THE PATTERN RECOGNITION BASED ANALYSIS OF PARAPARETIC PATIENT'S GAIT UNDER THE INFLUENCE OF BILATERAL STIMULATION

V. Valenčič, Č. Marinček[x], T. Bajd
Faculty of Electrical Engineering, University of Ljubljana,
Institute for Rehabilitation[x]
61000 Ljubljana, Yugoslavia

Summary

The paper describes the results of three years FES treatment on lower extremities of paraparetic patient. The therapeutic and functional rehabilitation methods are based on application of two functional electronical peroneal stimulators. A new method of gait evaluation based on pattern recognition methods was applied to measured results. This method is to be used for estimation of several types of gait deviations in different stride phases.

The result of the study is also relationship between basic gait parameters (step length, stride time) and shapes of gonigrams. The results of our work are confirming the hypothesis that spinal cord patient can benefit from FES from both therapeutic and rehabilitation points of view. The described gait evaluation method is also more objective than other present methods.

Introduction

The pattern recognition methods are representing the new possibilities of human gait analysis and evaluation /1/. The idea about gait pattern recognition arised from the fact that it is nearly impossible to rule out the complexity of normal gait with classical biomechanical modelling /2/. Anyway the estimating of pathological gait properties is even more demanding /3/.

The present systems for gait parameters measuring are enabling the collection of enormous quantity of time, kinematic, kinetic and electrophysiological data. The measured data are elements of multidimensional space where the possibility of intuitive human observation fails down. We have to find out the more powerful methods and more objective criterion of gait pattern analysis then the criteria of our subjective visual observation which is able to handle with twodimensional data space. The useful application of pattern recognition methods have been demonstrated by G.A. Bekey et al. /4/. Our approach to gait recognition is based on time and kinematic gait parameters.

The pattern recognition algorithms are implemented because of the following main purposes:

i.) Automatical detection of unstationarity and unregularity of gait

ii.) Quantitative gait evaluation in typical segments of particular stride

iii.) The estimation of natural gait classes by "Clustering Technique"

Problems item /i/ have been successfully solved /5/ and the advantages of methods such as objectivity, reliability, full automatical artefacts extraction and fast data processing have been found out.

Some experiences about quantitative gait evaluation in typical segments have been gained and their presentation is the subject of this contribution.

To develop the natural gait classes by "Clustering Technique" we need a plenty of gait patterns in the training set of normal and pathological gait measurements /paraparetics, tetraparetics, hemiparetics and amputees/. Our intention is to made the gait analysis, evalutation and diagnosis objective. In this stage we concentrate our efforts to the set of training patterns collection and to analyze the statistical dependence of basic gait parameters of paraparetics and tetraparetics. . The results are to be used for feature extraction algorithm synthesis in gait pattern recognition system.

Instrumentation

There are many methods for measuring the gait parameters. Our measuring equipment includes two switches on each shoe sole /on the heel and on the toes/ to give the information on the time parameters. The hip, knee, and ankle angles of both legs in a sagittal plane were measured by electrogoniometric system /6/. The step length and velocity of the center of gravity were registered by tachomether and potentiometer /7/.

The measured data are already processed with HP 2100 S minicomputer system. The walking parameters under the consideration are chosen corresponding to the purposes of investigation.

The gait measurement is under the control of a set of programs WAP - Walking Analysis Package /8/. In the package the following computer programs for experiment initialization are included:

- multichanell A/D conversion and data collection,
- permanent disc file data base establishing,
- time gait parameters determination,
- step length and gait symmetries calculation,

- the row goniograms and basograms plotting,
- artefacts and unstationary strides recognition and rejection out of the further analysis,
- goniograms averaging and stride time normalization,
- averaged goniograms plotting,
- calculation of hip, knee and ankle joint trajectories in sagittal plane with comupter graphic,
- pattern recognition methods based on gait "normalcy" estimation, and
- program for basic gait parameters analysis /7/.

The programs and subroutines are modulary organized and with WAM - Walking Analysis Monitor supervised during computation. The results of particular programs of on-line gait analysis are presented on an example of paraparetic gait later in the paper.

Methodology

Correlation analysis of normal and paraparetic gait

The measuring system /7/ is able to record 16 basic gait parameters notified with p_1, p_2, ..., p_{16}. Odd parameters p_1, p_3, ... p_{15} belong to right and even p_2, p_4, ... p_{16} to left lower extremity. Right and left step time, stride time, stance phase, stride length, push - off velocity, velocity minimum, it's occurence and step length were measured.

We expect some parameters to be linearly dependent. This is the null hypothesis regarding different correlations between normal and pathological gait parameters. With intention to verify this hypothesis the correlation matrix of parameters p_1, p_2, ... , p_{16} was calculated. 24 walking runs of normal and 36 runs of paraparetics and tetraparetics were measured. Correlation coefficients were tested on 0, 95 significant t level and the results are presented on Fig. 1. The normal gait parameters significancy is signed with items n and pathological with items p. Fig. 1. present us the high correlation among time parameters p_1, p_2, ..., p_6 for normal and pathological walking gaits considered.

There is also high linear dependency between all time parameters p_1, p_2, ..., p_6 and right and left velocities p_{11} and p_{12}, within the normal gait.

There is no significant correlation in patients gait, except for both stance times p_5 and p_6. We can conclude that there is no possibility to evaluate the normal or pathological gait with parameters p_5 and p_6 only, but it is necessary to observe at least one of the parameters p_1, p2, p_3 or p_4. Parameters p_7, p_8, p_9 and p_{10} of normal gait are linearly correlated with right and left step lengths p_{15} and p_{16}, what was not observed in pathological gait of paraparetics and tetraparetics. It is therefore necessary to include them into the gait analysis, evaluation and pattern recognition.

It is important to pay attention to the correlation of all symmetrical parameters for normal gait parameters such as minimum occurence and step length.

This discussion suggests the following conclusion: for objective paraparetics gait pattern recognition and analysis minimal set of parameters such as p_1, p_3, p_5, p_7, p_9, p_{13}, p_{14}, p_{15}, and p_{16} has to be measured. Other parameters can be abondoned.

It is important to notify the validity of this conclusions for pathology under consideration. With amputees and hemiplegics different results, which cannot be applied from above mentioned conclusions, are expected.

↓ / Parameters →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	p n														
3	p n	p n													
4	p n	p n	p n												
5	p n	p n	p n	p n											
6	p n	p n	p n	p n	p n										
7															
8							p n								
9							n	n							
10							n	n	p n						
11	n	n	n	n	p n	n			p	p					
12	n	n	n	n	p n	p n			p	p	p n				
13					p										
14												p	n		
15							n	n	n	n					
16							n	n	n	n					n

Fig. 1. The correlation coefficient significancy on 0,95 t level of 16 basic gait parameters of paraparetics /p/ and normal /n/ subjects.

Gait estimation based on the comparison of goniograms shapes

The pattern recognition algorithm was developed to obtain a method of objective goniograms shape estimation in particular stride phases. Gait period was devided in three typical segments regarding the flexion or estension of each joint as shown on Fig. 2. This division of stride time is convenient for application of pattern recognition methods the shapes of goniograms are studied in this typical intervals of stride. This division is specially important in study of spastic walking. The advantage of proposed method is also the lessening of error arrising from relative and indirect measurement. The method is sensitive only to the changes of goniograms shapes and not so much to the initial standing posture of subject and zero joint angles /2/.

Let us suppose that human walking is mostly periodical process. The normal walking pattern can be determined from the litherature or better measuring a normal population. Let us denote the normal walking pattern X_i:

$$X_{i,1} = (x_{i,1}, x_{i,2}, \ldots, x_{i,L}) \qquad (1)$$

Where i = 1, 2, 3 meaning the hip, knee and ankle goniogram respectively, and L indicates the dimensionality of vector space (L = 256).
The set Y represents the measured gait patterns. Let us denote the elements of Y as vectors Y_i^m of dimension L:

$$Y^m_{i,1} = (y^m_{i,1}, y^m_{i,2}, \ldots, y^m_{i,L}) \qquad (2)$$

where m = 1, 2 ..., M and M means the number of strides.

The averaging module of WAP is estimating the mean values of goniograms functions $Y_{i,1}$ (Eq. 3):

$$Y_{i,1} = \frac{1}{M} \sum_{m=1}^{M} Y^m_{i,1} \qquad (3)$$

Vectors X_i and Y_m already defined in Eq. 1 and 3 are multiplied with vector B. Linear transformation can be described as:

$$P^k_{i,1} = B^k_{i,1} \cdot X_{i,1} \; ; \quad i = 1, 2, 3 \; ; \quad 1 = 1, 2, \ldots, L \qquad (4)$$

where k denotes the index meaning the stride interval of under consideration interest. The index k takes the values 1, 2 and 3 corresponding to flexion and extenstion in stance phase and flexion in swing phase for knee and hip joint. In the ankle joint the flexion is replaced by plantar flexion while extension corresponds to dorsal flexion. The index i = 1, 2, 3 are meaning hip, knee and ankle respectively.

The same transformation has to be made for the measured vector Y_i :

$$Q^k_{i,l} = B^k_{i,l} \cdot Y_{i,l} ; \quad i = 1,2,3, ; \quad l = 1,2,\ldots, L \qquad (5)$$

where

$$B^k_{i,l} = (b^k_{i,1} \cdot b^k_{i,2}, \ldots, b^k_{i,l}, \ldots, b^k_{i,L}) ; \; b^k_{i,l} \in \{0,1\} \qquad (6)$$

From the Fig.2.the values of components $b^k_{i,l}$ (100% of stride time corresponds to L = 256) are derived. The same relationship belongs to parameters of both legs. The values of $b^k_{i,l}$ could be 0 or 1.

The similarity measure of patterns is defined from the well known relation /9,10/:

$$d^2 \; (P,Q) = (P-Q) \cdot (P - Q)^T \qquad (7)$$

With the E_q. /7/ only the comparison between pathological gait patterns and normal pattern is defined. The measured patterns are not classified in different classes only the irregularities of goniograms are estimated in particular stride intervals.

The shape of goniograms depends on walking velocity (quotient of step length and stride length). The arrising of error was lessened with time normalization. Perhaps, better approach would be the studying of normal and pathological gait patterns at different velocities.

The quantization of gait estimation is limited by measurement accuracy. The advantage of the described method is possibility of estimation of different pathological walking patterns with respect to normal pattern and quantitative observation of effects produced by different orthotic or prosthetic assistive devices.

Results and conclusions

To indetify the advantages of our approach we have selected from our experimental data collection the typical and most interesting long term follow-up study of Th XII spinal compressive cord injury paraparetic patient using bilateral peroneal stimulators /FEPO - 10/. The first measurement of this patient with the method of clinical computerized evaluation has been made in November 1975. Each experiment included 5 runs without and 5 with stimulation, and 5 runs during which stimulators were switched off to get

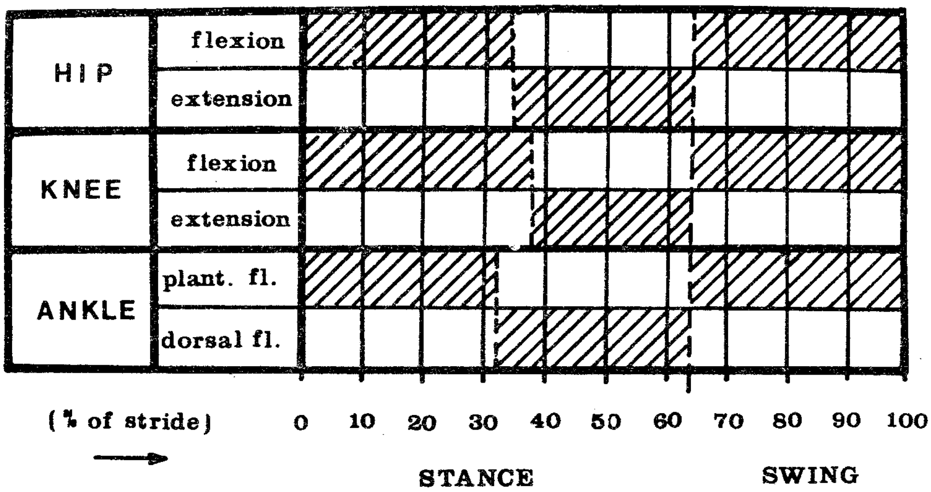


Fig. 2. Basic stride division convinient for gait pattern recognition

same information about the eventual short-tem overlastingeffect of FES. During first set of experiments it was observed that the spasticity was with stimulation significantly reduced what resulted in more save gait without crutches.

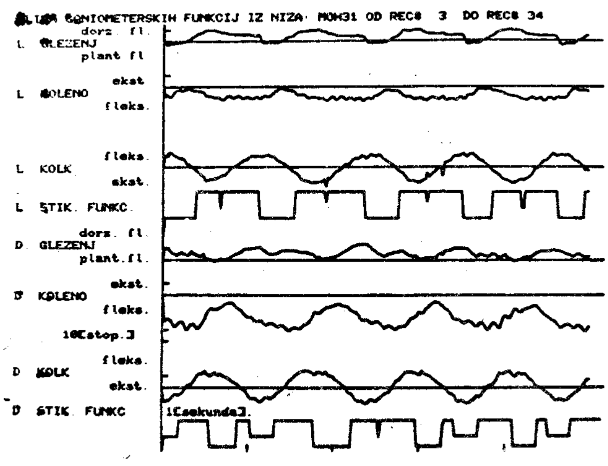
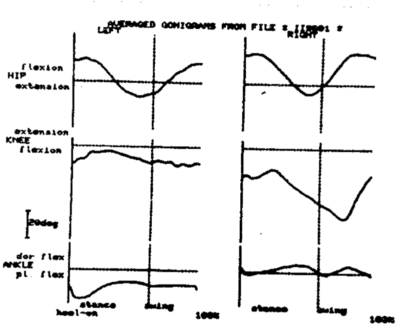


Fig. 3. The typical record of goniograms form first set of experiments in November 1975.

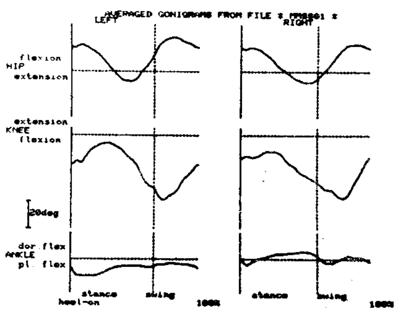


CLINICAL PATTERN RECOGNITION

			-----GRAFIC PRESENTATION-----		
-------RIGHT	LEG------		GOOD	BAD	VERY BAD
HIP	FL ST	133.2	***************		
HIP	FL SW	53.7	******		
HIP	EX	131.3	**************		
KNEE	FL ST	51.7	*****		
KNEE	FL SW	128.9	**************		
KNEE	EX	123.3	**************		
ANK	PF ST	52.3	******		
ANK	PF SW	55.3	******		
ANK	DF	32.1	********		
-------LEFT	LEG------		GOOD	BAD	VERY BAD
HIP	FL ST	35.9	*********		
HIP	FL SW	26.7	***		
HIP	EX	33.2	********		
KNEE	FL ST	134.8	**************		
KNEE	FL SW	365.9	*******************************		
KNEE	EX	175.7	*******************		
ANK	PF ST	257.2	**************************		
ANK	PF SW	137.5	********************		
ANK	DF	221.2	***********************		

Fig. 4. The plot of averaged goniograms and pattern recognition gait estimations without FES. The second set of experiments was made in December 1976.

A year later the same methodological approach was used and comparison was made. It has to be stressed that the patient used stimulators permanently at home as the orthotic device. Beside this the long term therapeutic effect has been observed.



CLINICAL PATTERN RECOGNITION

			-----GRAFIC PRESENTATION-----		
-------RIGHT	LEG------		GOOD	BAD	VERY BAD
HIP	FL ST	133.7	**********		
HIP	FL SW	59.8	******		
HIP	EX	97.7	**********		
KNEE	FL ST	57.3	******		
KNEE	FL SW	32.9	********		
KNEE	EX	143.7	***************		
ANK	PF ST	71.1	*******		
ANK	PF SW	45.7	*****		
ANK	DF	79.7	********		
-------LEFT	LEG------		GOOD	BAD	VERY BAD
HIP	FL ST	73.7	********		
HIP	FL SW	166.7	******************		
HIP	EX	162.3	*****************		
KNEE	FL ST	118.7	************		
KNEE	FL SW	37.6	*********		
KNEE	EX	73.4	*******		
ANK	PF ST	217.3	***********************		
ANK	PF SW	164.1	*****************		
ANK	DF	223.2	************************		

Fig. 5. The plot of averaged goniograms and pattern recognition gait estimations with FES, made in December 1976.

Fig. 4. and Fig. 5. present the print-outs of computerized graphics and clinical pattern recognition estimations which are based on theory described in previous chapter. They belong to paraparetic's gait without and with stimulation respectively.

After more than 2 years of FEPO use we repeated the experiment procedure obtaining same interesting results. Comparing the results with the results of the second experiment we found out only usnignificant difference between gait with and without stimulation. In both cases the gait pattern is much more normal like, what is in accordance with the patient's oppinion about abandoning the stimulators because there is nearly no more effect during stimulation /Fig. 6. /.

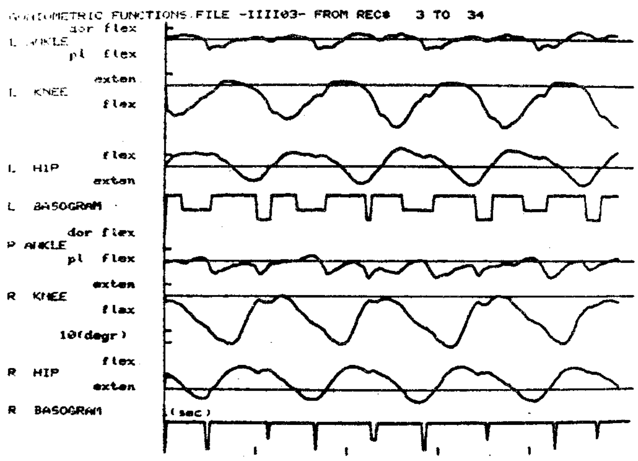


Fig. 6. The typical goniograms plot of paraparetic's gait after more than two years of FEPO use. The experiment was made in March 1977

Acknowledgment

This investigation was supported by Slovene Research Community and the Department of Health, Education and Welfare, Rehabilitation Services Administration, Washington D. C. and carried out within the Rehabilitation Engineering Center in Ljubljana.

REFERENCES

/1/ Valenčič, V., Bajd, T., Kralj, L., Stanič, U., Trnkoczy, A. and Kljajić, M., "Human Gait Analysis with the Aid of Pattern Recognition Methods", Proceeding of the 30th Anual Conference on Engineering in Medicine and Biology, Volume 19, Los Angeles, pp. 27.7, 1977.

/2/ Lamoureux, L.W., "Kinematic measurements in the study of human walking". Bulletin of Prosthetics Research, Spring 3 - 84, 1971.

/3/ Stanič, U., Bajd, T., Valenčič, V., Kljajić, M., and Ačimović, R., "Standardization of Kinematic Gait Measurement and Automatic Pathological Gait Pattern Diagnostics," Scand. Journal of Rehab. Med., Vol. 9, No. 3. pp. 95 - 105, 1977.

/4/ Bekey, G.A., Chang C.W., Perry, J., and Hoffer M.M., "Pattern Recognition of Multiple EMG Signals Applied to the Description of Human Gait.", Proceedings of the IEEE, Vol. 65. No. 5, May 1977.

/5/ Valenčič, V., Bajd, T., Stanič, U., "Obdelava goniometrskih funkcij z metodami razpoznavanja oblik in poprečenja po periodah hoje". Proceedings ETAN, pp. IV. 199 - 205. 1977.

/6/ Bajd, T., Stanič, U., Kljajič, M., Trnkoczy. A., "On - Line Electrogonometric Gait Analysis," Computers and Biomedical Research", Vol. 9. No. 5 439 - 444., 1976.

/7/ Kralj, A., and Bajd, T., "Simple Clinical Gait Measurement", The Sixth International Symposium on External Control of Human Exstremities, Dubrovnik, 1978.

/8/ Valenčič, V., and Bajd, T., WAP -"Walking Analysis Programs," Proceedings of First Mediterranean Conferance on Medical and Biological Engineering, Sorrento, Italy, Vol. 1. pp. 1, 61 - 64, 1977.

/9/ Andrews. H. C., "Introduction to Mathematical Technique in Pattern Recognition, New York, Wiley - Interscience, 1972.

/10/ Patrick, E.A., "Fundamentals of Pattern Recognition," New Jersey Prentice - Hall, 1st ed., pp.. 287 - 457, 1972.