orthopaedic disorders diagnosis,
hemi-paresis, sciatic neuralgia, Parkinson's disease,
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GAIT DISTURBANCES RECOGNITION FOR SOME ORTHOPAEDIC AND NEUROLOGICAL DISEASES DIAGNOSIS

The study was based on many experiments of gait characteristics analysis, finally on observations of 117 patients suffering from motor disturbances. Among them were 42 cases with hemiparetic syndrome, mostly after cerebral stroke, 52 cases affected by acute sciatic neuralgia and 23 patients with recognition of Parkinson - disease symptoms. The control group was 16 healthy adults selected from medical staff - examined by pedobarographic equipment - PSW [4]. Based on these observations several classification proposals have been introduced. The majority of works concern gait disturbances investigations for three remarkable neurological diseases. They provide us with new diagnostic techniques based on some gait measures implementation.

1. INTRODUCTION

Patients suffering from neurological or orthopaedic diseases demonstrate various motor disturbances, losing the motor control means, causing various gait disorders. For the disease description very deep analysis has to be undertaken. The most readable factors for gait analysis give a musculoskeletal system, describing the intact bones and joints with functions of muscles [1]. The main factor for physiological gait description provides a nerves system model, initialising and controlling muscle-motor functions and body tracing stability. A central nervous system (CNS) of a motor cerebral cortex provides impulses for muscle contraction. The gait disturbances are most common symptoms caused by various neurological and orthopaedic reasons.

In 1976 the gait analysis was carried out by Omisuse, where gait functions description and characteristic of the recorded data were discussed [1]. The data was recorded on a straight line drawn on a band of paper 7-8 m long and 0,5m wide. The patient's feet were covered by an iron oxide (Fig.1).

In many research laboratories very advanced and expensive equipment is available, where many devices for gait examination are still based on the idea of Gilles de la Tourette; the dynamometric platforms or mats are covered by a number of sensors (Fig.2) with the portable carpet capturing an electronic footprint. Variability of gait characteristics and body balance are analysed on-line [2].

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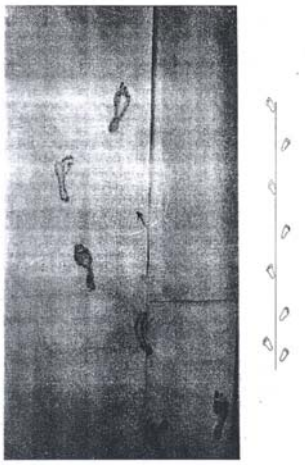

Fig.1. Footprints of a Gilles de la Tourette's

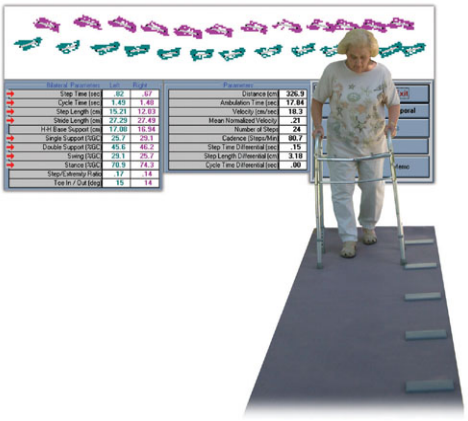

Fig.2. The sample walkway system

The paper is reporting results of several projects that were carried out over many years using technologies developed under the author's supervision. The equipment was developed for footprint analysis - Parotec System for Windows (PSW) [4], [5], [6], [7]. It is an example of the computer aided measuring equipment for data recording and interfacing (Fig.3).

Fig.3. The PSW equipment with sample interface (by Paromed GmbH)

The PSW machine collects the data, in static (while standing) and dynamic (while walking) gate cycles. The static data shows a pressure (load or a body gravity centre) distribution on insoles surface, in sensor-cells. The dynamic data shows various characteristics of patient's load movement trajectories, some gait stability factors, local energy distribution and a time diagrams of load distribution maps.

2. THE INVESTIGATION SUBJECTS SELECTION

The contribution presents some readable factors examining and describing visible motor disturbances of a patient's gait who is suffering from orthopaedic or from neurological disorder (hemiparesis, acute sciatic neuralgia and Parkinson's disease).

117 ambulatory and hospital adult subjects were under these studies. The selection criteria gave cases with bones or joints disorders or patients suffering from local disorders, acute musculoskeletal injures, dementia cases or difficulties in understanding of verbal instruction. Vestibule or visual affects, with any other non neurological muscles impairment (Fig 4.) was found. For the control group 16 healthy adults, from medical staff, have been recruited.

I. The hemiparetic gait

The majority of cases of hemiparetic syndrome were observed; as a result of a brain stroke [3], [4]. The hemiparetic gait illustrates a cerebrovascular disease with sudden disturbances in regional blood perfusion. In 80 % of these cases the stroke implies ischemia, 20% of strokes haemorrhage.

The state after the stroke is visible as:

- a face muscles paresis or paralysis, hand and / or leg paresis or paralysis; usually one-sided (the fifth posture in Fig.4),
- face, hand and/or leg anaesthesia; one-sided at general,
- gait disturbance in loosing balance and giddiness.

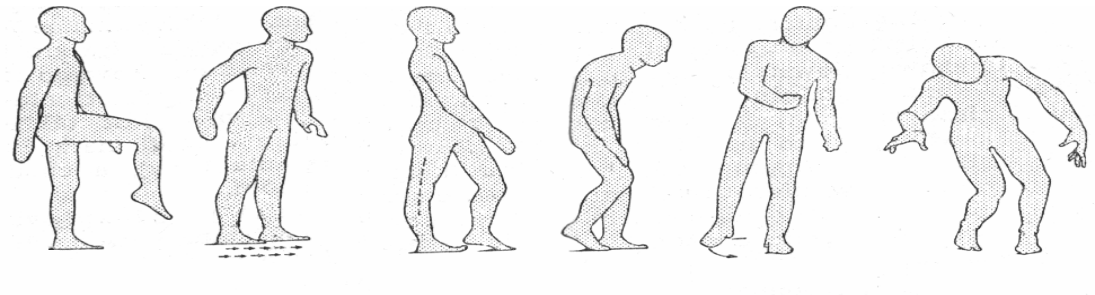

Fig.4. Several postures illustrating neurological diseases

The 42 ambulatory or hospital adult volunteer subjects, with the recognised hemiparetic syndrome were recruited. The 36 patients were at least 12 months post cerebrovascular accident (stroke), 5 of them were diagnosed as multiple sclerosis and 3 patients were post several head injuries.

In static part of examination the readable movement of body weight was observed and body gravity centre moved towards the affected body side. These characteristic features; were in direct relation to hemiparesis severity. Patient was fixing the body weight on the affected limb (in majority of cases in a heel region). The healthy leg was used for walk assistance only.

The severe left-sided hemiparesis, after the cerebrovascular accident illustrates Fig.5, with 98% of a body load on an affected leg, with 56% of the load in a heel region.

The dynamic part of the data records examination allows finding irregularities for new time characteristics, as a body weight centre translocation illustrating instabilities of patient's gravity reactions. These abnormalities illustrate the body load movement trajectories; their length and time relations. Some gravity centre movement concerns a foot floor hooking cases (for strokes – the fifth posture in Fig. 4), a floor contact time elongation characteristic for Parkinson's disease.

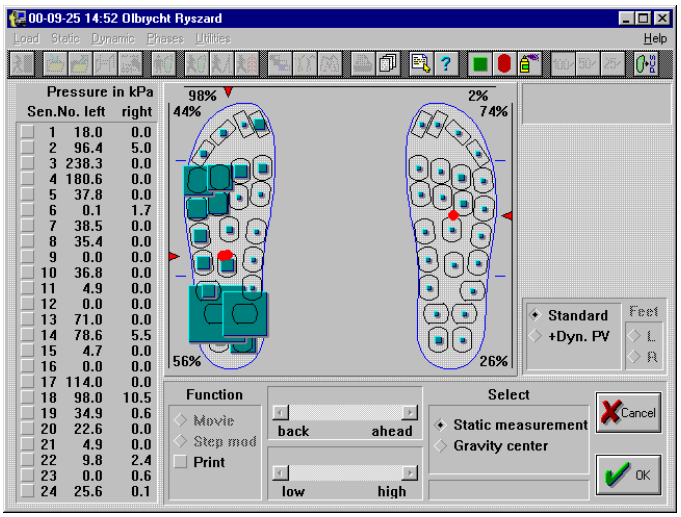

Fig.5. Severe left-sided hemiparesis; with a moved body weight

The example case with the right-sided hemiparesis was presented in Fig. 6; with visible elongation of body gravity centre trajectory on a paresis side; shorter on healthy side.

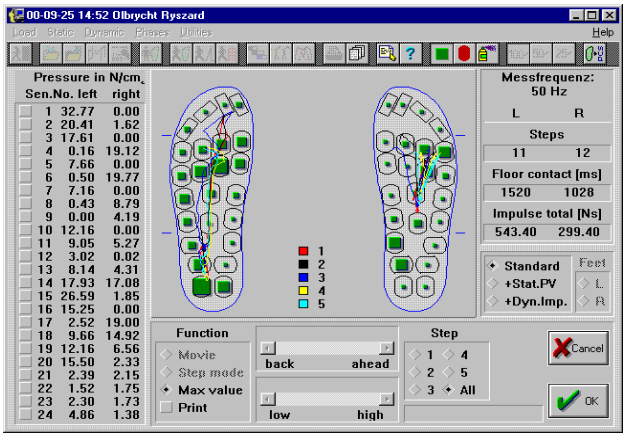

Fig.6 Gravity centre trajectories for left-sided hemiparesis after cerebral stroke

Some conclusions for hemiparesis:

The gravity centre was located on the healthy side of the body, in metatarsal region, with shorter trajectories. The affected limb is shifting from heel to toes zone irregularly; noticed as trajectories elongation. The floor contact and impulse values (energy absorbed by a foot surface) increase, within the heel zone of an affected foot, was recognised (visible in Fig.5). The results allow us creating regular patterns for gait disturbances, illustrating the hemiparetic syndromes:

- the body weight moves to the patient's affected limb and into the paretic limb direction, with this overload lasting longer,
- the patient has difficulties with carrying the affected limb, it is somewhat thrown forward then the healthy limb is carried into the paretic one,
- a toe of the affected limb is often hooking a ground.

II. The sciatic neuralgia

Fig.7. Scoliosis, with pain and muscle contractionin acute sciatic neuralgia (by K.Levit)

The term sciatic neuralgia describes the cluster of clinical signs causing pathology of so called, lumbar disc herniation. The lumbar pain is radiating to the left or right lower limb, due to compression of spinal radix in one of five vertebral spaces (Fig.7).

The pain signal that a lumbar disc has prolapsed – out from a spinal column, towards a vertebral canal, as in scoliosis. Patient suffering from sciatic neuralgia is walking slowly, avoiding extension of sciatic nerve and changing position (Fig.8).

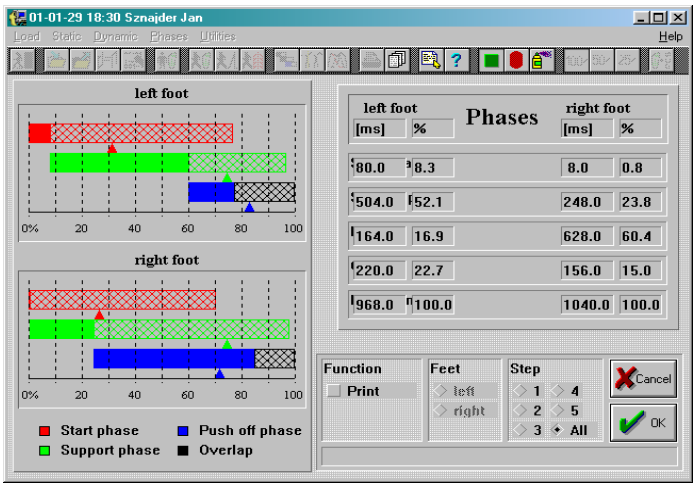

Fig.8 The right lateral sciatic neuralgia; floor contact time and impulse increase

In the majority of cases the body weight is moved into a heel region of a foot – for above 80% of all subjects. The dynamic measures examination indicated the floor contact time and impulse values increase on healthy limb in 14 cases (26,9%). The affected limb was burdened by 34 cases (65,4%).

In the static record-part, an observable movement of a body gravity centre towards one side was noticed. Traditional approach appoints that patient protects the affected limb, with a body weight shifted onto the healthy limb. The carried out experiments changed these assumptions, as majority of patients were burdening the affected leg; 65,4% of the investigated cases.

Characteristic rules, for gait disturbances in sciatic neuralgia:

- a body weight and gravity centre were distinctly moved into the affected limb,
- in majority cases the body weight is located close the gate heel zone,
- the floor contact time and impulse values increased within the affected limb area,

- irregular and tangled fluctuations of gravity centre placement were noticed at the affected body side.

III. The Parkinson disease

The Parkinson Disease (PD) symptoms are noticed as combination of many actions, as: hands tremor and rigidity of muscles (constantly tensed). The patient feels stiff, is shuffling legs. Various postural abnormalities are also observed (as in the fourth posture of Fig 4) [3].

Several ambulatory and hospital adult patients, with previously recognised PD, were recruited for their gait analysis. In 15 cases left-lateral domination of the disease was recognised (group A) and 8 cases with right-lateral domination (group B). Majority of them had moderate stage of Parkinson's disease or were in good responsibility on anti-Parkinson therapy. Pre-diagnostics indicated the gait disturbances that were asymmetrical, independently from the disease level.

In the static data examination a readable movement of body weight and body gravity centre were observed; in majority cases to the left side of the body; frequently within a heel region (in 78% of all PD cases).

For A group (left-lateral domination) - 13 cases (86,6%) fixed the body weight predominantly in a left foot-heel region, in 2 cases (13,4%) on a right foot-heel.

For B group (right – lateral domination) 4 cases fixed the body weight on left the heel region, 3 of them on the left forefoot and 1 case on the right heel zone.

Cases with left lateral PD, trajectories of body balance were longer on more affected limb. For cases of right lateral PD the same proportions were noticed.

In early stages of the PD the difference in length of foot gravity centre trajectories, between primarily affected limb and the other limb were slightly visible. For cases of severe PD stage the differences were significantly bigger (Fig. 9).

In majority cases the floor contact time and impulse values increase were noticed as well. Bilateral fluctuations (tremor) of the body load, usually dominate at one side (according to neurological symptoms).

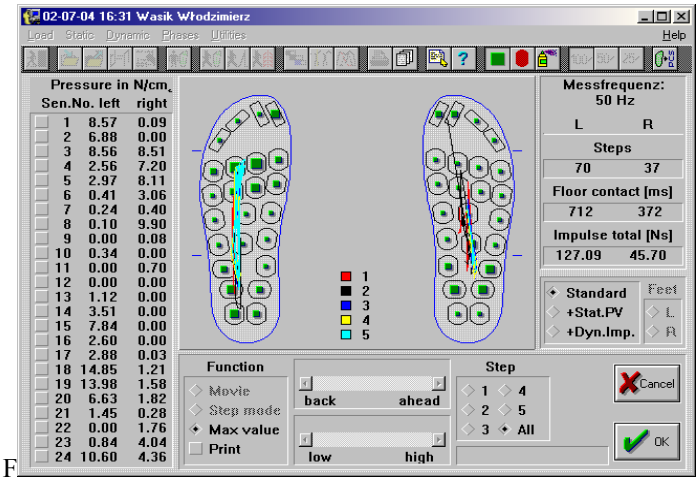

Fig.9. 67 years old male with severe left - lateral PD: irregular trajectory on a left side; caused by tremor

Characteristic rules, for gait disturbances in PD cases were recognised, as:

- asymmetrical lateralisation of gait disturbances (in 100% cases),
- for majority investigated cases a body weight was moved into a left limb and into a heel zone,
- elongation and irregularity of foot gravity centre trajectories on more affected limb, with increase when the severity of the disease is growing,
- in majority cases the floor contact time and impulse increase on more affected limb, with elongation of start and support phases time, on more affected limb was found.

Among many symptoms of PD several walking irregularities are observable, as:

- short-stepped or shuffling gaits (mainly in a walk initiating phase),
- postural stability observed as the body-balance troubles.

3. CHARACTERISTIC MEASURES FOR THE DISEASES FILTERING

Trying to reduce the redundant data and to select the most representative record components some characteristic measures, for the disease level recognition, have been extracted. These way specific norms for gait description were defined; as in examples bellow.

Step-cycle defines time interval measured between double ground contacts of the same foot (from left to left or from right to right foot) of physiological gait.

A Body-gravity Centre Pointer - *BCP* illustrates the static data part, marked by CB_s point in Fig.1010; showing a body weight distribution on a footprint.

A Body Balance measure - *BB* describes the length of trajectory of gravity centre movement (Fig.11), determining disturbances of body balance in a standing phase.

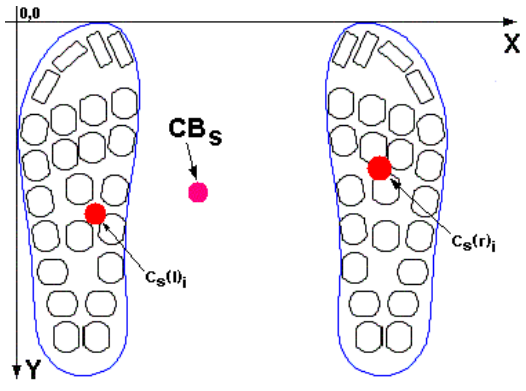

Fig.10. Body and feet gravity centres

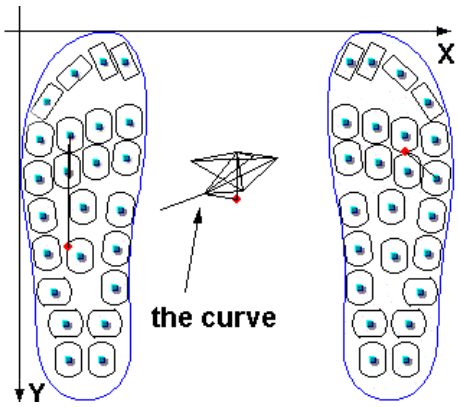

Fig.11. A gravity centre movement

Let us consider an example. Points $C_{S,i}$ describe a static data of two data records, with distance between them $d\left(C_{S,i-1}, C_{S,i}\right)$ or:

$$d\left(C_{S,i-1}, C_{S,i}\right) = \sqrt{\left(x_i - x_{i-1}\right)^2 + \left(y_i - y_{i-1}\right)^2}$$

where: x_i, y_i , define co-ordinates of points $C_{S,i}$.

Then the body balance measure ***B*** is defined by formula:

$$B = \frac{S_k}{n_s} \sum_{i=2}^{n_s} d\left(C_{S,i-1}, C_{S,i}\right)$$

with: n_s - samples number of static data,
S_k – scaling coefficient for insole size, defined as follows:

$$S_k = \frac{H_w}{h_f w_f}$$

h_f is length of the insole, w_f is width of the insole [mm],
constant H_w was defined empirically; is equal to: $H_w = 31500$ [mm^2].

Mean Step-time measure - *MS* in step-cycle, defines a mean floor-contact time in dynamic part of the record (in walking period). This time is calculated as an average value from all registered step-cycles.

The *MS* differences on left-step floor-contact and right-step floor-contact express the walk irregularities (asymmetry).

Cycle-time Limit measures - *CL* shows the floor-contact time limit of a foot in a single step-cycle, for dynamic record part, where two limits were assigned:

- the shortest cycle-time limit (minimum) CL_{min},
- the longest cycle-time limit (maximum) CL_{max}.

Step Phases Pointers - *SPP* are mean values from floor-contact time of tree step phases (Fig.12):

Starting-phase– concerns the load localised in a heel region, ω_n ,

Support phase – the heel and metatarsal regions carry a body load, ω_p,

Push-off phase– where the patient body load is in a front part (toes) of a foot, ω_w.

Expert medical stuff have to define physiological values of this measure then analysing the pointer values one can compare this threshold value with current states – noticed as physiology or pathological states.

The Step Phases Pointers – SPP is defined by $\boldsymbol{Q(\omega,\alpha)}$**;** medium time values of floor contact in the three phases:

$$Q(\omega,\alpha) = \frac{1}{mD_{FRQ}} \sum_{j=1}^{m} \sum_{k=1}^{n_{d,j}} g_k(F_{\omega,\alpha})$$

where: $\omega \in \{\omega_n, \omega_p, \omega_w\}$, defines the step phase (starting, support, push-off),
D_{FRQ} – is sampling frequency of dynamic data part [Hz],
$n_{d,j}$, defined number of the data samples of j–step,
$g_k(F_{\omega,\alpha}) = \begin{cases} 1 & gdy\, F_{\omega,\alpha} > F_{GR} \\ 0 & gdy\, F_{\omega,\alpha} \le F_{GR} \end{cases}$ defines maximal value of the strength in ω–sone and k–step of dynamic-data sampling rate,

where: $F_{\omega,\alpha}$ is a sum of strength on selected sensors, respectively to ω–zone and α–foot,
F_{GR} defines the limit of the strength.

Overlap Measure- *OM*, is a mean overlap time of single step-cycle (Fig.13), where both feet are carrying the body load. This measure describes distinguishable many neurological disturbances of a gait.

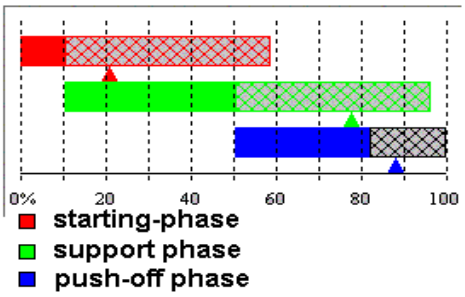

Fig.12. Step phases diagrams

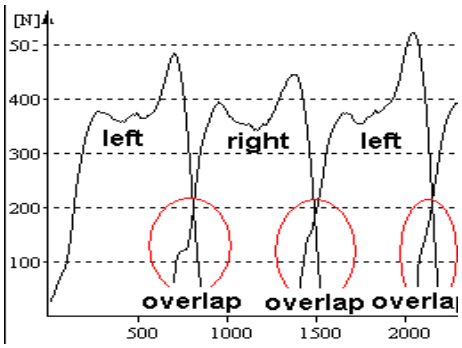

Fig.13. step strength graph for phases overlap

$$OM = \frac{1}{p}\sum_{i=1}^{p} t_{O,i}$$

where: p is number of over-laps in the dynamic record part,
$t_{O,i}$ is time duration of i–th over lap [ms].

Pressure Distribution measure- PD(α), expresses a mean value of strength recorded on sensors of a foot α in dynamic data part; strengths distribution on both feet with load distribution irregularities assigned as follows:

$$PD(\alpha) = \frac{1}{mG}\sum_{i=1}^{m}\int_{0}^{T_i} F_i(\alpha,t)dt$$

where: G is patent's weight,
T_i is duration of i–th cycle time,
$F_i(\alpha,t)$ defines function of the strength on the α–foot in i–th cycle time t:

$$F_i(\alpha,t) = \sum_{i=1}^{n_\alpha} P_i(t)\cdot S_i$$

with: n_α sensors number on insole at the α–foot,
$P_i(t)$ pressure on i–th sensor in time t,
S_i defines surface of the i–th sensor.

Lateral Oscillation measure – *LO*, describes the body balance disturbances of the gait. Also the perpendicular oscillations to direction of an affected limb were observable.

Lateral Oscillation Scope measure - *LOS,* is a distance between minimum and maximum values of the pressures in step-cycle (maximal range of lateral oscillations).

The examination of the above defined measures was carried out and compared with a group of healthy patients. We analysed all the above measures: the body gravity centre pointers - *BCP* dislocation, the body balance measure *BB*, the floor-contact time set (appointed by the mean step-time measure *MS* and the cycle-time limit measures *CL*). The overlap measure *OM* values, the lateral oscillation measure *LO* and a lateral oscillation scope measure *LOS* were also noticed. After these investigations their so called normal ranges were defined.

The patients suffering from the left-lateral hemiparesis after ischemic stroke indicate following regularities:

- for 57% cases of body gravity centre pointer *BCP* was placed outside the normal range, the body centre of gravity shift has been observed particularly towards an affected limb with visible movement into a heel region (the body load was divided between toe zone (46%) and the heel (54%)),
- for 72% of the cases a mean step-time measure *MS* increase have been noticed on the left limb; the mean step-time measure distribution was also divided into left and right limbs with 53% and 47% respectively,
- measures of the cycle-time limit CL_{min} and CL_{max} over-gone admissible level, for a left limb only (57% case for CL_{min} and 71% cases for CL_{max}); for 91% cases the CL_{min} value on a left foot was remarkable bigger than on the right foot,
- the mean cycle-time limit CL_{min} distribution was in ratio 53% for left foot and 47% for right foot, the mean cycle-time limit CL_{max} distribution was in ratios 54% for left foot and 46% right foot,
- the step phases pointers *SPP* were also remarkable different than its values noticed for physiological records, with mean distribution for felt and right limbs 42% and 58% respectively,
- also for 86% cases the value of overlap measure *OM* have over-gone or felt-down, the level treated as a physiological stage,
- the pressure distribution measure *PDM* has been noticed as bigger load on the left limb (72% cases in dynamic part of the record),
- the bigger values of a lateral oscillations measure *LO* (for 43% cases) and lateral oscillations scope *LOS* (for 57% cases) were also noticed,
- the balance of the body *BB* remained for these cases in a range classified as a normal stage.

GAIT DISORDERS DESCRIPTION

The Pressure Distribution measure makes possible to assign the body leaning, towards, in static cycle that is characteristic case for Parkinson's disease.

The Body Balance Measure allows determining the body stability disturbances recognition. For the above declared levels, determining the conclusions, the disease will be easy assigned.

The step-phases define specific time relations on three zones of the foot (for *Starting, Support and Push-off phases*). They provide the diagnosis with very representative data for brain strokes recognition.

4. CONCLUSIONS

After a long lasted field testing of the introduced products, gait characteristic analysis was undertaken. Several remarkable rules were found for hemiparesis, acute sciatic neuralgia and Parkinson disease with visible descriptors for the disease analysis. Introducing this technology to neurological practice one can find a new quality in diagnosis, quantitative evaluation and monitoring of the therapy progress. For the majority hemiparetic patients, individually determined physical and pharmacological therapies are milestones in recovery and rehabilitation processes.

These discussed measures provide the operator with many data units that can be fruitfully used for automatic conclusion making. Anyhow, much additional modification within the diagnostics techniques, are recommended; as interfaces for the data better readability should be provided.

The automatic conclusion making units are very encouraging; as demonstrated in several projects [12], [13], [14], [15], [18].

The majority of the defined above measures correspond adequately to the disease level. Looking at the specified components of the diseases recognition a spectrum of the patient walk characteristics have to be extracted.

The longer floor-contact time on the affected limb was detected in almost all cases for hemiparesis after ischemic stroke. An asymmetrical irregularity of walk and posture observed for left-lateral domination is contrary to the right-lateral domination.

Unfortunately it is difficult to find till now rules that define precisely measures of the left-lateral or right-lateral domination, which comes from difficulties of the diagnosis subject – the Parkinson Disease.

Early experiments with the automatic conclusion-making units (neural networks) were very discouraging. These PSW interfaces provide the user with a big range of diagnosis factors often difficult to classify in a proper way. The discussed new approach into classification processes, with extraction of single characteristic features (for neurological diseases) let us expect better possibilities of an automation of the Conclusion Making Unit (CMU), supported by the extracted diagnostic measures.

The CMU could effectively control both, the traumatic and the pharmacological rehabilitation processes, dosing rehabilitation training or drug portions.

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