medical diagnostics automation,
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THE BODY BALANCE MEASURES FOR NEUROLOGICAL DISEASE ESTIMATION AND CLASSIFICATION

The paper describes body balance characteristics needed for neurological diseases classification and for rehabilitation processes controlling during patient recovery processes. These diagnosis factors allow simplify the PSW (Parotec System for Windows) records recognition [1, 2] then a walk-motor disturbances level estimation. The discussed clinical experiments illustrate new methods for Parkinson disease and stroke progress monitoring. This study was based on many observations of patient walk disturbances recorded in PSW files describing the pressure distribution on an insole set of sensors [1, 2, 8]. The gait regular asymmetry in a data spectrum has been noticed as an independent factor from the disease duration and its severity. In majority of analysed cases for Parkinson disease a gravity centre of the body moved into a heel region. Trajectories of foot gravity centre elongation, their irregularities, a floor-contact time and paresis limb loading values increase also were observed. The PSW system has successfully been used for recognition and quantification of walk-motor disturbances, marking the neurological diseases level. Options available in PSW [1, 2] give the user many aims in putting proper diagnosis anyhow, due to simplify the training process of conclusion making unit several methods for data records modifications and the diagnosis factors extraction were also considered.

1. INTRODUCTION

A data record structure, being a subject of analysis, has been described in many papers [1, 2, 8]. The data record collected by Parotec System for Windows (PSW) controller is already used for several diseases classification.

The pressure distribution within a patient footprint is obtained by a set of sensors (installed in insoles). This record provides the medical services with various interfaces for patient walking analysis. The interfaces are also used for diagnosis support concerning neurological diseases classification.

The neural network engine is used as an automatic conclusion-making unit (CMU) [2] extracting the diagnosis factors from many components of the data record.

Majority of our experiments in clinics concerned the Parkinson disease (PD), one of the more baffling and complex neurological disease. A second group of the disease analysis concerned strokes of a brain. These classification and monitoring processes still remain mystery. The PD affects at least 1 from 100 people in age over 60. The Parkinson disease onset is very irregular, with various symptoms for almost every patient [4, 10] that is why a proper diagnosis is very

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troublesome. Several characteristic symptoms (with various combinations) of Parkinson disease can be distinguished, as: tremor of hands, rigidity with constantly tensed muscles, patient feels stiff with temporary paralysis, reduced spontaneous movement or postural abnormalities with stooped posture. Other common symptoms include a shuffling gait, a mask-like face with decreasing blinking and not readable handwriting. Also many additional characteristic features can be defined they were not discussed in this paper.

The Parkinson disability is also classified within following categories:

- one-sided tremor of the body, rigidity of muscles, temporary paralysis, reduced spontaneous movement or postural abnormalities,
- two-sided tremor of the body and as above,
- first symptoms of deteriorating balance, although still fully independent,
- help needed for daily living activities,
- unless assisted, confined to wheelchair or bed.

Among many symptoms of PD several walking irregularities are observable:

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

The PD is noticed when certain nerve cells (neurones) of a midbrain area (called *substantia nigra*) is dead or it is impaired. These neurones produce a vital substance called dopamine that is responsible for signals transmission into the *substantia nigras*. They control smooth co-ordination of the body movement [11, 12, 13].

An early stage of neurological disease (as PD) has to be caught that is very difficult problem even for experienced neurologists. For example when tremor is the only symptom of PD, the physician may need to observe the patient actions for more then several months.

A second neurological disease, in a scale of diagnostics complexity, is a stroke of brain. This disease is also defined as a sudden local or general brain disability that lasts above 24 hours or causes a death. The brain activity disturbances cause the blood vessel diseases only [5]. In majority cases (80 %) the stroke implies ischemia, 20% of strokes haemorrhage.

The result of brain stroke will be noticed as:

- a face muscles paresis or paralysis, hand and/or leg paresis or paralysis; one-sided generally,
- face, hand and/or leg anaesthesia; one-sided generally,
- gait disturbance in loosing balance and giddiness.

The symptomatic patient's action is his hemiparetic walk that is observable by PSW options. Following features represents the walk characteristics:

- the body weight load is shifted to the patient's affected limb and on the paresis limb this overload is longer present,
- the patient has troubles to lift-off the limb affected by paresis,
- the affected limb is moved forward then a healthy limb is put to the paresis one,
- the affected limb is usually stiff at a knee-joint, the foot is carried over a curve and curried up only in minimal grade,
- a toe is hooking a ground.

The limbs load is irregular exceeding physiological values (in standing). A source literature [3, 5, 6] describes several methods of a brain stroke recognition and classification, but very rear cases describe methods of walk disturbances analysis.

2. THE EQUIMENT INTERFACES

The PSW provides the user with source records that consist of static and dynamic data part. The static part of the record is available in two-dimensional map with pressure values in points of insoles, where sensors are installed. One of characteristic features shows a body gravity centre movement, as in example illustrated in Fig.1.

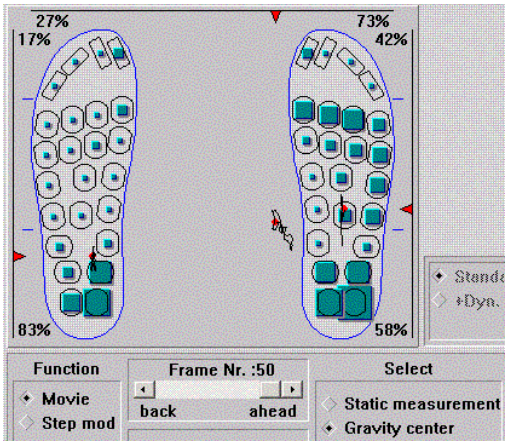

Fig.1. A body gravity centre movement.

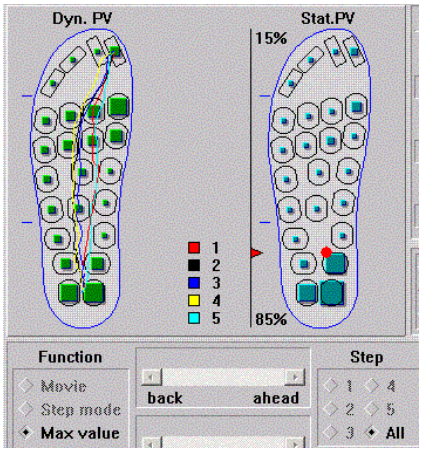

Fig.2. A dynamic measurement.

The dynamic part of the data record allows analysing current values of the pressure distribution in a walk cycle. The footprint is covered by trajectories (Fig.2) of the pressure central point flow in first five steps, indicating the walk stability level. The presented data also allows a local energy analysis; using time diagrams illustrating a pressure distribution.

3. MEASURES OF THE DISEASE

Early experiments with automatic conclusions [2, 6, 7] proved that the source record of PSW system (not pre-processed) gives no satisfactory diagnosis results. This record contains many factors of differently interpreted reasons.

Trying to reduce the redundancy and to select the most representative record components (for neurological diseases) the characteristic measures for the selected disease have been extracted. This way specific norm and its margins, illustrating the walk features, were found, also for walk disturbances of Parkinson disease and for hemiparesis after ischemic stroke.

Definitions of the measures for the discussed diseases extract parameters free from additional factors, as a patient weight, shoe-insole sizes, number of recorded steps, etc.

The defined measures cover the diseases characteristic features and they are well-defined data-inputs of the neural network conclusion-making unit. Afterwards the features of gait and body balance disturbance are formulated and standardised.

Step is a time interval measured in a walk when a single foot contacts with the ground; where one foot (left then right or right then left) touches a ground.

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 a physiological walk.

Definition 1. *A Body-gravity Centre Pointer*

A body gravity centre pointer *BCP* concerns static data record, marked by CB_s point in Fig.3, illustrating a body weight distribution on a footprint, where overload on foot-zones are visualised.

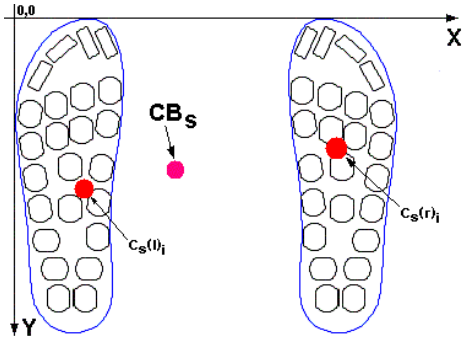

Fig.3. Body and feet gravity centres.

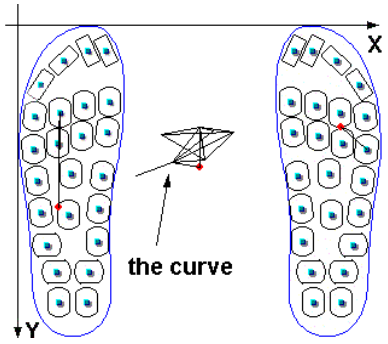

Fig.4. A trajectory of gravity centre movement.

Definition 2. *A Body Balance measure*

A body balance measure *BB* describes the length of trajectory of gravity centre movement (Fig.4) that determines disturbances of body balance in a period the patient standing. The measure is independent form a measure time and a shoe-sole size.

Definition 3. *A Mean Step-time measure*

A mean step-time measure *MS* in step-cycle defines a mean floor-contact time in dynamic part of the record. This step-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 asymmetry.

Bellow several examples are discussed, where a limb affected with paresis carries a load of a body longer than a healthy one.

Definition 4. *The Cycle-time Limit measures*

A cycle-time limit measure *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}.

These measures describe phenomenon of irregular and jerky gait [5].

Definition 5. *The Step Phases Pointers*

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

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

Push-off phase – where the patient body load is in a front part of a foot.

The step phases pointers *SPP* are the mean values from floor-contact time of tree step phases defined above (Fig.5). A medical expert has to define physiological values of this measure then analysing the pointer values one can compare this threshold value with current states. The conclusions concern comparison of pointers if they are in a limit defined as physiology or above, classified as pathology.

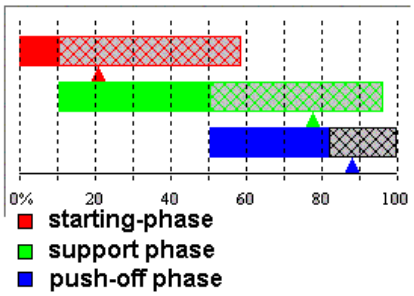

Fig.5. A step phases diagram.

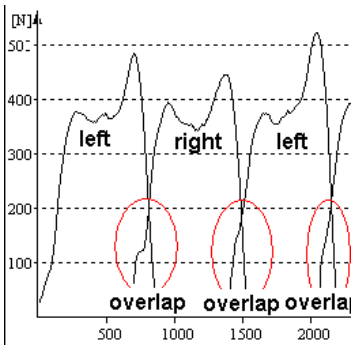

Fig.6. A step strength graph with the overlap phases.

Definition 6. *An Overlap Measure*

An overlap measure *OM* is a mean overlap time of single step-cycle (Fig.6), where both feet carry a body load. This measure says a lot about neurological disturbances of a gait.

Definition 7. *A Pressure Distribution measure*

A pressure distribution measure *PDM* expresses a mean value of strength recorded on insole sensors in single step-cycle of dynamic record part – the measure is standard by a patient's weight. This factor of the gait characteristics describes strengths distribution on both feet, where load distribution irregularities can be assigned.

Definition 8. *A Lateral Oscillation measure*

A lateral oscillation measure *LO* describes the body balance disturbances of a gait. Then also perpendicular oscillation to the direction of a patient gait direction is visible.

Definition 9. *A Lateral Oscillation Scope measure*

A lateral oscillation scope measure *LOS* is a distance between minimum and maximum values of the pressures distance recorded in a step-cycle. It means the maximal range of a lateral oscillation.

4. THE MEASURES CLINICS CHECK-UP

The all selected measures have been related to clinical records. The experiments have been carried out on three groups of diseases, selected by experienced doctors. The selection concerned group of patients, in age from 30 to 77 years, suffering from neurological diseases, as:

- left-lateral hemiparesis after ischemic stroke of 23 patients,
- right-lateral hemiparesis after ischemic stroke of 27 patients,
- Parkinson disease of 15 patients.

The examination of the defined above diagnostics measures have been done in comparison with a group of 33 healthy patients, called a control group.

Analysing the mean values of body gravity centre pointers *BCP* distribution (for all patients from control group) we noticed the pointers shift, both on a foot and body centres, towards a heel region (47% to 53%). A distribution of the *BCP* pointers is a ratio 50% left to 50% right foot. The body balance measure *BB* of these cases did not exceed a value that is accepted as a minimum of physiological range (here 3.1).

Also the floor-contact time set, appointed by the mean step-time measure *MS* and the cycle-time limit measures *CL*, defined range limit from 610 ms to 1200 ms. There is also a wide divergence for step phases. But distribution of the step phases is a ratio 50% left to 50% right foot, the same as the measures described earlier. An overlap measure *OM* value has been noticed form 16.1% to 20.4% for the control group. A lateral oscillation measure *LO* and a lateral oscillation scope measure *LOS* appoints the permitted range of oscillations, called a normal range.

The PSW records for patients earlier classified as left-lateral hemiparesis after ischemic stroke indicated following regularities:

- for 57% cases the pointer of body gravity centre *BCP* distribution was outside the normal range,
- the body centre of gravity shift has been observed particularly towards affected limb and visible into a heel region, it means that the body load was divided between the toe (46%) and the heel (54%) regions,
- in majority cases the body gravity centre pointers moved towards the left limb (55% into the left, 45% into the right limb),
- for 72% cases a bigger mean step-time measure *MS* have been noticed for the left limb,
- the mean step-time measure *MS* distribution was also divided between left and right limbs with 53% and 47% respectively,
- measures of cycle-time limit CL_{min} and CL_{max} over gone admissible level for 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 the same measure observed on a right foot,
- for 81% cases the CL_{max} value on a left foot was bigger than on the right one,
- 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 ration 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 fault down the range treated as a normal stage,
- the pressure distribution measure *PDM* has been noticed as a 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.

5. DISCUSION AND CONCLUSIONS

Closing the discussion of the carried out clinical experiments several regularities have been noticed.

The case called right-lateral hemiparesis after ischemic stroke was indicated by considerable load on right foot in dynamic record measures (for 77% cases). The floor-contact time is also bigger on right foot than on left one (in 84% cases).

The diagnostic measure levels, for cases presented above, were comparable with measure values recorded for left-lateral domination anyhow their characteristics were observed as in mirror.

What is more for the body balance *BB* measure values, for 23% cases, remarkable deviations were observed. For all cases an overlap measure *OM* was outside the eligible range.

For the Parkinson disease the movement of body gravity centre *BCP* pointer enlarged the diagnosis factors in 66% cases, where regular shift of the centre was observed - in ratio 37% into toe zone and 63% into heel region. Additionally the *BCP* movement is noticed within the limb that was primary affected by a paresis.

Only for 13% case the body balance abnormality have been observed, where the *BB* values were above an eligible level. For another 13% cases a floor-contact time increase for primary paresis limb was noticed.

Very extraordinary way of walking was recorded. In almost 53% cases the push-off phase was closed to zero. The PD (for 66% cases) indicated also another curiosum with overlap measure *OM* that was visibly above the eligible value.

There has been noticed overloading for primary paresis limb (53% cases) for dynamic measure. For over half cases number a lateral oscillation measure *LO* (for 53% cases) and a lateral oscillation scope measure *LOS* (for 40% cases) increases have been noticed, where the patient walk was uncertain and a limb load was asymmetrical.

All experiments in clinics are carried out for values analysis of indicated measures. These factors of diagnosis can be used as input signals of Neural Network Conclusions Making System.

Majority of the defined measures is readable adequately to the disease level. These disease characteristic features minimise the area of diagnosis and the extracted measures allow choosing the proper diagnosis looking at specified component of the disease description within a spectrum of the patient walk characteristics.

These neurological diseases classifiers concern walk and body balance disturbances. The property assigned measures allows describing the diseases stage. They can also be used for monitoring the patient recovery processes.

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.

The introduced diagnostic measures show asymmetrical walk disturbances for PD class of the neurological diseases. The heel region overload has also been observed within gravity of a body centre movement into this foot region.

A special attention has to be turned on into the eligible margins of value changes of the lateral oscillation measure, the lateral oscillation scope measure and zero on push-off phase time.

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

All investigated cases indicated changes in floor-contact time and an overlap time measures with elongation or shorting particular step phases.

Early experiments with the automatic conclusion-making units (neural networks) [2] were very discouraging. These PSW interfaces provide the user with big range of diagnosis factors often difficult to classify in a proper way. The discussed new approach into classification processes of

neurological diseases let us expect better possibilities of the CMU development, using properly appointed 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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