SLOVENSKÁ TECHNICKÁ
UNIVERZITA V BRATISLAVE
FAKULTA ELEKTROTECHNIKY
A INFORMATIKY

Ing. AndreasWeisze

Autoreferát dizertačnej práce

NEW METHODS OF IMPEDANCE ANALYSIS OF ACTIVE POINTS ON HUMAN SKIN

NOVÉ METÓDY IMPEDANČNEJ ANALÝZY AKTÍVNYCH BODOV NA ĽUDSKEJ KOŽI

na získanie akademickej hodnosti doktor (philosophiae, PhD.)

v doktorandskom študijnom programe: **Mikroelektronika**

v študijnom odbore **5.2.13 Elektronika**

Miesto a dátum:Bratislava, júl 2017

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ABSTRACT

Key words: active points, human skin, detection reliability, picture dynamic

The detection reliability and the precision are mandatory requirements and significant factors of the therapeutic measures being based on the acupuncture approach. Biocompatibility is just as important as the local recognition precisision. The pneumatic principle provides not only a primion degree of skin tolerance but an excellent behavior in recognition of any kind of diagnostic points. The repeatability and absence of feedback as well as the adaptability to different skin shapes define a new class of detection equipment.

Referencing the already established sensor platform the new quality of three generations of pneumatic heads was investigated concerning the advantages of application and the factors influencing the process and results of diagnostic points' recognition.

ABSTRAKT

Kľúčové slová: aktívne body, ľudská pokožka, spoľahlivosť detekcie, rozpoznávanie diagnostických bodov, dynamika zobrazovania

Tradičná čínska medicína je doplnkom konvenčnej medicíny v tom, že k nej pridáva prvky jedinečného holistického systému telesnej energie.Tieto doplnkové liečebné metódy pomáhajú skúseným odborníkom dosiahnuť utlmenie chronických bolestí alebo akútne bolestivých stavov. Základnou technikou stimulácie špecifických bodov, ktoré ležia na meridiánoch energie, ktoré prechádzajú ľudským telom, je ihlovanie.

Spoľahlivosť detekcie a precíznosť sú povinným požiadavkom a významným faktorom terapeutických postupov založených na akupunktúre. Spoľahlivé rozpoznanie zodpovedajúcich bodov na pokožke je podmienené vysokým stupňom vedomostí a súčasne žaduje aj veľké skúsenosti. Pre návrh dizajnu senzorov, ktoré majú viac ako jeden testovací hrot, je biokompatibilita rovnako dôležitá ako precíznosť a spoľahlivosť lokálneho rozpoznávania. Princíp, ktorý používa pneumatický pohon, poskytuje nielen vynikajúci stupeň tolerancie vzhľadom k pokožke, ale umožňuje aj dosahovať vynikajúce výsledky pri rozpoznávaní diagnostických bodov každého druhu. Opakovateľnosť a nejestvujúce spätné väzby spolu s prispôsobivosťou na rôzne formy pokožky definujú požiadavky na novú skupinu detekčných prístrojov, ktoré musia dosiahnuť vyššiu kvalitu než zavedené riešenia prístrojov vybavených pružinovou hlavou.

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1. Introduction

This thesis presents new investigations concerning the detection of active points on human skin. The disadvantages of the existing test head solution should be removed by a redesign improving the detection reliability on one hand while keeping a sufficient degree of biocompatibility – avoidance of skin irritation - on the other hand. The relevant qualities of test the head application are considered as well as the consequences of this sophisticated design on the detection reliability, precision, and picture dynamic.

The work covers the development of a new test probe on a pneumatic base to investigate active points on human skin in a more sophisticated way. For comparison reasons the standard spring head already used in the laboratory has been improved. The disadvantages under simple mechanical force application by springs were intended to get removed. On one hand the force variations between the tips could be reduced and on the other hand a flexible surface adaptation according to the appropriate acupoint environment was aimed. A significant improvement of skin compatibility is achieved, too.
Summarizing the investigation details the following aspects are intended:

- Detection reliability,
- Head comparison consideration,
- Picture dynamic under force deviation reduction pre-condition

1.1. Medical aspects

All over the world many people are suffering chronically pains being not a sign of immediate illness. Their treatment is an extremely complex matter and the traditional medicine is often limited to give simple tranquilizers for symptom attenuation. That’s why doctors often try to go new paths of therapy. And especially acupunctural applications are widely used nowadays [1]. It is one of the established methods of pain therapy.Appropriately, [2] points out that Acupuncture is frequently used for pain patientswhile hundredsof clinical trials testing its clinical effectiveness for pain-relatedsyndromes are available. According to Cabyoglu, Ergene, and Tan [3]acupuncture is nowadays a method of preference in most of the pain clinics.

Acupuncture is part of the Traditional Chinese Medicine beside the pharmaco-therapy, the nutrition therapy, the Qigong, and so on. The Traditional Chinese Medicine tries to keep or to reactivate the flowing of “Qi”, a kind of energy of life [1]. “The term “Acupuncture” consists of two words from the Latin:acus: needleandpuncture: insertion”[1]. Acupuncture is a method used to improve the body’s performance and functioning through natural healing [7]. E. Ernst defines the Acupuncture “as the practice ofinserting one or more needles into specific sites onthe body surface for therapeutic purposes. Acupuncture points can also be ‘stimulated’ withheat, electrical currents, pressure, laser light or shock waves.” [4].

The National Center for Complementary and Alternative Medicine (NCCAM) describes the term “acupuncture”as “a family of procedures involving the stimulation of anatomical points on the body using a variety of techniques”[6]. In this sense the acupuncture belongs to the complementary medicine covering “a diagnosis, treatment and /or prevention which completes mainstream medicine by contributing to a common whole, by satisfying a demand not met by orthodoxy or by diversifying the conceptual frameworks of medicine”.

The beginning of the professional electrical acupuncture can be considered as the year 1953 when Voll did develop the toolset for his measurements [5]. He defined not only the electrical frame of investigation but classified the methods of skin interface and methods of application, too.

1.2. Frame of investigation

The basic factor of alternative medical treatment is the exact location of the appropriate diagnostic point(s). The environmental conditions were aformentioned already. This chapter aims to define the relevant factors to be considered.It is assumed that temperature and humidity are in a comparable range during each and over all test sessions and the electromagnetic disturbances can be avoided by the appropriate distance between the proband and their sources.Obviously the pressure driven test tips will improve the biocompatibility concerning skin irritations and the risk of injury by any mechanical overload.For further investigation the

- Comparison between the spring and the pneumatic test head,

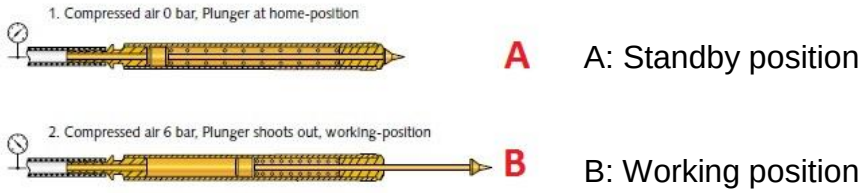
- Behaviour concerning skin preconditioning (earthing or offset),
- Material choice,
- Kind of proximity (vertical, tangential)

are taken into account.

2. Aims of the Dissertation Thesis

2.1. Sophisticated pneumatic headdesign

It is obvious that the ideal application would require reliable connectivity independent from pressure and independent from the distance between head and skin surface. In this sense the existing system of sensors basing on 64 test probes could probably be improved by active controlling of forces being made on the surface (**Figure 1**).



Source: Ingun Test Probes Catalog2013-14

Figure 1: Pneumatic test probes in both operational stages

Since the pressure within a gas is everywhere constant an active probe controlling shall be established for applying nearly unique forces on every needle and to compensate the different distances for any skin surfaces as far as possible. Although the applied air pressure works again each spring force with dependence on the elongation, too, the influence is weaker since the return spring force of the pneumatic tips are significantly lower than the forward forces of the spring tips are.
Mechanical influences by the sensor shall get minimized while keeping the electrical contact.

2.2. Investigation framework

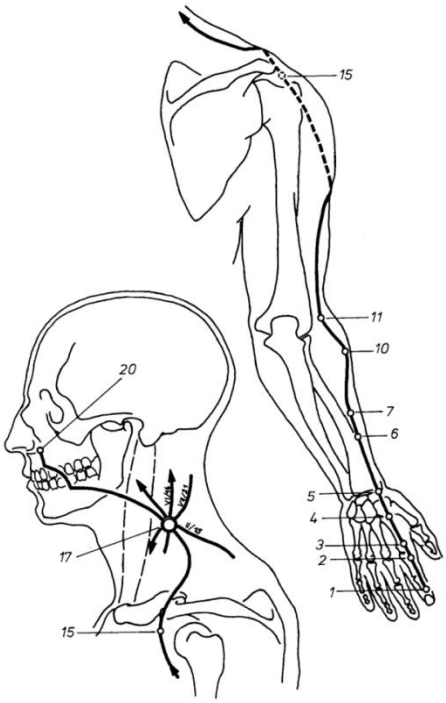


Figure 2: Li Meridian [5]

The meridian chosen primarily has been the Large Intestine LI, depicted from [5], later additionally the Meridians touching the hand's area.

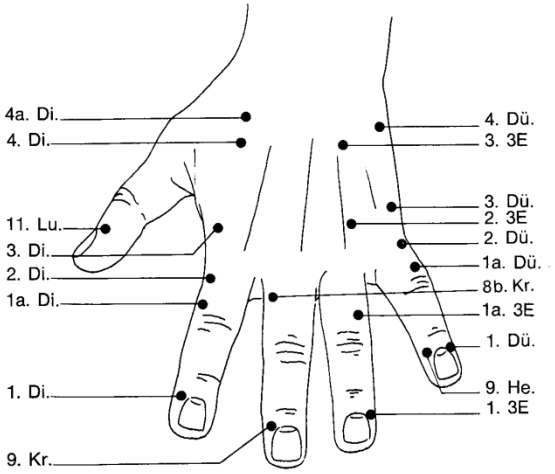


Figure 3: Hand's diagnostic points[5]

2.2.1. Methodology

The results are readed by MathLAB R2012a for the general optical impression. To drive the analysis the grabbed values are exported into EXCEL® to perform the calculations.

2.2.2. Depth of investigation

According to the aims of sequence and considering the requirements of result density two basic workflows are applied. For the detection of diagnostic points sequences doubling the test frequency (factor 2 based) have been used. One one hand the detailed frequency behavior does not play any role at this stage, on the other hand, the necessary sequence time is limited to a proband's acceptable value. Detailed sequences increasing the test frequency between 1.000 Hz and 16.000 Hz in steps of 1 kHz show the precise characteristic of test head.

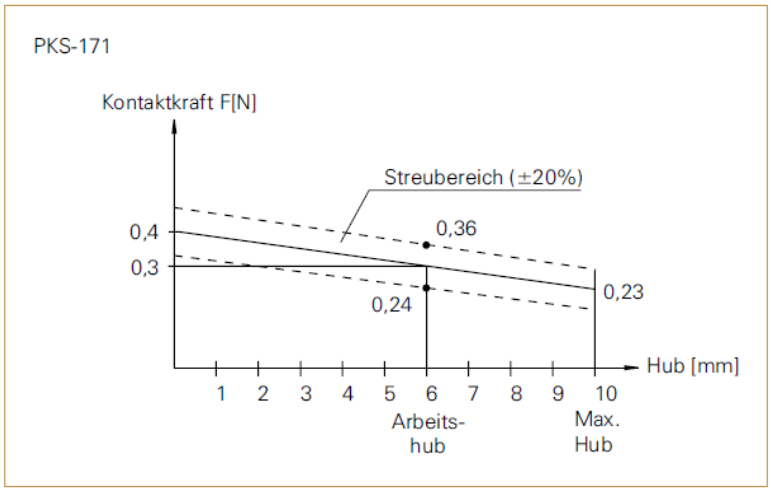
The mechanical probe placement has been investigated concerning optimization potentials. These points range from the kind of placement, the precision of placement, the pressure value control, and the different pressure levels of the single probes to the – unintended or intended – stimulation of the test probe area.

2.2.2.1. Pressure value control

The pneumatic moves of probes are determined by the compressors' input reduced by the spring constant of test probes. The variation of input pressure should influence the reliability and electrical connection quality.

2.2.2.2. Probe pressure

Since the pressure is equal within the pneumatic system all the probes get the same pressure, each. This is the case as far as the spring constant does not deviate significantly in the moving range. As close the elongations among the probes are the forces deviation will lower. And vice versa, as higher the level deviations are as the pressure difference of probes increase.



The ideal working range is set by the probe's specification around 6 bars.

Source: Ingun Test Probes Catalog2013-14

Figure 4: Pneumatic test probes in both operational stages

In the contrary to the standard spring probe a decreasing contact force is recognizable. Under these circumstances the spring returns the probe to its standby position, only. The contact forces are caused by the air pressure working against the spring forces in operation. The higher the stroke the higher the spring forces reducing the pneumatically caused elongation.

2.3. Model of detection and measurement process

The detection and measurement process is covering three layers influencing the results in a significant manner: electrodes placed on the skin surface, the boundary layer between electrode and epidermis, and the human skin and body structures.

2.3.1. Electrode's quality

For the consideration of the material behavior the boundary conditions between electrodes and skin have been focused on.

2.3.2. Boundary discussion

In the boundary area a reliable contact between sensor surface and skin epidermis shall be established. Obviously two criteria determine the immediate conductivity there, the electrodes' shape and diameter on one hand and the electrochemical behavior on the other.

2.4. Draft and research of pneumatic probe

Significant stages of head construction influenced the heads' behavior in a wide manner.

The basic head did not fulfill the necessary requirements of reliability and repeatability for a sufficient number of investigation sequences. Appropriate carrying layers were added keeping the electrodes' head shape. A block of boards allows forms a solid pattern of test tips. This standard test head has been defined as the reference for the laboratory sequences.

The heavy mechanical load to the skin connected with a significant limitation of led to the next generation of head applying the pneumatic principle of electrode traction. A new quality not only in the biocompatibility sense, but primarily for the characteristic of data collection.

Several stages are mentioned here only, from the beginning without any receptacles to save space to the usage of receptacles fot tip changing possibility with a higher degree of gas losses requiring a more performant compression unit.

3. Research Method

The laboratory investigations followed the aforementioned basics aiming to achieve a systematic and integrative consideration of the sophisticated pneumatic principle on the detection and observation of active points like traditional acupoints and further diagnostic points.Reduced impedances of active points and diagnostic points shall be shown relyable and repeatable.Summarizing and simplifying the immediate influencing factors an overview can be created as follows.

It is obvious, that increased contact forces and reduced cross sectionc will improve the detection reliability basically as long as the tissue integrity is not impaired by them.Both criteria reduce the dynamic of recognition by the compression of cell structures and intercellular space as a whole.

The preparation works lead to a framworke of laboratory investigations covering the discussed matters focusing on a comparison of mechanic (spring) and pneumatic head and the prove of the new quality of test probe on pneumatic base.

3.1. Basic design of laboratory investigations

For the primary considerations careful analysis of literature sources have been done. The provisional stage of laboratory works supported these investigations. By definition of more precise investigation borders the final stage was formed according to the external degrees of freedom.

3.2. External and internal factors

The limitation of available tip diameters restricts the immediate comparison between both applications. On on hand the mechanical load of a smaller spring tip is significant, on the other hand, a larger diameter of pneumatic tip is not possible because of the screwing tool for the pneumatic assembly.

Finally, two significant stages of investigation were covered over the measurement sequences. The first stage focused on the “free hand” placement of test heads. Already under this stage “Provisional investigations” a high degree of active point detection reliability has been achieved.For a better repeatability and a serious

scientific consideration a solution for the fixation of the research object had to be found. Additionally a special focus on suited tissues has been laid.

3.3. Provisional investigations

3.3.1. Behavior of the pneumatic head under placement consideration

Under consideration of the skin irritation degree the pneumatic head behavior has been verified with variable air pressure.

3.3.2. Li4 series

Initially a free comparison of the standard spring head and the pneumatic test head were done.The measurements have been done in series of repeated sequences without any removal of test head.

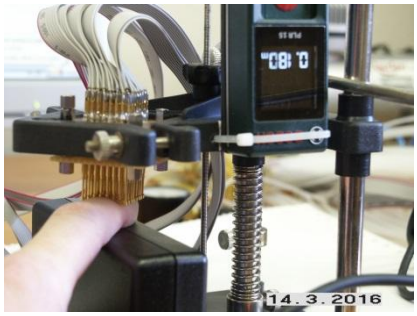
3.3.3. Li1 to Li5 mapping

The mapping series showed a sufficient correlation of diagnostic points to be expected and their measurements.

3.4. Final investigations on a fixing unit base

The fixation unit allows to create an investigation framework to observe the pressure and frequency dependance as well as the intra-day volatility. The mapping observation is covered by more objective considerations concerning the behavior of tissues under the influence of the both kinds of electrodes respectively the both kinds of head. For that purpose the fixation unit got a srewing unit to control and a distance meter to monitor the head's elongation.The elongation can be changed on a half a millimeter base to achieve an appropriate resolution of x-axis. By both means a significant adaptation to the skin surface and a high degree of repeatability have been achieved (the intra-

Figure 5: Fixation unit



day volatility is an exception in this context since an appropriate day coverage could not be built.To cover all necessary details two measurement qualities were defined. A “measurement cycle” with the complete frequency range between 1.000Hz and 16.000 Hz in steps of 1 kHz and a second “detection cycle” with repeated doubling of test frequency in the aforementioned frequency range expecting no significant influence to the detection reliability or in cases of long time measurement to avoid any deafness of finger and hand.

The observation frame was covering three steps:

- Comparison of mechanical and pneumatic principle depending on both the elongation and the frequency at the Li1 location.
- Comparison of mechanical and pneumatic principle while mapping the Li1 to Li3 area under frequency variation. Here a reduction of observation area has been done because of the tissue solidness.
- Intra-day mapping in finger’s area.

3.4.1. Frequency variation

For the verification of optimal frequency range the complete frequency range between 1.000Hz and 16.000 Hz in steps of 1 kHz was covered by the test sequences. Since the tissues are characterized by the capacities formed by the several tissue layers the conductivity over all rises with the applied frequencies. The relation between the single tip conductivity values does not change at all.

3.4.2. Elongation comparison

The elongation comparison aimed on showing the extended characteristic criteria.

The general behavior is characterized by a similar range of detection respectively recognition. It leads from the first contact (first row) as starting point of working elongation through the working area to the final elongation stage.

Both sequences have a recognizable change in the over all conductivity following the test probes' elongation. Obviously the mechanical solution has a clear dependence of recognition while covering the working area, additionally.

In the contrary the pneumatic solution shows a convincing behavior concerning the detection of acupoints and diagnostic points while the spring method appears to suffer on the heavy mechanical load driven on the skin with the applied diameter of 1.5 mm.

Both have an entrance condition with only partly contact of tips. Under the influence of the increasing mechanical force the basically capacitive quality of skin leads to a general increase of conductivity associated with less dynamic of readed pictures.

The pneumatic head behaves independent from the elongation since the forces exposing the skin are almost equal trough the operational range.

Obviously the difference of the highest and lowest tip result is influenced by the mechanical impact to the tissue. Appropriately the pneumatic head is more flexible and smoother in its application and shows a better point recognition

Since the main difference between both solutions is given by the acupoints' and diagnostic points' detection quality the further considerations deepens this point of view by covering the whole LI1 to LI3 (Beginning of Large Intestine Meridian).

3.4.3. Frequency and elongation summarization

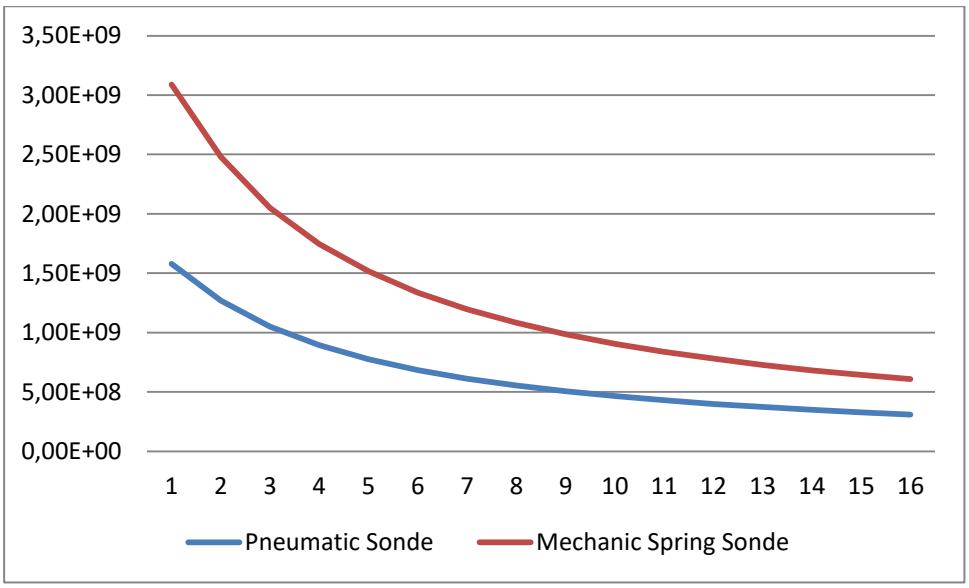
The dependences from frequency and elongation were summarized in a set of complete sequences showing the over all behavior of the pneumatic principle. It is obvious that from the beginning of the working characteristic the recognition repeatability and precision is excellent. Both repeatability and precision are independent from frequency variation, single tip diameter, and – within the working range – from the elongation of tips. Consequently a substantially smaller influence of the pneumatic test principle can be reported.

3.4.4. Li1 to Li3 mapping under operational stroke

The detection pattern of the mechanical head depends clearly on the frequeny used. This effect does not so strongly appear while applying the pneumatic electrodes. It is

obvious that the mechanical load of mechanical spring head changes the tissue distances and widths with appropriately a higher capacity and conductivity consequently.

Impedancy



Frequency in kHz

Surprisingly the conductivity over all, that means the addition of all the electrodes is not different comparing the mechanical and the pneumatical head. The diameter of the single electrodes proves to be the primary parameter.

3.4.5. Li1 to Li3 mapping under intra day consideration

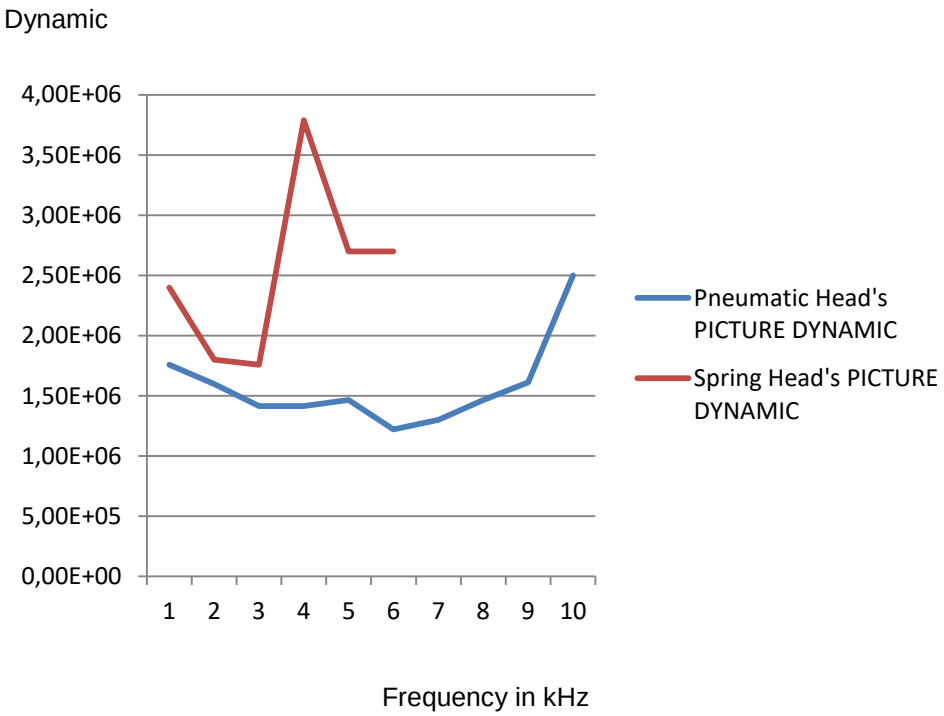
All these technical considerations are imbedded into an intra day volatility observation in the stages Morning/Noon/ Evening.

3.4.6. Finger area mapping under operational stroke

Assuming solid tissues as to be found in all the finger's areas have a good correlation between the acupoints'and diagnostic points' forecast and the measurement results respectively the recognition precision can be stated for the pneumatic principle. The detection reliability does not suffer from any intra day volatility of skin or body conductivity. The deviations appear to be caused by small differences on head placement between the day times.

4. Results and Discussion of the study

The dynamic of the pneumatic and the spring head (measured at 4.000 Hz) is given in the following figure.



The x-axis shows the elongation of both heads an the belonging dynamic within the picture of 64 tips.

The pneumatic dynamic curve shows a widely (between elongations of 1mm to 8 mm) constant value of dynamic (accepting an ordinate's range of 33 %). The mechanical spring head's behavior significantly more volatile and practically no range of similar or equal value.

Obviously the difference of the highest and lowest tip result is influenced by the mechanical impact to the tissue. Appropriately the pneumatic head is more flexible and smoother in its application and shows a better point recognition

Since the main difference between both solutions is given by the acupoints' and diagnostic points' detection quality the further considerations deepens this point of view by covering the whole LI1 to LI3 (Beginning of Large Intestine Meridian).

5. Summary of Results and Future Orientations

5.1.1. Results and benefits of the work - the method and realizations

A) A confirmation of voltage/impedance method for active point recognition, as the impedance minimum or the conductivity maximum on the active point area.

The issue of the voltage or impedance skin mapping, the issue of the image representation of the acupuncture points and the measurement of their properties was the investigation topic for many authors in the past. But it was not the main flow of the world research and therefore even nowadays there is a significant area for the basic research.

Various investigations confirmed the suitability of impedance method for the detection of active points. This principle is using a dedicated feature of the active points – the minimums of impedance respectively the maximums of conductivity of these skin areas.

The one of the crucial publications in this research area is the paper describing a research and measurements of American professor Robert O. BECKER and his team from Upstate Medical Centre in Syracuse, in USA, published in magazine "Psychoenergetic Systems" in 1976 yet [9].

Authors performed and described measurements by multielectrode probe (Fig. 78.), realized by a set of electrodes sequenced and fixed in holder, placed in matrix (similarly like in our measurements). LI meridian was chosen for measurements, because of the position of its active points and accessibility for the measurement.

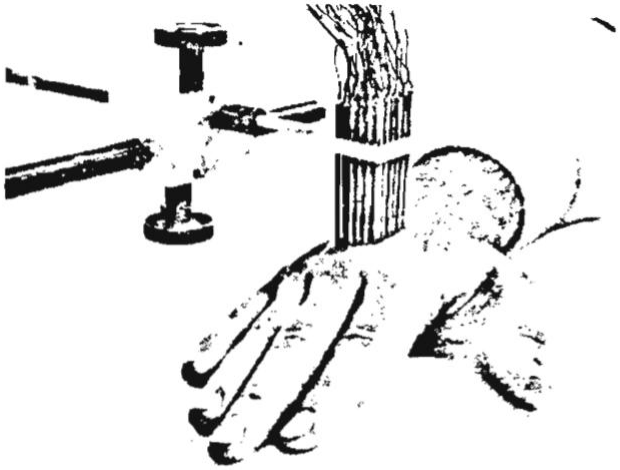


Fig.6: The shape and holding mechanism of the probe, electrodes over the acupuncture point LI4 [9].

Authors measured and displayed measured conductance charts of acupuncture points. They describe the maps of acupoints T4 and LI4 on chosen meridians in the paper. We show as a sample a measured map of LI4 acupoints that significantly correlates with previous research results of colleagues from the Biomechatronic laboratory, FEI SUT in Bratislava, the paper „Automatized Multi-electrode Voltage Map Measurement of Active Points on Skin“ from „COMMUNICATIONS 01/2011" journal [14].

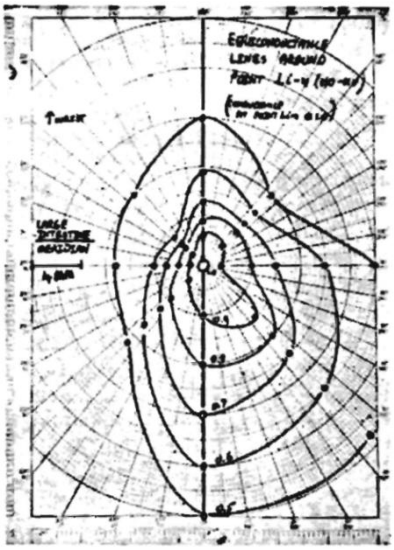


Fig.7: The shape and structure of acupoint LI4, conductance plots around [9].

Examples of probe discovering meridian and single detection are depicted from [9].

BECKER et al. also used a probe integrating a two part teflon body with a stainless steel wheel to achieve constants pressure and no drag between detector and skin surface. That allowed to scan about 50 cm of a meridian rapidly (Fig. 8).

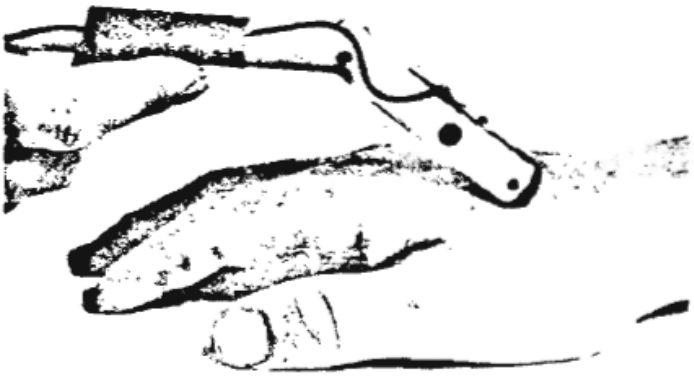


Fig. 8: Meridian scanning probe used in[9]

For recording the conductance field around single acupuncture points the authors made the measurements with a grid of 6 x 6 stainless steel electrodes mechanically touching the skin (Fig. 9).

Fig. 9: Multipoint probe used in [9]

The DC voltage source was a Wheatstone bridge which output has been directly displayed on a strip chart record respectively registered on the chart and later translated back into the original grid pattern.

B) A confirmation of usage and perspective of the matrix point mapping method for the shape of acupuncture point structure description and measurement. The matrix point mapping method uses the multipoint probe in [9] displayed concentric circles around the Li4 point (Fig. 10).

The lobe of the recorded conductance followed the change of meridian's direction, T4 point (Fig. 11). The authors suggested the presence of discrete structures at the center of the plot. As already mentioned before, the issue is more difficult and complex and the causality for presence of the voltage/impedance minimum, in spite of the following years of research of many authors is interpreted in various theories yet.Multiple measurements performed by our system also confirmed these investigations. Here we offer for comparison the following chart on active point surface achieved by measuring device (Fig**.12**), the dark blue color represents the center of an active point, the pale blue color its a narrower border and boundary yellow color is its contour [103]. Measured position is LI4 (mentioned above).

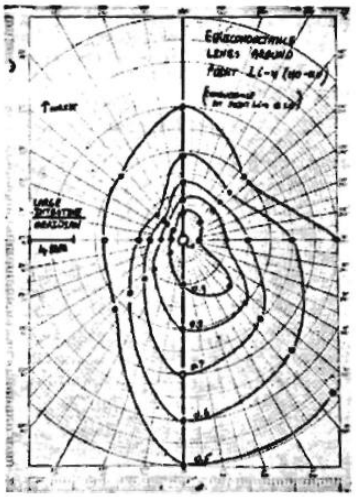


Fig. 10: Conductance field plot (Li4) [9]

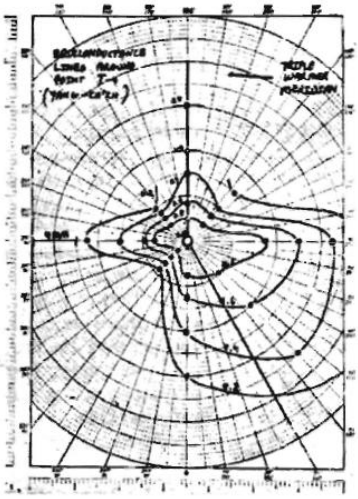


Fig. 11: Conductance field plot (T4)[9]

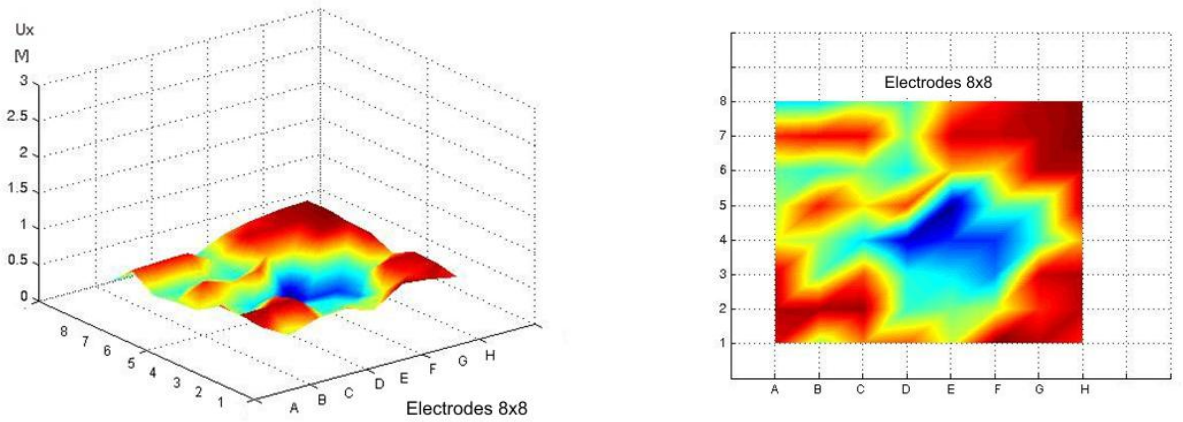


Fig.12: Voltage chart measured on position of active point No.4 on Li meridian in 3D visualization and 2D visualization.

Professor Becker et al. describes the measurement of the conductivity values in points 2, 4, 5 and 7 of Li-meridian and on points 3, 4, 7 and 8 of P-meridian (Fig.13). They obtained interesting results of higher conductivity on acupuncture points of measured meridians. The reproducibility of measured results was also confirmed.

Fig.13: Conductivity scans of meridians [9].

German researchers led by Sybille Kramer published their results in publication „Changes in Electrical Skin Resistance at Gallbladder 34" in „Journal of Acupuncture and Meridian Studies" in 2008 [10]. They have performed measurements on chosen acupoint GB34. Their own designed and realized flexible sensor created from the isolative foil and regularly placed steel electrodes in 8 x 8 area. The complex dimension of that realized sensor was 6 x 6 cm ([10]).

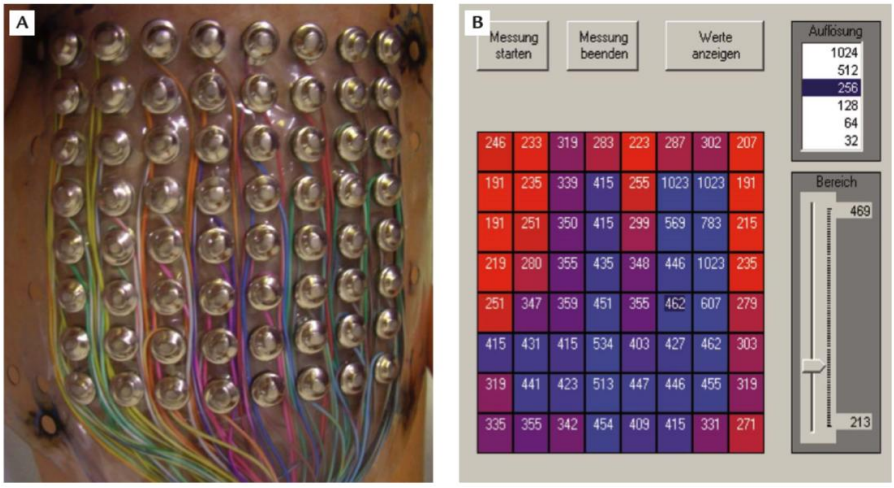


Fig.14: Array of 64 steel touching electrodes on plastic foil (A) and detail of analytic software with numeric and colour output (B), from paper [10].

A measured conductance map is displayed as follows, in colour 3D map, see Fig.15, or in form of 2D contour map, see **Chyba! Nenalezen zdroj odkazů.**.

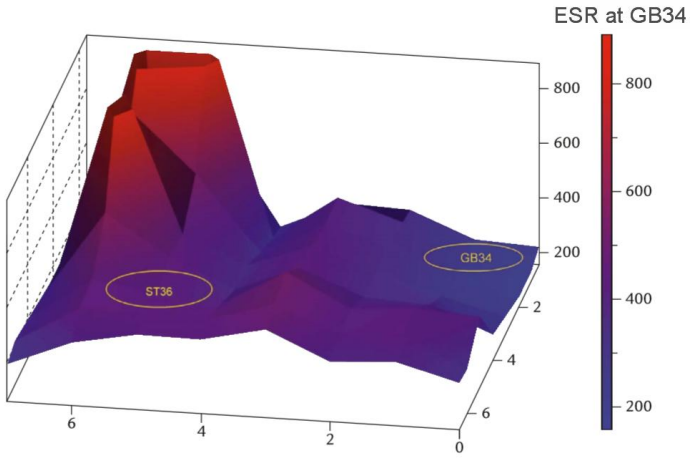


Fig.15:Colour graphical interpretation of conductance values measured by sensor, marked active points GB34 and ST36, in [10].

The authors performed measurement by DC driving current of amplitude 20 μA, voltage 4.8 V, period of measurement about 30 seconds. Measuring device was galvanically separated from the mains. Our system achieved from the beginning better parameters of measurement and apparatus than system from authors [10].

C) An improvement of the used mapping method.

Improvement of mapping method comes from using more sensitive designed and enhanced probe – measuring mapping head – both of them, mechanical mapping head with spring driven matrix electrodes and also enhanced pneumatic mapping head with regulated air pressure driven matrix electrodes.

Our experimental measurements were realized by voltage to 5 V, similarly as in work of previously mentioned authors, but we have used an AC driving electrical signal with adjustable frequency. We have included an influence of parameter of increased capacity of the parts of skin corresponding to acupuncture point, into our results. That acupoint has expressed itself via a lower sensed voltage drop on a lowered impedance of part of the skin. Using lower harmonic measuring current (f=1kHz, an amplitude about 1 μA) in the measurement there is minimized unwanted electrical influence on measured object [15].

Also the construction and dimensions of the probe are different. Our mapping head has more precious resolution of sensing square, in compare with sensor of mentioned authors. Our sensor has dimension of touching square only 2,5 x 2,5 cm, but the dimension of their probe is larger: 6 x 6 cm. Comparing the touching square our mapping head, while maintaining the same number of electrodes (8x8), our sensing probe has almost 6-times smaller square resp. 6-times higher resolution of measured structures of the skin [15]. From the point of view of measurement accuracy and the increasing of the measuring system resolution would be perspective to achieve a higher density of sensing electrodes, eventually the higher number of sensing electrodes.

In general, comparing method and measured maps from various authors, e.g. [9] and [10]with measured maps from our mechanical and pneumatic measuring probe, we can assume that more precious measurement was obtained by our measuring heads – higher density of measuring matrix electrodes of our probes (heads), better contact with skin and possibility to measure smaller acupoints than in [9], with a better access and measurement control than in [10].

D) Non invasive and ecological measurement with minimal impact on the human organism

Using lower harmonic measuring current (f=1kHz, an amplitude about 1 μA, far below the sensitivity threshold) during the measurement there is not unwanted electrical stimulation of body and minimized electrical disturbance of measured object. A measuring electric current is significantly lower than in previously mentioned measurements of [9], offering even the more precious and structured measured results.

Since a DC measuring current is influenced on one hand by the electrical potential of cells and tissue structures and on the other hand by the measuring current itself, then AC was used to eliminate unwanted potentials. The small amplitudes of AC current avoid any electrical stimulation of skin and body structures. The appropriate calibration matters were discussed in [10]. The basic mechanical test probe's construction, calibration, and application matters are described in [12].

E) Enhancement of acupoint measurement and accessibility of them using new designed pneumatic measuring matrix mapping head

Enhancement is also in the comfort and not disturbing measurement with electrodes of the pneumatic head gently touching the finger surface and pressing on it by the same pressure, expands the area of measurements and skin mapping with matrix probe method into previously inaccessible areas of human skin surface.

Performing a mapping skin measurement on the lateral side of hand finger, looking at Fig.16, it is noticeable that the side electrodes of the mechanical probe are pressed in less than the rows of central electrodes which are pressed in more deeply and the springs inside them have been pressing the tips of these selected electrodes on the skin by the higher force than the side electrodes. That fact causes non-equal measuring conditions on the examined part of skin. The higher mechanical force of the central electrodes induces skin irritation and higher perspiration and that temporarily changes the quality of the electrical contact for the measuring electrodes, causes lower measured voltages on certain electrodes, falsely showing the lower impedance of that part of skin.

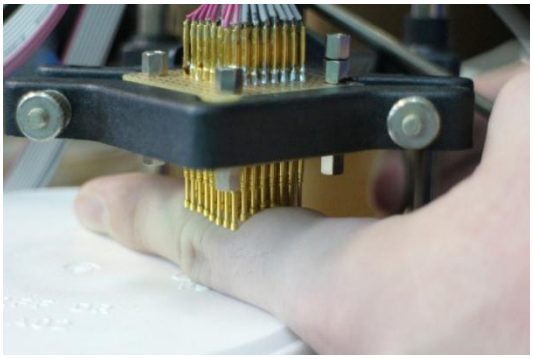


Fig.16: Measurement on uneven surface – mechanical probe

In addition, from acupuncture point of view, undesired mechanical pressure unwillingly stimulates active points on skin in spite of the diagnostic measurement of the important electrical properties of them. They have been influenced and changed then. The impact of that mentioned undesired mechanical influence on the measured object is noticeable [14].

But in the pneumatic construction the tips of all the electrodes have been pressing on the skin by the same lower and comfortable force. Because of that an equal measuring conditions for whole the probe are established.

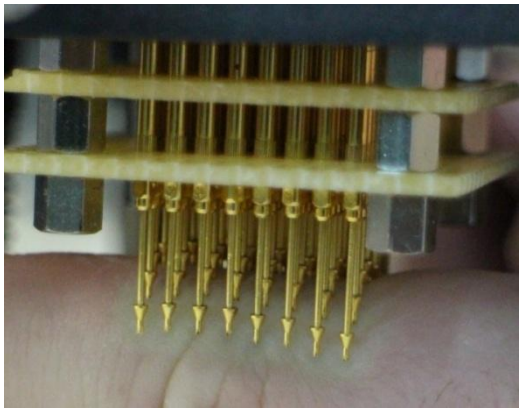


Fig.17: Measurement on uneven surface, electrodes-skin touching detail – pneumatic probe

Constant air pressure in the pneumatic system pressing on pistons of all the electrodes causes the same and lower force pressing on the skin under the electrodes, therefore skin irritation, perspiration and temporary change of quality of electrical contact for all measuring electrodes are the same, see Fig.17. All the

electrodes in the pneumatic probe system have the same measuring conditions and have been measuring only the electrical differences on skin induced by the skin structure and an active point presence [14].
In general, for the application of the spring test probe and the pneumatic probethe test conditions are summarized as follows:

- Manual application
- Choice of a solid skin area (Li2)

The forces of application the probe were chosen subjectively, but documents clearly the influence on the measurement process. Primarily the connection does not cover the whole pattern of the probe showing the typical characteristic of a detected active point. By a gentle force increase the probe get complete picture of conductance but the recognition probability decreases clearly. Under the application of strong forces the conductance field loses the details and presents a kind of overall conductivity. The basic behavior of the pneumatic head is similar from the first contact until the wide elongation.

F) Influence of the driving pressure on measurement and the dynamic map recognition using a pneumatic measuring matrix mapping head.

In the frame of this work several series of measurements were done aiming to document the excellent recognition behavior by the slighter characteristics of the pneumatically driven probe.

Probe type comparison summary

Spring probe Pneumatic probe

Technical parameter consideration

Frequency behavior between 1.000 to 10.000 Hz, resp. 16.000 Hz

Both mechanically driven and pneumatic probe shows a widely frequency independent behavior within the mentioned range.

Elongation behavior = operational working range

The enhanced operation of the pneumatic head is obvious and given by its typical length.

The conductivity plot mirrors the limited operational range of the head and the biocompatibility view caused by the linearly increasing forces applied to the tissue layers.

In the pneumatic application the forces by the air compression work against the backdiving spring forces making the characteristic slower and the impact smaller within the complete working range.

Application recognition consideration

The factors mentioned above cause an excellent recognition behavior in the pneumatic probe's application.

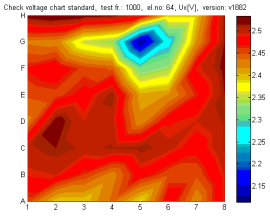


Fig. 18: Conductance field plot (Li1), spring driven probe

The recognition degree applied at the same place Li1 at 1 kHz and operational pressure is significantly more detailed (Fig. 19). The over all conductance is lower by less impact to the tissue structures. The recognition degree of pneumatic probe is convincing. The relation between successful recognition and done tries follows the increasing pressure applied on the probe's tips until it deceases again until the common conductivity prevails by the skin compression. The optimum of pressure provides a recognition quote of nearly 100 percent (Tab. 17) in repeated measurements.

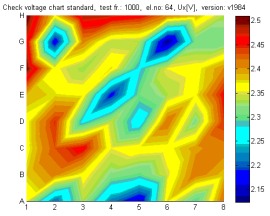


Fig. 19: Conductance field plot (Li1), pneumatic probe, operational pressure

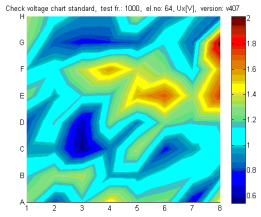


Fig. 20: Conductance field plot (Li4), pneumatic probe

As well the single point measurements (Tab. 18) on the left as the Li1 to Li5 sequences (Tab. 19) on the right have an excellent precision and repeatability. A special consideration focused on the intra-day

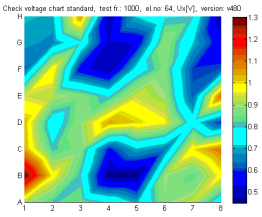


Fig. 21: Conductance field plots (Li1), pneumatic probe,

optimized pressure characteristic. On pneumatic measurement base it can be **optimized pressure** neglected since there is no significant influence to the recognition behavior under changed day time probably caused by the practically not appearing impact to the skin tissues. In other words, the pneumatic probe shortens the skin recovery time into a neglectable factor.

G) Practical confirmation of the existence and the location of different active points (acupoints), their shape and arrangement in specific "meridian" pathways.

Under laboratory conditions a significant recognition degree of traditional acupoints and the further diagnostic points could get confirmed. As an example the index finger's Li1 to Li3 area is shown in the right column. Each of the diagnostic points is recognizable precise, their locations are documented where they were expected theoretically.

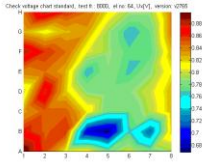


Fig. 22: Li1 to Li3 (1)

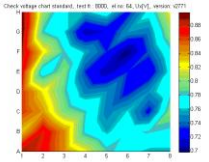


Fig. 23: Li1 to Li3 (2)

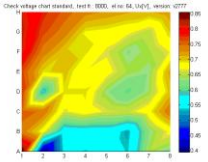


Fig. 24: Li1 to Li3 (3)

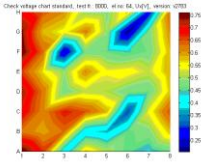


Fig. 25: Li1 to Li3 (4)

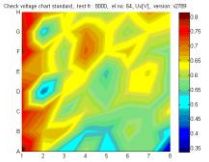


Fig. 26: Li1 to Li3 (5)

H) Practical visualization of different active points (acupoints) in Matlab graphical output, simultaneous online measured data storing in "ACU-snapshot" file into data-files and Matlab graph-file.

The stored data and measured graphs are useful for possible offline processing and statistical equations and future possible research.

The stored results in Matlab 3D graph-files offer the possibility to rotate and change the appropriate look and consideration of measured acupoint, respectively the part of measured voltage/impedance skin map.

5.1.2. Future orientations and next possible extension of the research and realized mapping system

A) An improvement of the electrode matrix sensing head with the metal electrodes (mechanically spring driven electrodes or pneumatic driven versatile electrodes).

An improvement could be realized by removing the metal electrodes and replacing the touching area of the probe by the combination of the conductive and isolative rubber matrix, elastic and driven by air pressure (from behind).

This enhancement was in our considerations yet, but wasn't realized before because of the very difficult technical realization in our laboratory conditions and economic situation. In the future and with the greater financial support would be possible to realize the new rubber kind of the mapping probe which would be even more "patient friendly" than used pneumatic mapping head.

B) Common stimulation of a measured acupoint, into it's central position measured by the matrix probe (head) - realization of the diagnostic and therapeutic system in one.

The processor controlled system would be able to concern the defined stimulating signal into central part of measured acupoint and to stimulate it, immediately it would be able to measure the impact of stimulation influencing the acupoint in mapped area of skin and also to analyze the shape and dynamic range of the considered acupoint, to measure the final healing effect. A complex diagnostic-therapeutic system could be realized.There is a wide range of application from the defined electrical stimulation of the recognized location, the mechanical stimulation of the single point by a pneumatic valve to the complex electrical and mechanical stimulation by electrical actors and a pneumatic switching matrix. Complete electrical and pneumatic patterns could spread their healing effect to the patient. In the result a realization of the diagnostic and therapeutic system in one appears possible. An integration into concepts of expert systems appears realistic allowing the data based support of diagnostic and therapeutic measures.

6. Conclusion

The detection of the location of acupoints has been done in the past in different ways ranging from the STIMUL 3 device and the more sophisticated matrix heads. A lot of publications were issued treating the skin impedance analysis for acupoint allocation. By this thesis a significant higher degree of recognizability, acupoint (contact) adaptation, and bio-compatibility was focused on. The application of pneumatic principle while rastering the skin surface provides a new quality of recognition of low impedance dots because its biocompatibility on one hand an its excellent no feedback behavior on the other hand. The main drawback of this method is its cost aspect resulting from the preparation unit for air and pressure supply. Newertherless the potential of pneumatic head are amazing, just considering the variety of variations straight ahead. The optimization possibilities range from the enhancement of covered area, further patterns of rastering up to the chance of electrical or pneumatic stimulation as measures of treatment.

The problems of the already established spring driven head can be summarized as follows. Primarily a good detection reliability is given as long the application does not exceed a certain mechanical load. A large number of repeated measures can not only cause significant skin irritations but furthermore they will decrease the impedancy of the whole covered area. That reduces the dynamic of the results meaning a closer value between the minimum and maximum single tip at all and decreasing with their application. The detection probability becomes lower. The pneumatic head solve this limitation in a smart way. The more smooth over all behavior treats the tissue gently. That leads to a neglectable influence to the skin layers and their integrity. Over a wide range the pressure does not change the results of repeated measurements. Appropriately the application of pressure can be minimized without any disadvantages.

The pneumatic principle and its laboratory application marks a milestone in impedancy measurement technology. The smooth characteristic in view of its application and the nearly perfect linearity lead to a unique quality of diagnostic point recognition.

In the preview a further development in handling, detection und finally mechanical or electrical stimulation appears to worth. The handling covers almost the whole body generally, but for the objectivation specific body fixation according to the proposed unit can ensure the appropriate repeatability. The placement gets a more precise base with a tissue fixation unit on one hand and motorous movement of head on the other hand. The disadvantage of this further development is obvious, less flexibility in the handling.For the detection itself a primary DC stimulation could be used to focus not only on the absolut value but to the change of charge, too.From the technical point of view several optimization matters of the test head can be taken into account. Additional tips could not only achieve a better coverage in the detection process but much more a edge independent measuring. The edges have rare single effects of water collection showing low impedancy behavior, mistakenly. Additionally an increased monitoring would show any feedback in the meridian by observation of more than one diagnosticpoint. For the final stage stimulation can be into according. A significant afford is necessary to implement a mechanical stimulation toolkit by the single tip controlling valves. From this point of view the electrical stimulation of the detected diagnostic point seems to be more efficient, since levels and waveforms of stimulation signals can be generated electronically an get repeated acoording to the tip number. A number of requirements have to fulfilled for that purpose from the single pneumatic driven control of the tips via the pattern triggering to the large number of measurement inputs.

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Resumé

Mnoho ľudí na celom svete trpí chronickými bolesťami, ktoré nie sú dôsledkom momentálneho ochorenia. Ich liečenie je extrémne komplexnou záležitosťou a tradičná medicína sa často obmedzuje iba na podávanie jednoduchých upokojujúcich prostriedkov za účelom utlmenia symptómov. To je príčinou, kvôli ktorej sa lekári často pokúšajú hľadať nové cesty terapie. V súčasnosti sa veľmi často používajú predovšetkým rôzne aplikácie akupunktúry. Akupunktúra je jednou z uznávaných zavedených metód liečby bolesti a je súčasťou tradičnej čínskej medicíny, ktorá aplikuje okrem nej aj farmakoterapiu, dietetickú výživu, Qigong atď. Tradičná čínska medicína sa snaží udržiavať alebo reaktívovať tok “Qi”, istého druhu životnej energie. Pojem “akupunktúra” sa skladá z dvoch slov z latinčiny: acus - ihla a puncture – vloženie. Akupunktúra je metóda, ktorá sa používa pre zlepšenie výkonnosti a funkcií tela pomocou jeho prirodzeného uzdravenia. Akupunkturálne body sa dajú stimulovať aj teplom, elektrickým prúdom, tlakom, laserovým lúčom alebo rázovými vlnami.

Pri hodnotení už zavedených senzorových platforiem sme skúmali novú kvalitatívnu úroveň troch generácií pneumatických hláv so zameraním na prednosti ich aplikácie a na faktory, ktoré ovplyvňujú postup a výsledky rozpoznávania diagnostických bodov.

Táto téza predstavuje nové výskumy, ktoré sa týkajú detekovania aktívnych bodov na ľudskej pokožke. Nevýhody v súčasnosti existujúcich riešení testovacej hlavy by sa mali odstrániť zmenou jej designu, ktorá na jednej strane umožní zlepšenie spoľahlivosti detekcie, a na druhej strane udrží dostačujúci stupeň biokompatibility – odstránenie dráždenia pokožky. Posudzujú sa jednak relevantné kvality aplikácie testovacej hlavy, ako aj dôsledky tohoto sofistikovaného designu na spoľahlivosť detekcie, precíznosť a na dynamičnosť zobrazovania.

Dizertačná práca obsahuje vývoj novej testovacej sondy na pneumatickom základe, ktorá dokáže skúmať aktívne body na ľudskej pokožke sofistikovanejšou cestou. Pre umožnenie porovnávania bola vylepšená štandardná pružinová hlava, ktorá sa v laboratóriu používala už v minulosti. Cieľom bolo odstrániť nevýhody

aplikácie jednoduchej mechanickej sily vyvodenej pružinami. Na jednej strane bolo možné zredukovať výkyvy pôsobiacej sily medzi hrotmi, na druhej strane išlo o docielenie adaptácie pružného povrchu podľa prostredia, ktoré sa nachádza v okolí akupunkturálneho bodu. Okrem toho sme dosiahli výrazného zlepšenia kompatibility pokožky.

Pri zhrnutí detailov výskumu išlo o nasledujúce aspekty:

- spoľahlivosť detekcie,
- posúdenie porovnateľnosti hláv,
- dynamičnosť zobrazenia pri redukcii odchýlok veľkosti pôsobiacej sily.

Základným faktorom alternatívnej terapie je exaktná lokalizácia zodpovedajúcich diagnostických bodov.

Táto dizertačná práca je zameraná na dosiahnutie podstatne vyššieho stupňa rozpoznateľnosti, na adaptáciu (kontaktov) akupunkturálnych bodov a na biokompatibilitu. Aplikácia pneumatického princípu pri rastrovaní povrchu pokožky poskytuje novú kvalitatívnu úroveň rozpoznávania bodov s nízkou impedanciou na základe ich biokompatibility na jednej a ich vynikajúceho správania sa bez spätnej väzby na druhej strane. Hlavnou nevýhodou tejto metódy sú s ňou spojené vysoké náklady, ktoré vyplývajú z nevyhnutnosti prípravy zariadenia pre prívod vzduchu a tlaku. Napriek tomu je potenciál pneumatickej hlavy skutočne vynikajúci, aj keď by sme brali do úvahy už len široký rozsah možných variácií. Možnosti ďalšej optimalizácie siahajú od skvalitnenia pokrytej oblasti, cez ďalšie vzory rastrovania až k širokým možnostiam elektro alebo pneumatickej stimulácie ako liečebného postupu.

Pneumatický princíp a jeho laboratórna aplikácia predstavuje ďalší míľnik vo vývoji techniky merania impedancie. Hladký priebeh charakteristiky pri jeho aplikácii a jej takmer perfektná linearita vedie k dosiahnutiu jedinečnej kvality rozpoznávania diagnostických bodov.

Za hlavné prínosy dizertačnej práce možno považovať:

1. Návrh originálnej maticovej mapovacej metódy na zobrazenie, popis a meranie tvaru a štruktúry akupunktúrnych bodov.

2. Základný výskum v oblasti napäťovo-impedančného mapovania pokožky a výskumu vlastností akupunktúrnych bodov, s následnou experimentálnou validáciou napäťovo-impedančnej metódy rozpoznávania aktívnych bodov na pokožke ako impedančného minima alebo vodivostného maxima v oblasti aktívnych bodov.
3. Pôvodný návrh a realizácia pneumatickej maticovej snímacej sondy s neinvazívnym a ekologickým snímaním vlastností pokožky s minimalizovaným rušivým dopadom na ľudský organizmus.
4. Nová originálna metodika napäťovo-impedančného mapovania pokožky (metodické aj technické riešenie z hľadiska hustoty snímania, použitia rôznych budiacich signálov, minimalizácie budiaceho napätia a meracieho prúdu, rýchlosti spracovania a grafickej interpretácie nameraných výsledkov) a pôvodný výskum vplyvu budiaceho tlaku elektród sondy na meranie a dynamiku rozpoznávania aktívnych bodov.

Zdá sa, že sa dá predpovedať ďalší vývoj aplikácie, detekcie a nakoniec mechanickej alebo elektrickej stimulácie. Aplikácia vo všeobecnosti pokrýva takmer celé telo, ale pre objektivizáciu špecifických fixácií podľa navrhovanej jednotky je potrebné zabezpečiť zodpovedajúcu opakovateľnosť. Umiestnenie sa dostáva na precíznejší základ pomocou upevňovacích prvkov na jednej a motorického ovládania pohybu hlavy na druhej strane. Nevýhoda tohto ďalšieho vývoja je zrejmá, a to predovšetkým zníženie flexibility manipulácie. Z technického hľadiska sa dá uvažovať o rôznych optimalizačných zmenách testovacej hlavy. Je tiež potrebnéimplementovať sadu nástrojov riadenia mechanickej stimulácie pomocou jednohrotových ovládacích ventilov.Z tohto hľadiska sa elektrická stimulácia detekovaných diagnostických bodov zdá byť účinnejšia, keďže hladiny a tvary vĺn stimulačných signálov je možné generovať elektronicky a opakovane takým spôsobom, že to bude zodpovedať počtu hrotov. Pre tento účel musí byť splnený celý rad požiadaviek, od samostatného pneumatického ovládania jednotlivých hrotov až po veľký počet meracích vstupov.