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GAIT CHARACTERISTIC FEATURES EXTRACTION FOR NEUROLOGICAL DISEASES DIAGNOSTICS

This study was based on observations of 117 patients suffering from motor disturbances. Among them 42 cases with hemiparetic syndrome, majority of them after cerebral stroke, 52 cases affected by acute sciatic neuralgia and 23 patients with recognition of Parkinson - disease symptoms. To the control group 16 healthy adults were selected, from medical staff of clinics. All subjects were examined using pedobarographic equipment - Parotec System for Windows (PSW) [1]. Based on these observations several pattern solutions have been introduced. They concern gait disturbances descriptions in three distinguished neurological diseases. These findings extracted a new data from the PSW records and options with new diagnostic techniques, based on the gait characteristics observation.

1. INTRODUCTION

The gait abnormalities analysis can be recommended for neurological disorders recognition, as a final stage of patients' investigations. Some differences, from physiological (so called normal) state are expected to be found.

The diagnostics system operator needs some indicators, providing him with these characteristics description and all measures of the gait abnormalities with its differences from physiology.

The carried out investigations concern the characteristic differences of the current data record, as:

- patient posture description,
- body balance trajectories and the gait stability evidences,
- over-going time-range norms,
- a step length measures,
- footprints on standing (static) and walking (dynamic).

In many clinical practices a proper recognition of the above characteristic features was possible in time of traditional; neurological investigations. Anyhow, several diseases with their specific cases (ex. early Parkinson's disease level) were found. The disorders of their gait characteristics were appointed as the only observable diagnosis factor.

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Till today, none of these gait disturbances fast classification method has been developed. The gait characteristics classification, with their specific measures definition, will give the user the aim of diagnostics, therapy (rehabilitation, pharmacotherapy) and the disease level judgment.

The carried out clinical experiments, organised by experienced stuff are fundaments to the classification procedures described in this contribution.

The diagnostics methods used at present clinical scale, concern a main state of the patient's health recognition. Unfortunately, not enough care was given for finding any regulations to these disorders analyses. What is more, the applied measures are to general for the stroke level (*Scandinavian Neurological Stroke Scale*) recognition. The discussed gate disturbances were assigned by five points scale classes only, as:

- patient is able to go through distance of 5 m; without any help, -12 points,
- patient is walking with the equipment support, - 9 points,
- patient has to be supported by somebody, - 6 points,
- patient is sitting without any help equipment, - 3 points,
- patient is laying in bed or sitting in the invalid-chair, - 0 points.

The examination of the neurological disorders has been made by EDSS (*Expanded Disability Status Scale*) procedures, used for neurological disease level assignment; explaining the patient's ability of passing the distance without stopping with or without any support (as a stick). These statements are much to far from the diagnosis statements and from any treatment recommendations.

2. THE GAIT CHARACTERISTICS

For walking characteristics complexity description the Mumenthaler's investigation (classifications) were introduced. They provide us with characteristic classes of the gait disturbances; listed below.

1. Paraspastic (paraparetic) gait with several characteristic features, as straight of shin, trailed feet on a background – shifted with external rotation.
   Etiology: multiple sclerosis, cerebrovascular disease, spinal trauma.
2. Hypokinetic gait: hunched posture, short steps, motionless of the body; with limbs placed slowly and none regularly.
   Etiology: Parkinson's disease, cerebrovascular disease, depression or catatonia.
3. Dystonic gait: with additional, irregular and involuntary movements in every stage of the step.
   Etiology: Atetosis, baliom, torsial dystonia, after treatment in large doses of levodopa.
4. Atactic gait: with ataxia's abnormal co-ordination of movements, patient strikes his limbs heavily on background; disorder of the body balance caused by irregular run; a walk on wide basis (called „sailor's step").
   Etiology: polyneuropathies, some intoxications, cerebellar syndrome; for example in multiple sclerosis.
5. Gait in muscular paresis
   (a) Hemiparesis: affected limb is remarkable more loaded, the gait is hedgehopping, (affected leg erected in knee, the foot is bent footingly and outside; in time of

transgression the foot is carried out and it rolls a turn). When patient uses a cane, it is kept at the healthy limb side.

Etiology: stroke, after cranio-cerebral injuries or surgery, sometimes in multiple sclerosis.

(b) Isolated, peripheral paresis of muscle foot's rectifer is producing so called „unilateral wading gait".

Etiology: paralysis of a peroneus nerve, lesions of roots L4 and L5 in lumbar discopathy; spinal muscular athrophy.

(c) Bilateral, peripheral paresis of a foot-muscle rectifier producing "bilateral wading gait".

Etiology: polyneuropathies, Charcot- Marie- Tooth's disease, spinal muscular athrophy.

(d) Paresis of a knee muscles rectifiers; with flattened affected limb. Walking down difficult although possible – with the paresis's limb exceeded to front.

Etiology: paralysis of femoral nerve; with bilateral symptoms observed in myopathies or polymiositis.

(e) Paresis of hip adductors produces disturbances in pelvis's stabilisation in horizontal position of walking. This failure is relative, as a movement of a trunk is shifting the body centre into a side of a burdened limb; sufficient for the disorder localisations. It is called Duchenne's hobbling gait. In case it is observed on both sides a waddle walk is noticed.

Etiology: damage of an upper gluteal nerve after intramuscular injection, congenital or postraumal hip luxation, myopathies (especially in muscular progressive dystrophia).

6. Gait disorder caused by a pain. The pain in walking cycle causes avoidances, modifying or shortening the pain-side characteristics. Majority of cases has none neurological background, as:
   (a) Limping punctation – pain of a calf caused by muscular ischemia (stenosis of femoral artery); it forces patent to stop, and it retreats after a time.
   (b) Limping of horse's tail with a pain causing a horse's tail roots as a result of insufficient space in vertebral canal, of degerative processes. Characteristic pain in time of walking forcing to stop; not retreated in standing position. It forces to change a spine position.
   (c) Pain in a lumbar region, often radiating to lower limb (sciatic or femoral neuralgia) in course of lumbar discopathy.
   (d) Pains in neighbourhood of pelvis and groins (degenerative changes of hip joints), with intensifying pains in time of movement, hugging side surface of lower limbs (so-called "general strips") regretting during a walking cycle.
   (e) Groin's pain in time of walking (damage of n. illio-inguinalis) in majority cases as compression syndrome after a surgery treatment.
   (f) Pain of long bones; of lower limbs and knee joints (tumors or cysts, osteoporosis, Paget's disease, degeneration of knee joint) – observed in time of walking.
   (g) Pains of feet (flat-foot, calcaneal spurs, chronic inflammation of Achilles's tendon, Morton's disease) occur during longer walking periods, especially for bad chosen footwear, with hard sole or in time of carrying any weights.

7. Iregular gait, strange disorders of walking, which happen as opposite to the described above abnormalities; sometimes difficult for foreseeing (hysteria or others psychiatric disorders).

In all above neurological diseases remarkable factors of gait characteristics can be used, for their abnormalities diagnostics.

3. THE GAIT MAIN DESCRIPTORS IN A FOOTPRINT

Foot is very complex mechanical organ, producing many actions and reactions of a body. It is reacting as a shock absorber of dynamic changes and motor actions, moving the body onto their specific trajectories, in their temporary relations.

These characteristics became our fundamental ideas for choosing the data from Parotec System for Windows (PSW); the footprint recorder.

The diagram of physiological gait characteristics

The static data distribution of PSW record corresponds with symmetrical, standing position; comparable load on both feet (Fig. 1). The gravity centre point is located in the middle of support quadrangle.

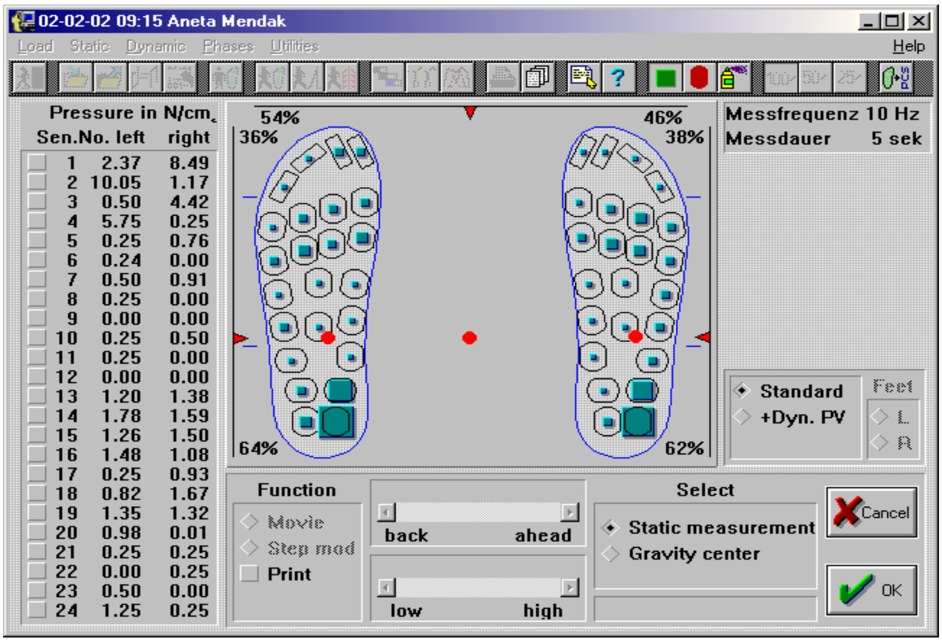

Fig. 1 The static record illustration of healthy volunteer (control group)

The dynamic data distribution corresponds with a trunk inclination (Fig. 2), towards one limb into lateral side, as well as to front, with lifted complementary limb. The gravity centre point goes beyond the support quadrangle. Then, the complementary limb moves to front, leaning on a floor.

The support quadrangle is reduced to smaller size responding, in size of burdened limb. Point of gravity centre is shifted into this quadrangle.

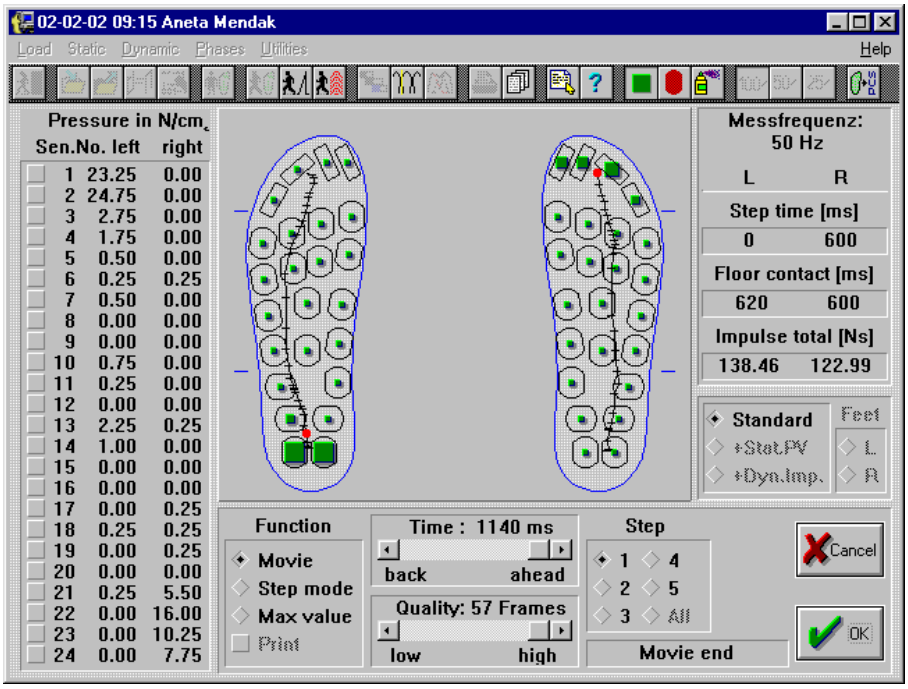

Fig. 2 The dynamic main factor of gait characteristics illustrations

When the heel of the limb touches the floor, a foot bends almost 30 degrees into a floor direction. A full burden begins on the heel zone, and then the gravity centre goes along axis of the foot, different from anatomical ones. The dynamic load trajectory runs along the line from external part of the heel to 3rd metatarsal bone, crossing between 1st and 2nd toes.

3.1. THE DATA INTERFACES

The static part of the record was illustrated by maps (Fig. 1) describing many factors of a body load distribution.

Various visualisation interfaces provide the user with:

- the body load transfer from back to front side of a foot and between left / right limb (in standing period).
- a pressure distribution in three zones of a foot (heel, front, metatarsus) and a body load distribution between both limbs; left / right (in walking phase).

In majority cases the static map of the pressure distribution abnormality allows recognise the early state of the disease. The load rotation (body balancing) disturbances in standing position can suggest neurological reasons of the observed disorders.

For example a static visual interface is indicating a one-sided load location; the more affected limb is distinguished or more complex problems when patient is unable to keep a body balance stable.

The pressure distribution (the load location) may assign the patient’s trunk leaning directions. For example, the leaning forwards suggests the Parkinson’s disease.

4. THE EXAMPLE DIAGNOSIS OF GAIT DISORDERS

4.1. THE STATIC MEASURES

They concern measures of a body centre dislocation, observable by sensors pressure of a body load centre distribution between both limbs.

The user can define several factors of the diseases characteristics, as:

– a one-sided overload; the lateral load,
– an unstable posture (of a body balance disturbances); the body balance transition with postural instability is noticed.

In Fig. 3 an example of remarkable balance disturbances are noticed. Patient is balancing into his right limb; the left limb is used only for supporting assistance (stabilisation). The body weight centre was placed on one side of the body on overloaded limb.

Etiology: Cerebellar lesions, affection of vestibular system, myelosis funicularis, Parkinson disease, functional disturbations.

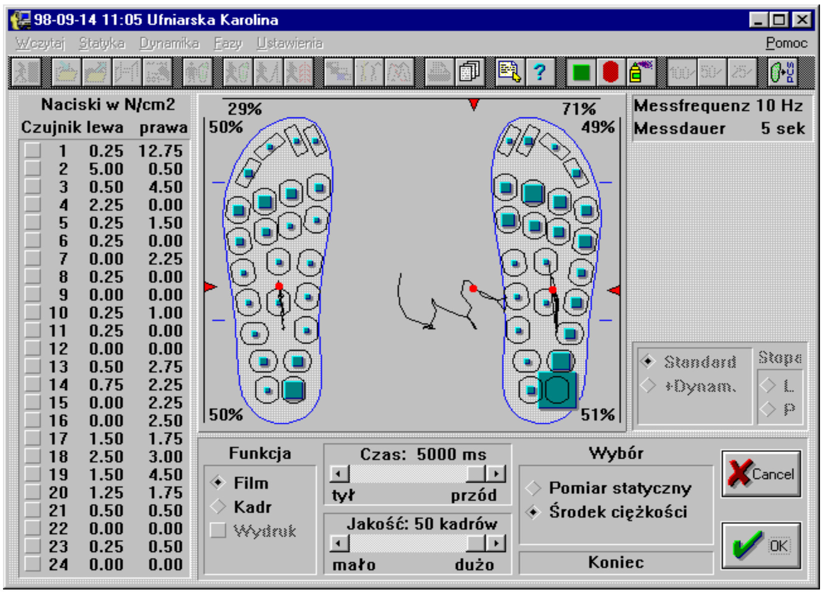

Fig. 3 An example of patient body balance disturbances

In Fig. 4 another example diagnosis has been introduced. There a large left-sided hemiparesis, after a brain stroke was recorded. Then, 98% of a body weight is carried by the left; an affected limb, with 56 % of the load, concentrated within a heel region.

The right limb is used for walk assistance only, where 2% of the body weight was located.

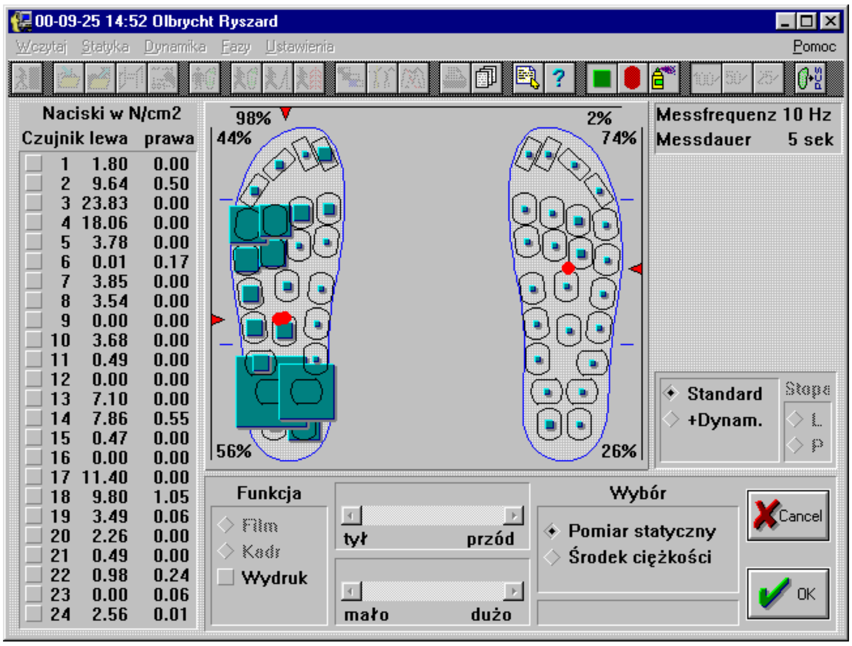

Fig. 4. A large left-sided hemiparesis after a brain stroke

Characteristic features: The characteristics for hemiparesis – the body weight and gravity centre move on an affected limb, mostly into a heel region. The scale corresponds strictly with intensity of the paresis.

In Fig. 5 the record illustrating a case of right-sided Parkinson's disease recognition was presented. There a distinct lateralisation of body weight and gravity centre, into left side is observed.

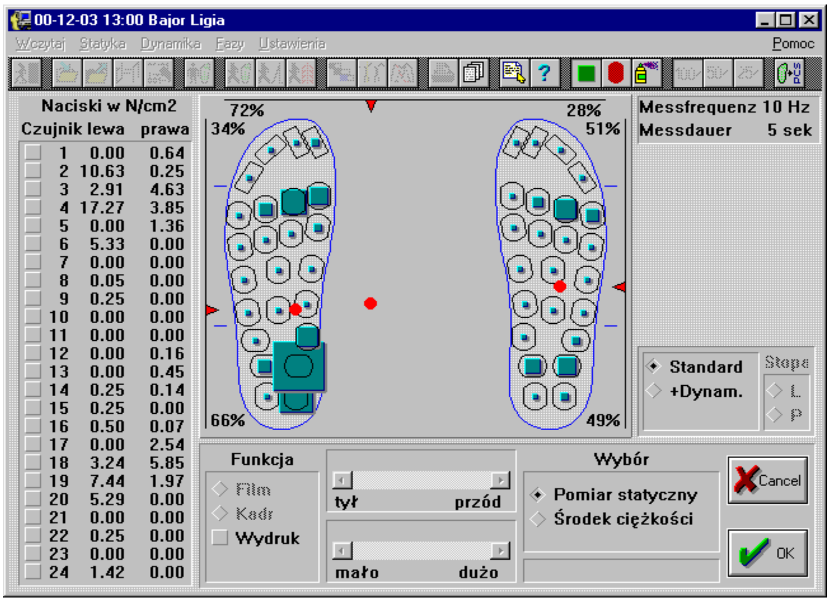

Fig. 5 A case with right-sided Parkinson's disease.

Characteristic features: The distinct lateralisation of a body weight and gravity centre was observed; usually into a left side. In majority cases into a heel region, independently from primary affected limb. These symptoms are unclear. Additional verification on more cases is needed.

In Fig 6 an example data record, with a right-sided sciatic neuralgia is shown. A higher load in a heel zone, on an affected limb with lateralisation on a side of healthy limb was recorded.

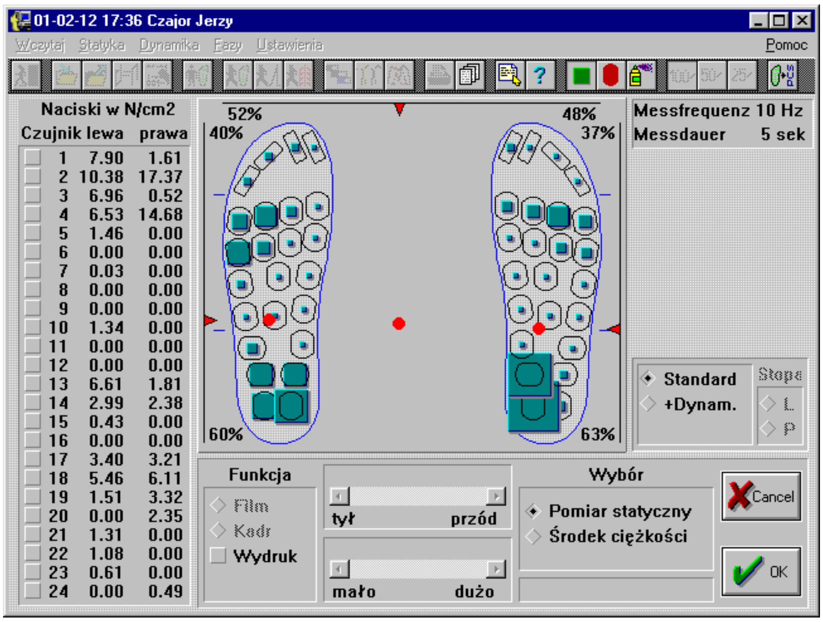

Fig. 6 A case of a right-sided sciatic neuralgia

Characteristic features: In a sciatic neuralgia the burdened limb is related to convexity of scoliosis. The convexity of scoliosis comes from a side of the root (radix) compression.

4.2. THE DYNAMIC MEASURES

The gait disturbances analysis (with movie or step mode options) allows considering closer the disease reasons. The dynamic histogram of the gait provides us with medium values of a whole data sequence. The dynamic visualization in 2D and 3D maps of the pressure distribution with time diagrams of the pressure flow; in every gait cycles, are there available.

In a step mode the user observes the patient gait in subsequent time interval. The 2D example data map was presented in Fig. 7. There medium values of a pressure flow (from every sensor) can be analysed.

The deformation places on a foot are visible, especially on 3D map (Fig. 8). Very useful diagnosis factors are provided with a load time diagrams (Fig. 9) of three characteristic zones (start phase, support phase and push-off phase) at a foot, called phases.

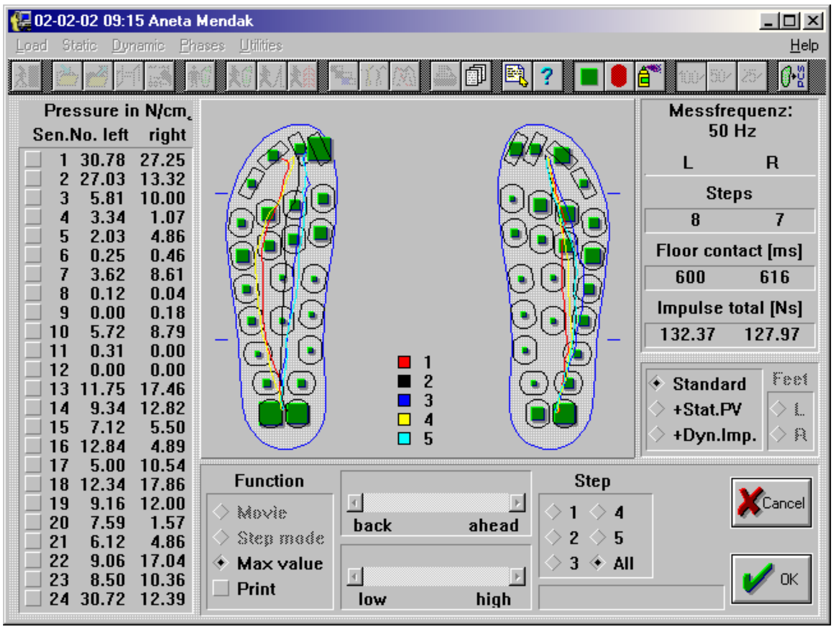

Fig. 7. The example dynamic, 2D data map

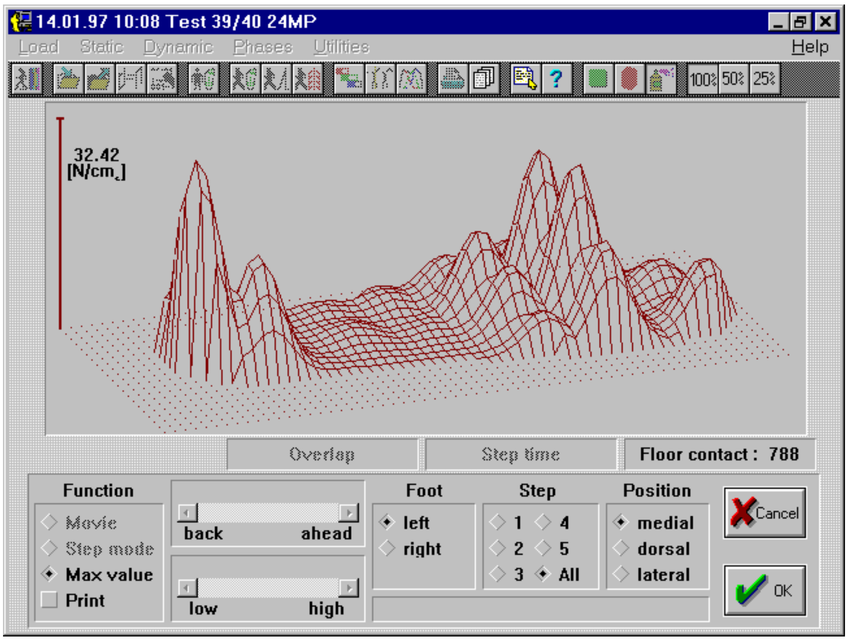

Fig. 8 The example dynamic, 3D data map

The over gone times, above physiological values, a pain regions or paresis with their precise localisations, can be localised. The animation (movie) mode let us follow the gait abnormalities spotting, giving precise characteristics of a pain placement. These indicated places allow defining the pain range and its reasons.

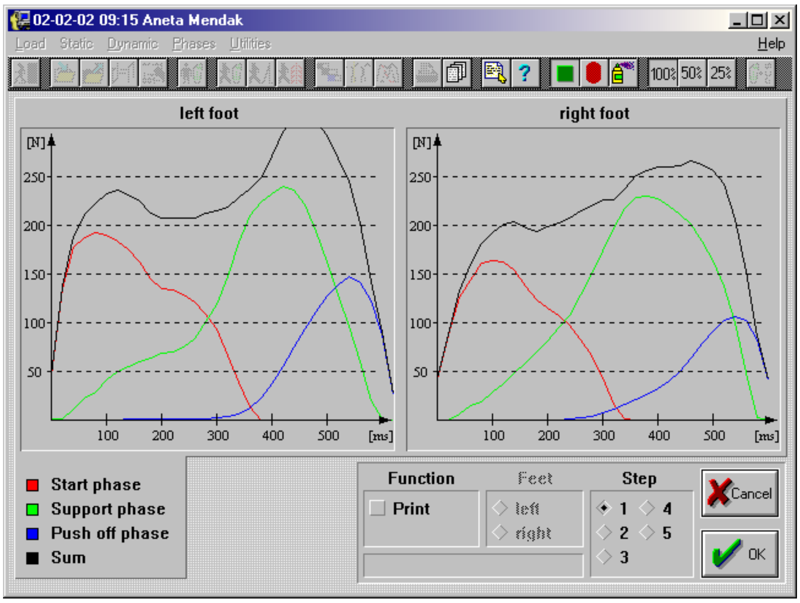

Fig. 9 A load time diagrams

The trajectory of the gravity centre displacement allows estimating the muscles tense, balance disturbances or paresis grade of lower limbs. The movie mode let the user follow the gait abnormalities spotting for precise characteristics of the gait finding. The phases' description provided us with a medium gait time (floor contact time averaged for all cycles; in milliseconds) and step time deviation in a gait cycle.

This option indicates very precisely the feet hooking on a floor in push off or support phases, by non-burdened feet.

The body lateral deviation defines the grade of gait unsteady, in axis perpendicular to walking direction; as a measure of balance disturbances in time of walking.

In the dynamic data the following characteristic units are under consideration:

– trajectories of body weight centre movement,
– a foot floor contact with a ground,
– pressure values distribution (called pulses),
– phases time relations.

4.3. BODY WEIGHT CENTRE TRANSLOCATION TRAJECTORIES

The translocation of the body weight centre describes some instability of patient gravity reactions. For these abnormalities measure several characteristics were distinguished, as: the trajectory shape, regularity, length and time relations. Irregular movement of the gravity centre concerns a foot floor hooking cases (for strokes), a floor contact time elongation characteristic for Parkinson's disease. In Fig. 10 the dynamic record part for right-sided hemiparesis was presented; with visible elongation of the gravity centre trajectory on a paresis side; shorter on healthy side.

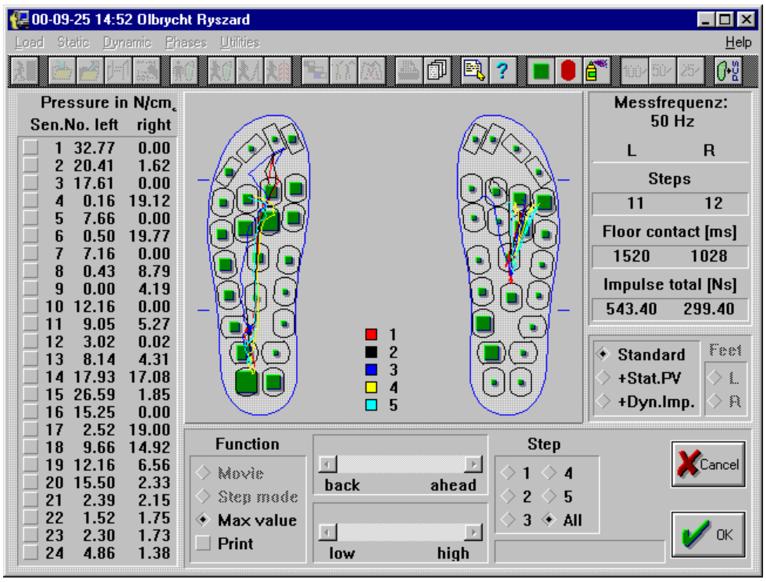

Fig. 10 Right-sided hemiparesis after cerebral stroke

Characteristic features, for Hemiparesis: Gravity centre located on healthy side of the body, mostly in metatarsal region, with shorter trajectories. The affected limb shifts from heel to fingers, irregularly that is visible as trajectories elongation, with largest disturbances at 1st and 2nd phases of the step.

Characteristic features, for Parkinson's disease: Bilateral fluctuations (tremor) of a load, usually dominated at one side (in accordance with neurological symptoms).

Characteristic features, for sciatic neuralgia: Irregular and tangled fluctuations of gravity centre at the affected body side.

4.4. FLOOR CONTACT TIME AND IMPULSE RELATIONS

The floor contact is presented with value of impulse; usually bigger on side of presence (domination) of neurological symptoms. It is proportional to the pathology level. The same relations are visible for impulse values (foot hitting strength on a floor). In Fig.11 the example record was presented; with partial right-sided hemiparesis. The time of floor contact is almost three times longer on affected limb, with impulse over seven times bigger at the side of paresis.

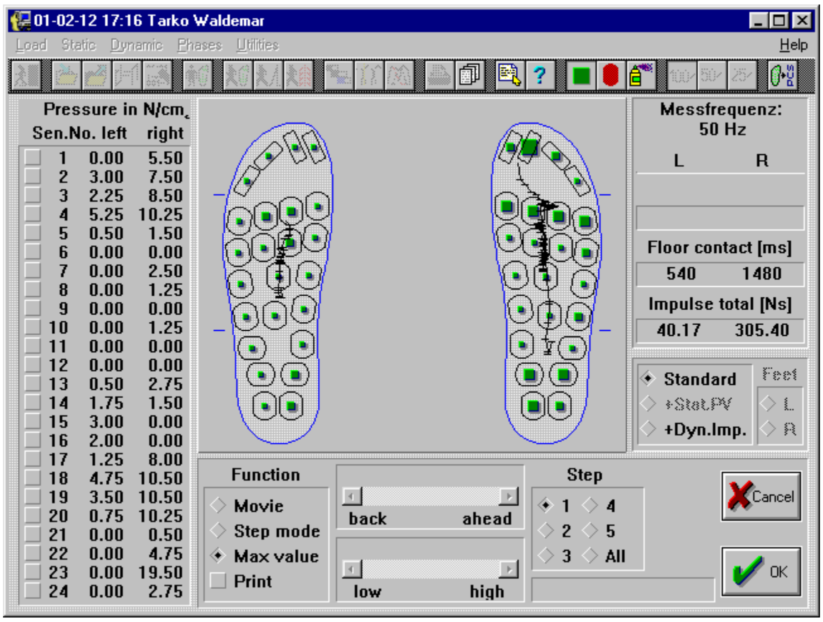

Fig. 11 The right-sided hemiparesis example impulses

Characteristic features, for hemiparesis: Elongation of a step duration time of the affected limb. With: significantly larger impulse, visible on the affected side, in heel region and on healthy side - in metatarsus.

Characteristic features for Parkinson's disease: Elongation of floor contact time and impulse enlargement on a side with domination of neurological symptoms (the step duration time longer at mostly affected limb).

Characteristic features for sciatic neuralgia: Elongation of floor contact time with impulse enlargement at the affected limb (the step duration time longer for a painful limb).

4.5. PHASES TIME RELATIONS

The average times of start, support and push-off phases can be treated as coefficients of step stages analysis. Start phase describes the initial period of the step, where body weight goes through the heel. Then the second foot is usually in push-off phase.

The support phase shows a period of step, in which a body weight goes through heel and metatarsus. In a push-off phase the body weight goes across toes, when a second foot begins its start phase.

The example phases for right-sided lateralisation in Parkinson's disease has been presented in Fig. 12. There are visible extensions of start and push off phase on the affected limb – side.

The overlap phase shows a floor contact of both feet at the same time, with a body load translocation from one foot to another.

The step time characteristics provide us with an important supplementary data of a gait stability analysis. Anyhow, there large variability within the same groups of diseases can be noticed.

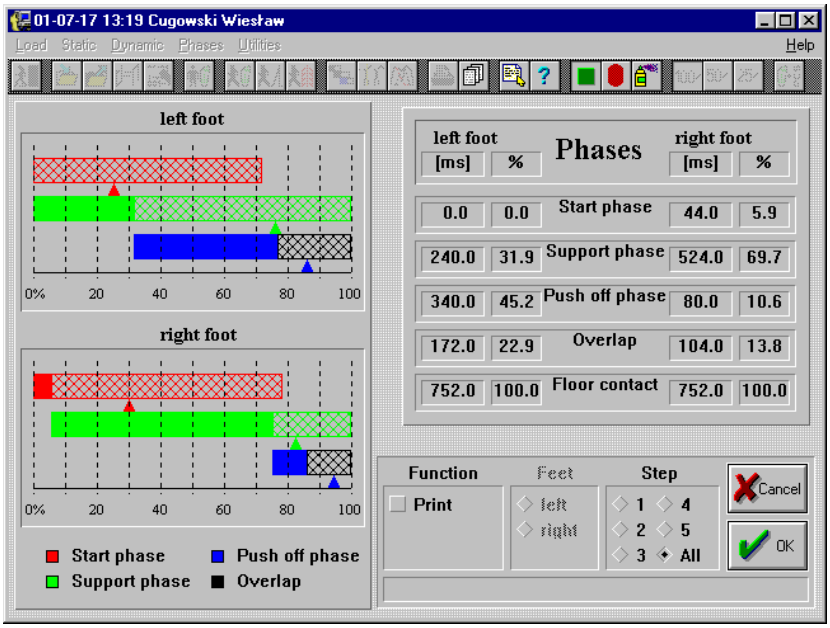

Fig. 12 The Parkinson's disease phases example record

Characteristic features for hemiparesis: Variable values of phases time relations. Frequently, with the start phase elongations, shortening of push-off and overlap on the affected limb.

Characteristic features for Parkinson's disease: Variable values of phases time relations. Frequently, with elongation of start and support phase on a side of dominated neurological symptoms.

Characteristic features for sciatic neuralgia: Variable values of phases' time relations, with no significant regularity.

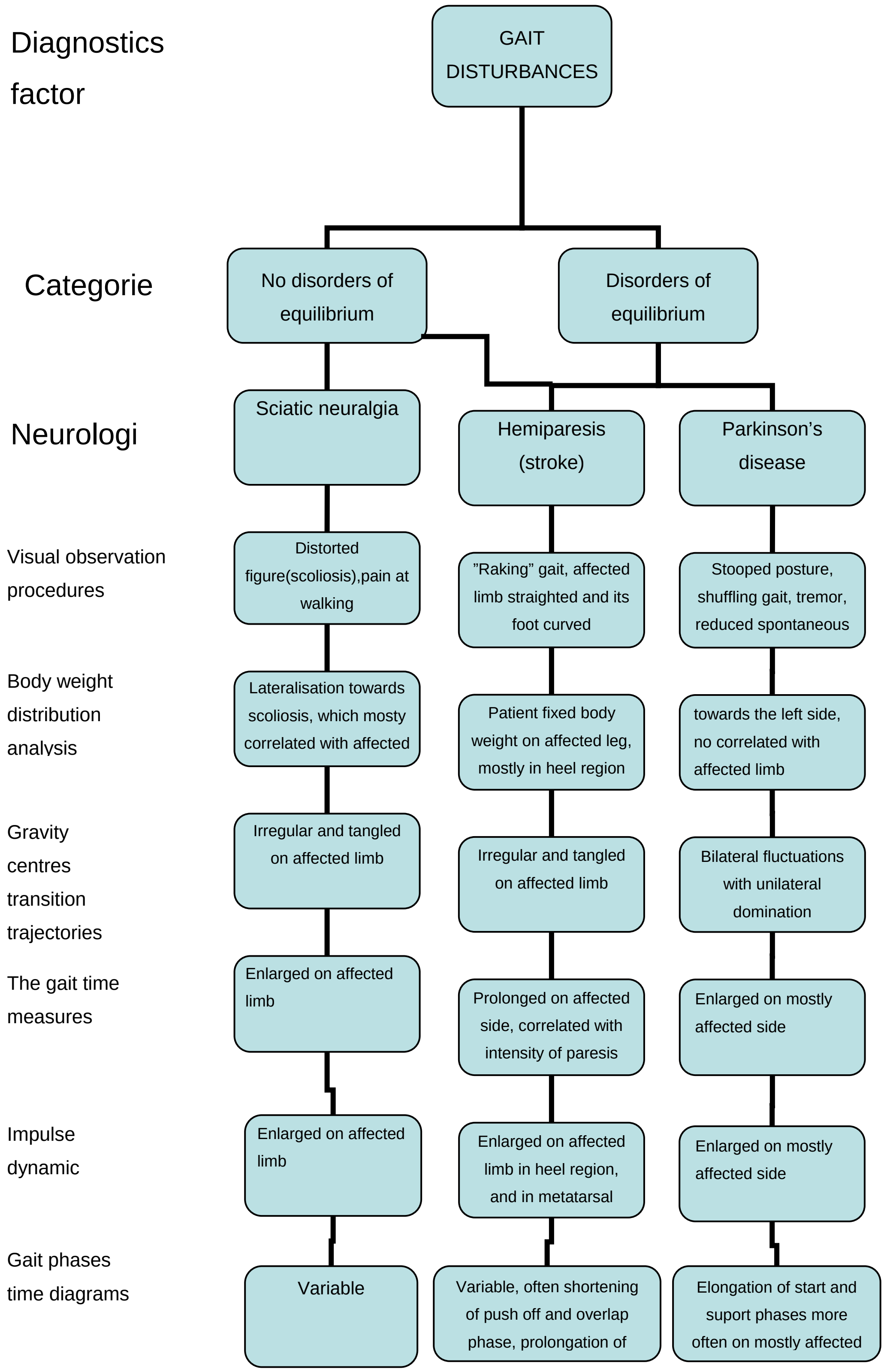

Fig.13 Gait disturbances classification algorithm

5. FINAL CONCLUSIONS

The gait characteristics registration provide the user with remarkable data evidences permitting to define some formal approaches supporting neurological diseases diagnosis (Fig. 13)

Although the gait descriptors permit putting some restrictive diagnostic procedures the exact statement concerning the diseases class with final recognition of the disease is still under consideration.

The characteristics of body trajectories translocations are very useful support for diagnosis for a complex medical investigation. It can also remarkable support the disease monitoring in time of various rehabilitation processes, where a body motion characteristic features analysis is helpful.

The study brings us many data files illustrating some effectiveness components of the rehabilitation processes monitoring; by several cases with hemiparesis after cerebral strokes.

The earlier observations affirmed that body weight is transferred to the paresis limb shifting a gravity centre into affected limb. The maximum values of the body load were registered in a heel zone. Burden of a paresis limb strictly corresponds with paresis level.

After the medical treatment the decrease of muscular strength deficit was detected, with some tendency of body weight equal distribution on both feet. The gravity centre moved into a central line, with shift into the healthy limb direction. The gravity centre trajectories became longer as well as the floor contact time values with diminished impulse on an affected foot.

The step phases time values in healthy side were still similar to those in a control group, however in the affected side elongation of start phase (burden on heel), and support (burden on metatarsus) were noticed.

In time of the successful rehabilitation processes all values of step stages showed distinct tendencies of coming into normal stages that correlate with restoration of motion efficiency.

Finally the dislocation of a body gravity centre, called posturogram was introduced to clinical evaluation of the body balance disturbances analysis. This sample analysis provided us with very essential conclusions of early diagnosis of Parkinson’s disease. Also remarkable positive in giving opinions specific pharmacotherapy processes effectiveness evaluation.

The investigations results, although satisfying, should be evaluated in categories of general recognised disorders diagnostics. The gait disturbances analysis that come from neurological reasons, have to be estimated within their final diagnosis contribution proportions.

From the other hand the gait characteristics recorders offer many precise and quantitative descriptions with their immediate introductions into further clinical practices.

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