox test after rejecting hypothesis (Brown-Forsythe test) of variation's homogeneity in both sets

For typical and hemiplegic subjects, results of appropriate statistical test are presented in Table 2. Results for subjects with Spina Bifida and Cerebral Palsy are presented in Table 3.

The results show that parameter P5 at hip joint and parameters P5, P6 at knee joint and parameters P4, P5 and P6 at ankle joint are statistical significantly different between typical and hemiplegic subjects. Also, results show that parameter P6 at knee joint and parameters P1-P4 at ankle joint are statistical significantly different between subjects with Spina Bifida and Cerebral Palsy.

Conclusions

The P1-P6 parameters of polynomial function calculated for each joint of human leg separately have been comprised between selected types of human gait based on statistical tests. The results show that human gait analysis based on autocorrelation function can be as useful supplement of methods used today.

The result of Chauvenet's criterion rejects some gait strides. It affected especially on standard deviation value (the average values were changed a little).

The authors are conscious of some limitations of above studies. The results are limited to the group of persons chosen for investigation and selected types of human gait. It has been assumed that an extension of investigated material on other subjects will not change overall results. After adding a new type of gait pathology, more sophisticated statistical tool like analysis of variance could be required.

Acknowledgments

The authors would like to thank the Białystok Technical University for the support of the work by grant No. W/WM/1/2009.

References

[1] **Bendat J. S., Piersol A. G.** Engineering applications of correlation and spectral analysis, Wiley-Interscience, New York, 1980.

[2] **Derlatka M.** Application of Kernel principal component analysis in human gait, Journal of Vibroengineering, 2005, Vol. 7, No. 3, 27-30.

[3] **Derlatka M., Pauk J.** Data Mining in Analysis of Biomechanical Signals. Solid State Phenomena, 2009, Vols. 147-149, 588-593.

[4] **Kotowski A.** Parametric description of vibration using the autocorrelation function. Solid State Phenomena, 2009, Vols. 147-149, 606-611.

[5] **Olney S. J., Griffin M. P., McBride I. D.** Multivariate examination of data from gait analysis of persons with stroke. Phys Ther, 1998, 78(8), 814–828.

[6] **Pauk J., Jaworek K.** Parametric identification of lower limbs during walking of a man. Design & Nature, WIT Press, Southampton, 2002, 361-366

[7] **Romei M. et. al.** Use of the normalcy index for the evaluation of gait pathology. Gait and Posture 19, 2004, 85-90.

[8] **Taylor J. R**. An introduction to error analysis. The study of uncertainties in physical measurements. Polish edition. Wydawnictwo Naukowe PWN, Warsaw, 1995.

[9] **Wolf S.**, **Loose T., Schablowski M., Doderlein L., Rupp R., Gerner H. J., Bretthauer G., Mikut R.** Automated feature assesment in instrumented gait analysis. *Gait & Posture* 23, 2006, 331-338.