Evaluation of postural stability using fuzzy logic

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***Abstract*—** This study presents the experiment focused on balance disorders diagnosis determination. The main idea is based on the measured data, expert diagnosis and the use of fuzzy logic. The data used in this experiment were measured under the static conditions on the posturography platform. The patients were split into three groups: peripheral, central and normal, based on doctor's diagnosis. Membership functions for the fuzzy logic were created based on these samples. These functions foundations based on the standards obtained from a set of measurements performed on selected patients and expert base. From the obtained results was found, that for the group of selected patients - without balance disorders, using the proposed methodology, it was found that in 60% of them can be clearly said, that it is a normal patient, without balance disorders and in the remaining 40% of the results was inconclusive, from 85 patients in the group of patients with peripheral balance disorders using the proposed methodology, it was found that in 78% can be clearly argued that these patients are with peripheral balance disorders and in the remaining 22% of the results were inconclusive and from 82 patients in the group of patients with central balance disorders using the proposed methodology, it was found that in 83% can be clearly argued that these patients are with central balance disorders. Remaining 17% of the results were inconclusive. From the performed experiments appears, that proposed methodology has good possibility to distinguish whether patients have impaired balance or not, but ability to distinguish patients with peripheral balance disorders in patients with central disorder seems weak. However, research continues and the application of other modern methods can eliminate this weakness.

***Keywords*—** Balance disorders, fuzzy logic, membership function, peripheral vestibular deficits, posturography, vestibular dysfunction.

I. Introduction

POSTUROGRAPHY, also known as a test of balance is a general term for methods used to measure postural stability on static or dynamic measuring platforms. The principle of measurement is detection of the center of foot pressure (CFP) during examination on a posturography platform.

The CFP projects the center of gravity of the body to the ground. It must be maintained within the area defined by the feet. Balancing requires information from the vestibular, somatosensory and visual system.

Failure of any of these systems causes specific balance disturbances. Even between the lesions of the central and peripheral vestibular systems are observable clinical differences which may be reflected in the body sway measurement. Posturography is an objective technique, so it is not burdened by subjective interpretation, and the results can be documented both graphically and numerically. This enables a detailed assessment of postural balance, a comparison of results, and an ability to archive [2, 4, 8 and 13].

This article is dealt with only static posturography. Static posturography is based on the principle of measuring the shifts in CFP on a stationary platform [2, 8 and 13]. Opinions on the importance of posturography and its position among other machine-based techniques in vestibulology are divided. Prevailing opinion is that both posturography techniques (SCPG and DCPG) are beneficial especially for the quantitative assessment of postural balance [1, 3, 5, 8 and 13]. Posturography is deemed a suitable complement to standard vestibular examinations, especially in patients with CNS pathology and is useful for evaluating susceptibility to falling [6, 7, 10 and 13].

There are many studies deal with the differential diagnosis of balance disorders of the human but there are not many studies using modern methods. This article deals with the differential diagnosis of balance disorders using a fuzzy logic.

II. Fuzzy logic

Fuzzy logic is a form of many-valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. [9, 12] Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false.

The term “fuzzy logic” emerged in the development of the theory of fuzzy sets by Lotfi Zadeh (1965). A fuzzy subset A of a (crisp) set X is characterized by assigning to each element x of X the degree of membership of x in A (e.g., X is a group of people, A the fuzzy set of old people in X). Now if X is a set of propositions then its elements may be assigned their degree of truth, which may be “absolutely true,” “absolutely false” or some intermediate truth degree: a proposition may be more true than another proposition. This is obvious in the case of vague (imprecise) propositions like “this person is old” (beautiful, rich, etc.). In the analogy to various definitions of operations on fuzzy sets (intersection, union, complement, …) one may ask how propositions can be combined by connectives (conjunction, disjunction, negation, …) and if the truth degree of a composed proposition is determined by the truth degrees of its components, i.e. if the connectives have their corresponding truth functions (like truth tables of classical logic). Saying “yes” (which is the mainstream of fuzzy logic) one accepts the truth-functional approach; this makes fuzzy logic to something distinctly different from probability theory since the latter is not truth-functional (the probability of conjunction of two propositions is not determined by the probabilities of those propositions). [11, 17]

Two main directions in fuzzy logic have to be distinguished (cf. Zadeh 1994). Fuzzy logic in the broad sense (older, better known, heavily applied but not asking deep logical questions) serves mainly as apparatus for fuzzy control, analysis of vagueness in natural language and several other application domains. It is one of the techniques of soft-computing, i.e. computational methods tolerant to suboptimality and impreciseness (vagueness) and giving quick, simple and sufficiently good solutions. [9, 11 and 17]

Fuzzy logic in the narrow sense is symbolic logic with a comparative notion of truth developed fully in the spirit of classical logic (syntax, semantics, axiomatization, truth-preserving deduction, completeness, etc.; both propositional and predicate logic). It is a branch of many-valued logic based on the paradigm of inference under vagueness. This fuzzy logic is a relatively young discipline, both serving as a foundation for the fuzzy logic in a broad sense and of independent logical interest, since it turns out that strictly logical investigation of this kind of logical calculi can go rather far. [9, 17]

In the past decade, fuzzy logic has proved to be useful for intelligent systems in medicine.

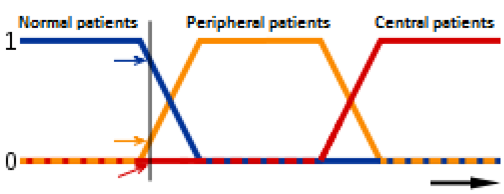

Fig. 1: Schema of the fuzzy logic diagnosis [9]

In this image, the meanings of the expressions normal, peripheral, and central patients are represented by functions mapping a diagnostic scale. A point on that scale has three "truth values"—one for each of the three functions. The vertical line in the image represents a particular value that the three arrows (truth values) gauge. Since the red arrow points to zero, this diagnosis may be interpreted as "not central". The orange arrow (pointing at 0.2) may describe it as "slightly peripheral" and the blue arrow (pointing at 0.8) "fairly normal". It can be concluded that the patient is without balance disorders. [9]

III. Balance Disorders

A balance disorder is a condition that makes you feel unsteady or dizzy, as if you are moving, spinning, or floating, even though you are standing still or lying down. Balance disorders can be caused by certain health conditions, medications, or a problem in the inner ear or the brain.

Our sense of balance is primarily controlled by a maze-like structure in our inner ear called the labyrinth, which is made of bone and soft tissue. At one end of the labyrinth is an intricate system of loops and pouches called the semicircular canals and the otolithic organs, which help us maintain our balance. At the other end is a snail-shaped organ called the cochlea, which enables us to hear. The medical term for all of the parts of the inner ear involved with balance is the vestibular system (see Fig. 2). [14]

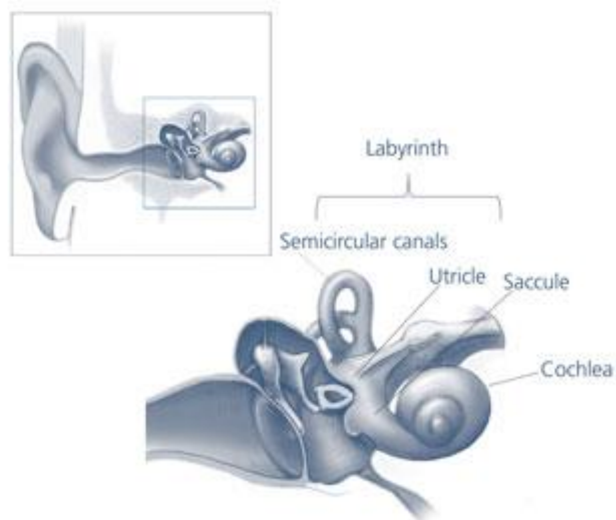

Fig. 2: The vestibular system in relation to the ear [14]

A. *How works the vestibular system*

Our vestibular system works with other sensorimotor systems in the body, such as our visual system (eyes) and skeletal system (bones and joints), to check and maintain the position of our body at rest or in motion. It also helps us maintain a steady focus on objects even though the position of our body changes. The vestibular system does this by detecting mechanical forces, including gravity, that act upon our vestibular organs when we move. Two sections of the labyrinth help us accomplish these tasks: the semicircular canals and the otolithic organs.

The semicircular canals are three fluid-filled loops arranged roughly at right angles to each other. They tell the brain when our head moves in a rotating or circular way, such as when we nod our head up and down or look from right to left.

Each semicircular canal has a plump base, which contains a raindrop-shaped structure filled with a gel-like substance (see Fig. 3). This structure, called the cupula, sits on top of a cluster of sensory cells, called hair cells. The hair cells have long threadlike extensions, called stereocilia, that extend into the gel. When the head moves, fluid inside the semicircular canal moves. This motion causes the cupula to bend and the stereocilia within it to tilt to one side. The tilting action creates a signal that travels to the brain to tell it the movement and position of your head. [14]

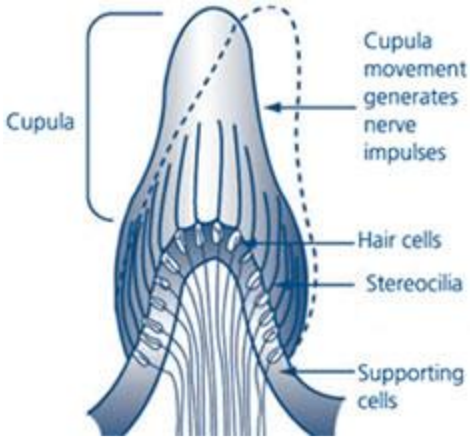

Fig. 3: The role of the cupula in balance [14]

Between the semicircular canals and the cochlea lie the otolithic organs, which are two fluid-filled pouches called the utricle and the saccule. These organs tell the brain when our body is moving in a straight line, such as when we stand up or ride in a car or on a bike. They also tell the brain the position of our head with respect to gravity, such as whether we are sitting up, leaning back, or lying down.

Like the semicircular canals, the utricle and the saccule have sensory hair cells. These hair cells line the bottom of each pouch, and their stereocilia extend into an overlying gel-like layer. On top of the gel are tiny grains made of calcium carbonate called otoconia. When you tilt your head, gravity pulls on the grains, which then move the stereocilia. As with the semicircular canals, this movement creates a signal that tells the brain the head's position.

Our visual system works with our vestibular system to keep objects from blurring when our head moves and to keep us aware of our position when we walk or when we ride in a vehicle. Sensory receptors in our joints and muscles also help us maintain our balance when we stand still or walk. The brain receives, interprets, and processes the information from these systems to control our balance. [8, 14]

B. The symptoms of a balance disorder

If your balance is impaired, you may feel as if the room is spinning. You may stagger when you try to walk or teeter or fall when you try to stand up. Some of the symptoms you might experience are:

- Dizziness or vertigo (a spinning sensation)
- Falling or feeling as if you are going to fall
- Lightheadedness, faintness, or a floating sensation
- Blurred vision
- Confusion or disorientation

Other symptoms are nausea and vomiting, diarrhea, changes in heart rate and blood pressure, and fear, anxiety, or panic. Some people also feel tired, depressed, or unable to concentrate. Symptoms may come and go over short time periods or last for longer periods of time.

C. Causes a balance disorder

A balance disorder may be caused by viral or bacterial infections in the ear, a head injury, or blood circulation disorders that affect the inner ear or brain. Many people experience problems with their sense of balance as they get older. Balance problems and dizziness also can result from taking certain medications.

In addition, problems in the visual and skeletal systems and the nervous and circulatory systems can be the source of some posture and balance problems. A circulatory system disorder, such as low blood pressure, can lead to a feeling of dizziness when we suddenly stand up. Problems in the skeletal or visual systems, such as arthritis or eye muscle imbalance, also may cause balance problems. However, many balance disorders can begin all of a sudden and with no obvious cause. [14]

D. Types of balance disorders

There are more than a dozen different balance disorders. Some of the most common are: [8, 14, 15 and 16]

- **Benign paroxysmal positional vertigo (BPPV) or positional vertigo** is a brief, intense episode of vertigo that occurs because of a specific change in the position of the head. If you have BPPV, you might feel as if you're spinning when you look for an object on a high or low shelf or turn your head to look over your shoulder (such as when you back up your car). You also may experience BPPV when you roll over in bed. BPPV is caused when otoconia tumble from the utricle into one of the semicircular canals and weigh on the cupula. The cupula can't tilt properly and sends conflicting messages to the brain about the position of the head, causing vertigo. BPPV sometimes may result from a head injury or just from getting older.

- **Labyrinthitis** is an infection or inflammation of the inner ear that causes dizziness and loss of balance. It frequently is associated with an upper respiratory infection such as the flu.

- **Ménière's disease** is associated with a change in fluid volume within parts of the labyrinth. Ménière's disease causes episodes of vertigo, irregular hearing loss, tinnitus (a ringing or buzzing in the ear), and a feeling of fullness in the ear. The cause of this disease is unknown. For more information, read the NIDCD fact sheet Ménière's Disease.

- **Vestibular neuronitis** is an inflammation of the vestibular nerve and may be caused by a virus. Its primary symptom is vertigo.

- **Perilymph fistula** is a leakage of inner ear fluid into the middle ear. It can occur after a head injury, drastic changes in atmospheric pressure (such as when scuba diving), physical exertion, ear surgery, or chronic ear infections. Its most notable symptom, besides dizziness and nausea, is unsteadiness when walking or standing that increases with activity and decreases with rest. Some babies may be born with perilymph fistula, usually in association with hearing loss that is present at birth.

- **Mal de debarquement syndrome (MdDS)** is a balance disorder in which you feel as if you're continuously rocking or bobbing. It generally happens after an ocean cruise or other sea travel. Usually, the symptoms will go away in a matter of hours or days after you reach land. However, severe cases can last months or even years.

E. Diagnosis of balance disorders

Diagnosis of a balance disorder is difficult. There are many potential causes—including medical conditions and medications.

To help evaluate a balance problem, your doctor may suggest you see an otolaryngologist. An otolaryngologist is a physician and surgeon who specializes in the ear, nose, and throat. An otolaryngologist may request tests to assess the cause and extent of the balance problem depending on your symptoms and health status.

The otolaryngologist may request a hearing examination, blood tests, an electronystagmogram (which measures eye movements and the muscles that control them), or imaging studies of your head and brain. Another possible test is called posturography. For this test, you stand on a special movable platform in front of a patterned screen. The doctor measures how your body moves in response to movement of the platform, the patterned screen, or both.

F. Treatment of balance disorders

The first thing a doctor will do to treat a balance disorder is determine if your dizziness is caused by a medical condition or medication. If it is, your doctor will treat the condition or suggest a different medication.

Your doctor also may describe ways for you to handle daily activities that increase the risk of falling and injury, such as driving, walking up or down stairs, and using the bathroom. If you have BPPV, your doctor might prescribe a series of simple movements, called the Epley maneuver, to help dislodge the otoconia from the semicircular canal. You begin the Epley maneuver by sitting upright, with the help of a trained therapist, then quickly lie down on your back, turn your head to one side, and wait for a minute or two before sitting back up again (see Fig. 4). For some people, one session will be all that is needed. Others might need to repeat the procedure several times at home to relieve their dizziness. [4, 14]

Fig. 4: Dislodging otoconia using the Epley maneuver [14]

If you are diagnosed with Ménière's disease, your doctor may recommend changes in your diet, such as reducing the use of salt in your food and limiting alcohol and caffeine. Not smoking also may help. Some anti-vertigo or anti-nausea medications may relieve your symptoms, but they can also make you drowsy. Other medications, such as the antibiotic gentamicin or corticosteroids, may be injected behind the eardrum to reach the inner ear. Although gentamicin helps reduce dizziness, it occasionally destroys sensory cells in the cochlea and causes permanent hearing loss. The risk of hearing loss can be lowered if small doses of gentamicin are given off and on until your symptoms decrease. Corticosteroids don't cause hearing loss; however, research is underway to determine if they are as effective as gentamicin. Surgery on the vestibular organ may be necessary if you have a severe case of Ménière's disease.

Some people with a balance disorder may not be able to fully relieve their dizziness and will have to develop ways to cope with it on a daily basis. A vestibular rehabilitation therapist can help by developing an individualized treatment plan that combines head, body, and eye exercises to decrease dizziness and nausea.

To reduce your risk of injury from dizziness, avoid walking in the dark. You also should wear low-heeled shoes or walking shoes outdoors and use a cane or walker if necessary. If you have handrails in the home, inspect them periodically to make sure they are safe and secure. Modifications to bathroom fixtures can make them safer. Conditions at work may need to be modified or restricted, at least temporarily. Driving a car may be especially hazardous. Ask your doctor's opinion about whether it's safe for you to drive. [14]

IV. VESTIBULAR FUNCTION TESTING

The spectrum of diseases causing vertigo is very broad, hence the first visit a doctor you have to try to provide him as much information as possible. The exact description of the symptoms helps doctors diagnose, determine the strategy of further examination and plays an important a role in treatment.

It is useful to know in particular:

- at which time the dizziness occurs

- what it causes (changes in atmospheric pressure, emotional or physical stress, premenstrual period)
- symptoms, such as (nausea, tinnitus, increase in arterial pressure, sweating, headache, tendency to fall, etc.)
- what medicines you are taking, because dizziness can be caused by the use of certain drugs
- if you have recently suffered a head injury or neck. For example, cervical spine injury in a car accident when the head when braking or crash the car reversed rapidly forward and back

After gathering the data history and measure blood pressure the doctor performed a number of simple tests of balance function testing. [6, 9, 8, 18]

A. *Romberg test*

Romberg's test or the Romberg maneuver is a test used by doctors in a neurological examination, and also as a test for drunken driving. The exam is based on the premise that a person requires at least two of the three following senses to maintain balanced while standing:

- proprioception (the ability to know one's body in space)
- Vestibular function (the ability to know ones head position in space)
- vision (which can be used to monitor changes in body position)

A patient who has a problem with proprioception can still maintain balance by using vestibular function and vision. In the Romberg test, the patient is stood up and asked to close his eyes. A loss of balance is interpreted as a positive Romberg sign.

The Romberg test is a test of the body's sense of positioning (proprioception), which requires healthy functioning of the dorsal columns of the spinal cord [6, 9].

V. Static posturography

All measurements were performed on an STP-03 computerized posturography platform under the standard conditions of measurement in audio-vestibulology laboratory.

Investigations carried out in the sound damping room laboratory under conditions to ensure silence. Basic examination of all patients on the posturography platform is performed in a natural standing position.

A. *The evaluation parameters of static posturography*

Posturograph STP-03 software (widely use in Czech Republic) calculates the value of the way and area of the patient center of gravity circumscribed over the posturographic platform (frequency analysis).

Evaluates the ratio between these values for the examination with open and closed eyes are important parts of vertigo assessment (visual analysis of balance control) shows the direction and magnitude of the vector amplitude of gravity and calculates the resultant vector (vector analysis).

B. *Frequency analysis*

Parameter Way, W (cm/s) describes the path of moving center of gravity, but because the examination time given a constant number, Way is characterized as the speed of center of gravity.

Parameter Way for open eyes is marked with postfix f; (Wf) - visual fixation. Way for the closed eyes is marked with postfix s; (Ws) – visual suppression.

$$M_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$
$$W = \frac{T^{-1}}{n} \sum_{i=1}^{n} M_i \left[\frac{mm}{s}\right] \quad (1)$$

Where:

M_i	particular element of way calculation
T	measure period [s]
x,y	center of gravity coordinates
n	number of measured samples

Parameter Area, A (cm2/s) indicates the area, which describes variation of center of gravity during the examination. Like the parameter Way, Area for the visual fixation is marked (Af) and for visual suppression (As).

$$N_i = \frac{\left| \begin{matrix} (y_{i+1} - y_0) * (x_i - x_0) \\ -(y_i - y_0) * (x_{i+1} - x_0) \end{matrix} \right|}{2}$$
$$A = \frac{1}{t} \sum_{i=1}^{n-1} N_i \ [mm^2/s] \quad (2)$$

Where:

N_i	particular element of area calculation
t	length of measure [s]
x_0, y_0	average values of center of gravity coordinates *(3)*

$$x_0 = \frac{1}{n} \sum_{i=1}^{n} x_i$$
$$y_0 = \frac{1}{n} \sum_{i=1}^{n} y_i \quad (3)$$

C. *Vector analysis*

Parameter LAT (cm / s) is the resulting lateral vector amplitude of the center of gravity (the length of the lateral deflection of the center of gravity during the period of measurement). It is measured by device a visual fixation Xf and Xs visual suppression. Like the physical assessment of neurological attitudes, this parameter is to be seen as indicators of the peripheral vestibular lesion.

Parameter Ant-Post (cm / s) is the vector amplitude of anteroposterior center of gravity (the length anteroposterior displacement during the measurement). It is also measured during visual fixation Yf and Ys visual suppression. Like the physical assessment of neurological attitudes, mild anterior vector dominance in the physiological state of equilibrium is considered normal; the imbalance is to be seen as indicators of central lesions.

The instrument automatically calculates the ratio of anteroposterior and lateral components of the examined balance (AP / LAT) during visual fixation ALf and suppression of ALs, which represents the overall directional preponderance amplitude gravity investigated.

D. Analysis of visual inspections balance

Derived parameters, known as Romberg Way (RW, Wf / s) is the ratio of the Way with open and closed eyes. It expresses the proportion of visual inspections to maintain postural balance.

RbgArea derived parameters (RA, Af / s) is analogous calculations and interpretations as RbgWay.

VI. The using of the fuzzy logic in the differential diagnosis of balance disorders

In this work was used of the range of categories for the evaluation of postural equilibrium SCPG to obtain at the University Hospital in Hradec Kralove with reference to the evaluation range of other physicians. The values used in this work were actually measured on posturography platform STP-03 and was diagnosed by doctor.

The aim was to use fuzzy logic to distinguish at first, whether it is a person with the disorder balance or not. It was then ascertained whether the patient has with the disorder balance disorder of the peripheral vestibular syndrome or central vestibular syndrome. [8]

A. Preparation of the data

From the data obtained with the posturographic platform were chosen patients who were initially diagnosed by a doctor. These patients were divided into groups of peripheral and central disorder and patients with normal balance.

B. Evaluation of data using fuzzy logic

For each parameter was created the membership function, which had been evaluated measured data from STP-03.

C. Membership function of the parameters in the visual fixation

Membership functions for parameter Way, W (cm / s) which describes the path of moving circumscribed over the posturography platform during the testing

$$Wf(x) = \begin{Bmatrix} 0, & if\ x < 1{,}7939 \\ 1, & if\ x > 2{,}5798 \\ \frac{x-1{,}7939}{|x-2{,}5798|+(x-1{,}7939)} & if\ 1{,}7939 \le x \le 2{,}5798 \end{Bmatrix} \quad (4)$$

Membership function for the parameter Area, A (cm2 / s) the surface, which describes center of gravity, investigated during the examination

$$Af(x) = \begin{Bmatrix} 0, & if\ x < 0{,}4423 \\ 1, & if\ x > 0{,}7374 \\ \frac{x-0{,}4423}{|x-0{,}7374|+(x-0{,}4423)} & if\ 0{,}4423 \le x \le 0{,}7374 \end{Bmatrix} \quad (5)$$

Membership functions for parameter LAT (cm / s) is the resulting lateral vector amplitude of the center of gravity (the length of the lateral deflection of the center of gravity during the period of measurement)

$$Xf(x) = \begin{Bmatrix} 0, & if\ x < 16{,}3097 \\ 1, & if\ x > 24{,}6109 \\ \frac{x-16{,}3097}{|x-24{,}6109|+(x-16{,}3097)} & if\ 16{,}3097 \le x \le 24{,}6109 \end{Bmatrix} \quad (6)$$

Membership functions for parameter Ant-Post (cm / s) is the vector amplitude of anteroposterior center of gravity (the length anteroposterior displacement during the measurement)

$$Yf(x) = \begin{Bmatrix} 0, & if\ x < 15{,}2723 \\ 1, & if\ x > 22{,}7030 \\ \frac{x-15{,}2723}{|x-22{,}7030|+(x-15{,}2723)} & if\ 15{,}2723 \le x \le 22{,}7030 \end{Bmatrix} \quad (7)$$

D. Membership function of the parameters in the visual suppression

Membership functions for parameter Way, W (cm / s) which describes the path of moving circumscribed over the posturography platform during the testing

$$Ws(x) = \begin{Bmatrix} 0, & if\ x < 2{,}0909 \\ 1, & if\ x > 3{,}1489 \\ \frac{x-2{,}0909}{|x-3{,}1489|+(x-2{,}0909)} & if\ 2{,}0909 \le x \le 3{,}1489 \end{Bmatrix} \quad (8)$$

Membership function for the parameter Area, A (cm2 / s) the surface, which describes center of gravity, investigated during the examination

$$As(x) = \begin{Bmatrix} 0, & if\ x < 0{,}6194 \\ 1, & if\ x > 1{,}0934 \\ \frac{x-0{,}6194}{|x-1{,}0934|+(x-0{,}6194)} & if\ 0{,}6194 \le x \le 1{,}0934 \end{Bmatrix} \quad (9)$$

Membership functions for parameter LAT (cm / s) is the resulting lateral vector amplitude of the center of gravity (the length of the lateral deflection of the center of gravity during the period of measurement)

$$Xs(x) = \begin{Bmatrix} 0, & if\ x < 17{,}9141 \\ 1, & if\ x > 26{,}9694 \\ \frac{x-17{,}9141}{|x-26{,}9694|+(x-17{,}9141)} & if\ 17{,}9141 \le x \le 26{,}9694 \end{Bmatrix} \quad (10)$$

Membership functions for parameter Ant-Post (cm / s) is the vector amplitude of anteroposterior center of gravity (the length anteroposterior displacement during the measurement)

$$Ys(x) = \begin{Bmatrix} 0, & if\ x < 17{,}4213 \\ 1, & if\ x > 25{,}9679 \\ \frac{x-17{,}4213}{|x-25{,}9679|+(x-17{,}4213)} & if\ 17{,}4213 \le x \le 25{,}9679 \end{Bmatrix} \quad (11)$$

VII. Conclusion

The aim of this study was using fuzzy logic to implement experimental procedures testing failures equilibrium apparatus.

The work dealt specifically with the differential diagnosis of balance disorders, it is essential vestibular question.

Therefore clearly differentiate whether a patient is with balance disorders (peripheral, central) or healthy individuals without balance disorders.

Data utilized in this study were measured at posturography platform STP-03 at the University Hospital in Hradec Kralove and diagnosed by a doctor. This data was divided into three sets according diagnostic split to the group of patients without balance disorders, which were evaluated 50 patients, as well as the group of patients with peripheral vertigo, which were evaluated 85 patients and the group of patients with central disorder where were evaluated total of 82 patients. It was selected for several measuring elements for which the membership functions were created. Specifically, parameters W (path), A (area), X/s (length of lateral deviations) and Y/s (length of anterior deviations).

Of the 50 patients in the group of patients without balance disorders using the selected methodology, it was found that in 60% of them can clearly say that it is a normal patient, without balance disorders and in the remaining 40% of the results was inconclusive, as shown in Fig. 5.

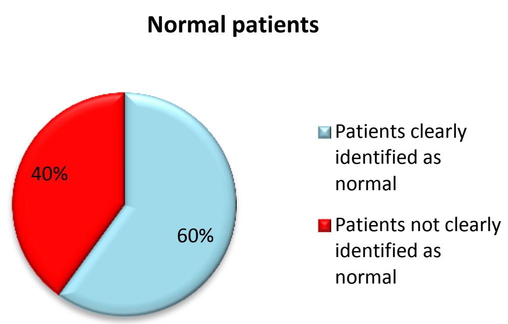

Fig. 5: Result evaluation of normal patients

Of the 85 patients in the group of patients with peripheral balance disorders using the selected methodology, it was found that in 78% can be clearly argued that these patients are with peripheral balance disorders and in the remaining 22% of the results was inconclusive, as shown in Fig. 6.

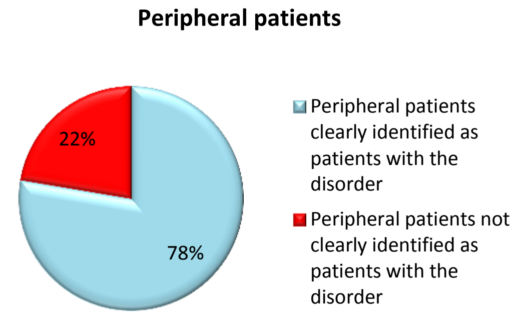

Fig. 6: Result evaluation of peripheral patients

Of the 82 patients in the group of patients with central balance disorders using the selected methodology, it was found that in 83% can be clearly argued that these patients are with central balance disorders and in the remaining 17% of the results was inconclusive, as shown in Fig. 7.

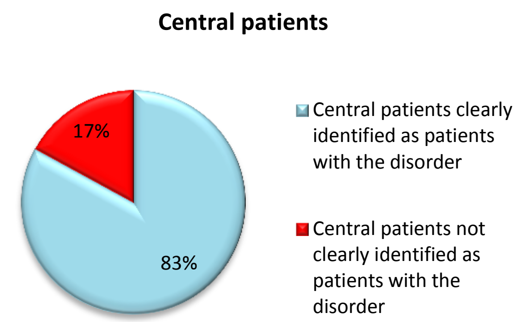

Fig. 7: Result evaluation of central patients

These results show that only 76% of the total numbers of patients corresponding to the diagnostic division a doctor. Due to the solved problem is such a poor result. The work was only possible to distinguish whether patients have impaired balance or not, but cannot be chosen methodology to distinguish patients with peripheral balance disorders in patients with central disorder. For a given problem would perhaps be better to choose another method such as neural networks.

VIII. Acknowledgements

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References

[1] Baloh RW, Jacobson KM, Beykirch K, Honrubia V. Static and dynamic posturography in patients with vestibular and cerebellar lesions, Arch Neurol, 1998,55, 649-654.
[2] Baron J. History of posturography, in: Vestibular and Visual Control on Posture and Locomotor Equilibrium, Ie, ed., KargerVerl, 1985, 54-59.
[3] Basta D, Clarke A, Ernst A, Todt I. Stance performance under different sensorimotor conditions in patients with post-traumatic otolith disorders, Journal of Vestibular Research, 2007,17, 25–31.

[4] Brandt T, Dieterich M, Strupp M. Vertigo and Dizziness: Common complaints. Springer, London, 2005.
[5] Cohen HS, Kimball KT. Usefulness of some current balance test for identifying individuals with disequilibrium due to vestibular impairments, J Vestib Res, 2008, 18, 295-311.
[6] Di Fabio RP. Sensitivity and specificity of platform posturography for identifying patients with vestibular dysfunction, Phys Ther, 1995, 75, 290-305.
[7] Di Fabio RP. Meta-analysis of the Sensitivity and Specificity of Platform Posturography, Arch Otolaryngol Head Neck Surg, 1996, 122, 150-156.
[8] Drsata J., Computer posturography in the diagnosis and rehabilitation of vertiginous states, Ph.D Thesis, Hradec Kralove, 2007
[9] "Fuzzy Logic". Stanford Encyclopedia of Philosophy. Stanford University. 2006-07-23. Retrieved 2008-09-30.
[10] Ghulyan V, Paolino M. Posturography for evaluating risk of falls in elderly unstable patients, French Oto-Rhino-Laryngology, 2005, 88, 97-103.
[11] KIYAK, E. and F. CALISKAN. Application of Fuzzy Logic in Aircraft Sensor Fault Diagnosis. INTERNATIONAL JOURNAL OF SYSTEMS APPLICATIONS, ENGINEERING & DEVELOPMENT, 2012. WSEAS Press, p. 317-324. Available from: http://naun.org/multimedia/UPress/saed/17-927.pdf
[12] NOVÁK, Vilém, Irina PERFILIEVA a Jiří MOČKOŘ. Mathematical principles of fuzzy logic. Boston: Kluwer Academic, c1999, xiii, 320 p. ISBN 07-923-8595-0.
[13] VALIŠ, Martin, Jakub DRŠATA, David KALFEŘT, Pavel SEMERÁK a Jan KREMLÁČEK. Computerised static posturography in neurology. Central European Journal of Medicine. 2012, vol. 7, issue 3, s. 317-322. DOI: 10.2478/s11536-011-0152-8. Available from: http://www.springerlink.com/index/10.2478/s11536-011-0152-8
[14] National Institute on Deafness and Other Communication Disorders (NIDCD). <i>Balance Disorders</i> [online]. 2010 [cit. 2013-09-12]. Available from: https://www.nidcd.nih.gov/health/balance/pages/balance_disorders.aspx
[15] PIVNICKOVA, Lucie, Viliam DOLINAY and Vladimir VASEK. Multilayer neural network in differential diagnosis of balance disorders. Proceedings of the 16th WSEAS International Conference on Systems, Kos Island, Greece, July 14-17, 2012. WSEAS Press, p. 356-361. Available from: http://www.wseas.us/e-library/conferences/2012/Kos/CIRSYS/CIRSYS-60.pdf
[16] PIVNICKOVA, L.[75], VASEK, V.[15], DOLINAY, V.[10]: Algorithms in the examination of the postural stability. In 13th WSEAS International Conference on Automatic Control, Modelling & Simulation (ACMOS' 11). Lanzarote, Canary Islands, Spain, May 27-29, 2011: WSEAS Press, 2011. s. 374-376. ISBN 978-1-61804-004-6.
[17] STANFORD ENCYCLOPEDIA OF PHILOSOPHY. Fuzzy Logic [online]. 2010 [cit. 2013-09-12]. Available from: http://plato.stanford.edu/entries/logic-fuzzy/
[18] Zadeh, L.A. (1965). "Fuzzy sets", Information and Control 8 (3): 338–353.
[19] DOLINAY, J., DOLINAY V., DOSTÁLEK P. and VASEK V. Tilt-measuring device for Posturography. 4th International Conference on Bioscience and Bioinformatics (ICBB '13) In: Chania, Crete Island, Greece: WSEAS Press, 2013, p. 3. ISBN 978-960-474-326-1.
[20] PIVNICKOVA, L., DOLINAY V. and VASEK V. Application of fuzzy logic in the evaluation of postural stability. 4th International Conference on Bioscience and Bioinformatics (ICBB '13) In: Chania, Crete Island, Greece: WSEAS Press, 2013, p. 5. ISBN 978-960-474-326-1.