A COMPUTER BASED METHOD TO ASSESS GAIT DATA

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Abstract: **The aim of Instrumented Gait Analysis is to support clinicians' decision making process concerning diagnosis and treatment strategies. Movement Analysis systems are used to measure data such as joint kinematics or kinetics during gait in a quantitative way. However, data evaluation is performed subjectively by experienced physicians for a specific clinical problem (diagnose individual disabilities in the locomotor system, plan and validate therapies). There is a growing need for methods for objective, standardized data analysis even in case of individual variations in the very complex gait pathologies. This article covers the development of a modular, computer-based methodology to quantify the degree of pathological gait in comparison to normal behaviour, as well as to automatically search for interpretable gait abnormalities and to visualize the results. The successful application of the novel methods to a group of CP (Infantile cerebral palsy) patients is demonstrated.**
Keywords: **Quantification of gait disorders, Gait Analysis, Cerebral Palsy, Time series comparison, Data Mining**

Introduction

Gait laboratories are well established in supporting clinicians regarding quantification of patients with gait disorders. Interpretation of time series obtained from gait analysis (e.g. joint kinematic) is a complex task requiring extensive experience in the field and a high degree of clinical expert knowledge. Computer-based methods offer the possibility of being a valuable tool for a simplified and automated evaluation procedure. However, results obtained from existing procedures often suffer from lack of interpretability and are difficult to relate to the physician's clinical observations [1]. The goal of this work was to develop a data mining system that helps to identify and quantify prominent features in pathological gait analysis data. Additionally novel visualization methods are developed for highlighting the principal abnormalities of the individual patient under investigation.

Patients and Methods

In this study the therapy effects in a group of 43 diplegic ICP patients are analysed before (PRE) and after (POST) injection of Botulinum-Toxin. The gait data of 10 healthy subjects each with different self-selected walking paces (slow, medium, fast), serve as a reference. For this example, the kinematic time series $u_i[k]$ are evaluated of every joint i and their samples k.

According to Figure 1, the data evaluation process is divided into the

1. calculation of deduced time series (e.g. joint velocities, norm deviations),
2. computation of single features from all time series (e.g. mean, minimum or maximum values) for the whole stride (STRI), stance (ST) and swing (SW) period, and further gait phases [2],
3. feature evaluation for the given clinical problem, as well as
4. classifier design,

and finally the visualization of the results. Especially for the state of the gait quality, deduced time series are calculated for each joint i

$$N_i[k] = \frac{\left|u_i[k] - \bar{u}_{i,Norm}[k]\right|}{\sigma_{i,Norm}[k]} \qquad (1)$$

with the mean time series $\bar{u}_{i,Norm}[k]$ of all healthy subjects and their standard deviation (STD) $\sigma_{i,Norm}[k]$. The interpretation is the distance related to the half of norm corridor width. In addition, due to the weighted difference (and thus normalization to the reference group) in combination with the single feature calculation it is possible to calculate one overall parameter for different joints. For the evaluation process, the first and second step is a collection of potential features comprising the aim of computing interpretable features. The latter steps assess all the features relevant to a given clinical problem or task, which include the necessity of sorting out redundant, irrelevant and noisy features. This part is realized by the use of fuzzy and statistical methods [3].

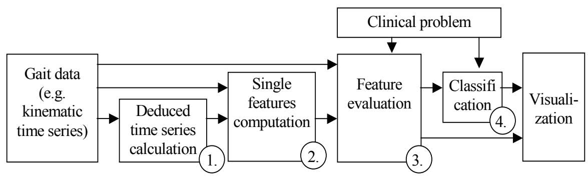

Figure 1: Data evaluation process

The clinical problem is formulated as a crisp or fuzzy classification, or relevance rating, for example "where are the main patients' deviations related to healthy behaviour at different paces" (main problems), "what are the most discriminate patients features in comparison to physiologic gait" (patients characterization), or "what kind of changing arises during therapy" (PRE-POST evaluation).

Results

The application is divided into diagnosis and therapy tasks. Based on equation (1) it is possible to detect the main pathologies within a certain group of patients for every gait phase and joint, Figure 2. Here, the degree of norm deviation of the whole group is shown in different grey scales. As an example, the norm deviation of this patient's right ankle (shown in Figure 2) averages for the whole stride with $N_{ANK,STRI}=7.7$ (7.7-fold "half norm corridor" distance to $\overline{u}_{i,Norm}[k]$) whereas its major problems are in swing period with $N_{ANK,SW}=10.9$ compared to stance period with $N_{ANK,ST}=5.6$. Further on, it could be stated that by combining this feature from other joints, it is possible to reproduce clinicians' evaluation in a quantitative way [4].

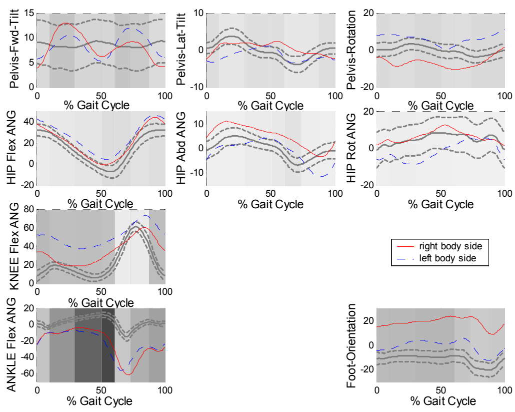

Figure 2: Kinematic chart of a patient (thin lines) in relation to the main norm deviations of its pathological group (intensive grey), and normal behavior (solid bold line - mean, dotted bold lines - variance)

A further application of these methods aims for the characterization of patients' data. It bases on the automatic detection of the main different feature combination, found by the fuzzy system, Figure 3.

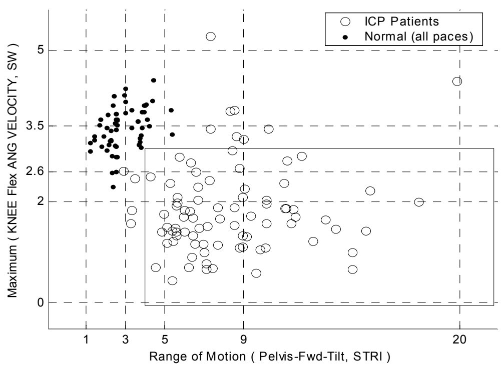

Figure 3: Two characteristic features to discriminate between all observed ICP patient's and normal gait

The fuzzy rules detected two ICP behaviour mechanisms: The pelvis double bump pattern (expressed in a rather increased Range of Motion) and a rather reduced capability of knee joint motion during swing (expressed in a decreased joint angle slope), also compare Figure 2.

Evaluating the patients data with respect to different observation dates, the therapy progression can be quantified, using these methodologies. By means of this patient, shown in Figure 2, the treatment effects provide a reduction in the norm deviation at the ankle during the whole stride with $N_{ANK,STRI}=4.1$, the stance $N_{ANK,ST}=2.4$ and swing $N_{ANK,SW}=6.7$. In general, a significant improvement is observed for the whole patient group at their ankle (major problem, see Figure 2) $N_{ANK,STRI}=6.2 \pm 4.0$ (PRE) and $N_{ANK,STRI}=3.6 \pm 2.3$ (POST), paired t-test: $p<0.001$. With the ankle norm deviation a relationship could be observed between the degree of PRE-therapeutic stage and changing after therapy, Figure 4

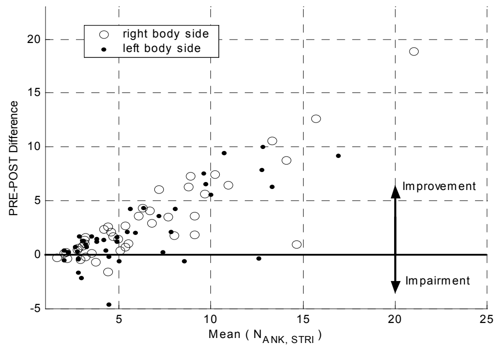

Figure 4: Changing of the averaged ankle norm deviation with respect to the PRE-therapeutic stage

Discussion and Conclusion

This methodology for automated movement data evaluation determines gait mechanisms in a systematic, quantitative way to support the clinicians' decision making process. The novel concept bases on interpretable features, which permits an inherent insight in the automatic evaluation process. Thus, the whole evaluation process and the obtained results are transparent for validation of clinical plausibility.

REFERENCES

[1] T. Chau "A review of analytical techniques for gait data. part 1: Fuzzy, statistical and fractal methods", Gait and Posture, vol. 13, pp. 49-66, Feb. 2001

[2] J. Perry, "Gait Analysis. Normal and Pathological Function", Thorofare: Slack Inc, 1992.

[3] R. Mikut, et al., „Diagnoseunterstützung für die Instrumentelle Ganganalyse (Projekt GANDI)", Forschungszentrum Karlsruhe, FZKA-6613, http://bibliothek.fzk.de/zb/berichte/FZKA6613.pdf 2001.

[4] J. Dieterle, T. Loose, M. Schablowski, R. Mikut, R. Rupp, R. Abel, "A new measure for assessing gait quality in SCI patients with 3-d gait analysis" Accepted Paper, ESMAC Leuven / Belgium, Sep. 2002.