# Driving Pressure Influence in Voltage Maps Measurement Process Using Advanced Pneumatic Mapping Probe

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DOI: 10.15598/aeee.v14i2.1730

***Abstract.*** *Our paper deals with the method of the voltage-impedance map measurement process as a method useful for the electric mapping of human skin. The area of research extends from the basic research to its practical application in acupuncture skin mapping and acupuncture point localization and visualization. The problem of sufficient skin coverage and electrical contact with measuring electrodes is solved by the conventional mechanical telescopic electrodes and by the pneumatic matrix electrode probe. A 2D or 3D voltage-impedance map of skin is an output of the measuring, interpretation and evaluation process. New pneumatic construction of measuring probe was implemented to achieve a better coverage of specified skin area and get a reduced force range of the touching electrodes allowing the steady contact of the skin-electrode. A skin contact is related to the driving pressure of touching electrodes. Our paper offers experimentally measured results, voltage maps of skin on specific areas, selected measured and described acupuncture points and their applications in electro-acupuncture.*

## Keywords

***Acupuncture point, driving pressure, human skin, measuring probe, pneumatic electrodes.***

## 1. Introduction

Scientific research in physics, medicine and in electrotechnics consider a human skin as a subject of interesting and perspective research area. Skin behaviour from the electro-technical point of view is influenced by its structure and material. Specific parts of human or animal skin are called acupuncture points or active points; they are also depicted in various research publications. These points can be located by the results of the impedance-voltage map measurement. Acupuncture points (ACU-points) have been used in Traditional Chinese Medicine for more than few thousand years. Not only nowadays researchers try to describe them properly, to measure their electrical properties and to publish their results [1]. ACU-points are used in electro-acupuncture and in new non-standard diagnostic and therapeutic methods in medical devices [2]. Researchers consider these channels (meridians) as areas in the extracellular space where the electric charges flow through. A deviation of energy flow in comparison with normal values causes a misbalance of the body and can cause illness. Measuring of voltage-impedance minimums and reduced impedance on some areas of skin is useful for the unfolding of ACU-points. Acupuncture points are specific dynamic objects. They are changing their shape and intensity according to the circadian biorhythms [3] as various living systems [4]. During the specific hours of the day and also according to the measured person they are larger and deeper and more distinguishable but in some hours of the day (low meridian activity) they are scarcely visible and measurable. Their shape and properties are also influenced by the health conditions of the examined person and the corresponding organs. The maximal dynamic range of measurement is not the only considering factor for skin mapping and the active point recognition process. The state of skin, wet or dry surface, particular skin-electrode connection quality are changing and influence the measurement and recognition process.

## 2. Mapping Method and Skin Voltage Measuring Device

An experimental acupuncture measuring and mapping device developed at Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava was used for experimental measurements and skin mapping [5]. Correct operation and function of experimental skin voltage mapping device are controlled by processor ATmega16. For the communication with the control Personal Computer (PC), the USB to UART converter is used as a virtual serial port. The processor is equipped with a serial port, 10-bit A/D converter and Serial Peripheral Interface (SPI). Four analog multiplexers were used for the controlled reconnection of measuring electrodes touching measured object. The device utilizes a modified version of a peak detector, the DDS synthesis generator AD9833 (Fig. 1).

The control computer and the measuring mapping device are galvanically separated by a two channel insulator circuits, because of the safety of the patient (Fig. 2). There is also a different way to protect the operator or the measured human object from potential electric injury. It is fully guaranteed by supplying the device from accumulators.

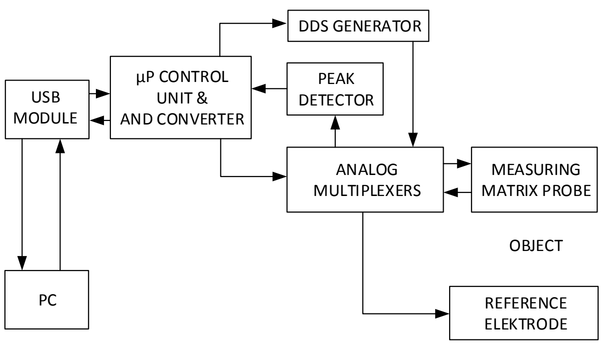



**Fig. 1:** Functional block diagram of mapping device.

The skin interaction and surface contact are provided by the electrodes of the measuring probe. All the electrodes measure the change of voltage with regard to a reference electrode [5] - a drop of potential on the skin induced by driving measuring electrical current from the generator of the device, flowing through the unknown skin or body impedance.

A measuring device is allowed to apply driving voltage from 0 V to maximally 5 V. An electrode with a larger contact area was used as reference. Mechanical or pneumatic telescopic matrix probes were used for measuring. Similar mapping method of acupuncture point measurement was introduced also in [6], where a larger and less sensitive non-telescopic kind of measuring probe was used.

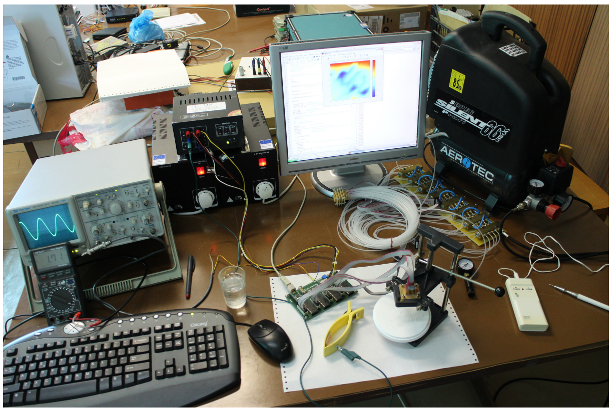


**Fig. 2:** Realized experimental mapping device with connected matrix probe, the reference electrode and practical supporting devices with the control computer.

Figure 2 shows a look into the laboratory with pneumatic-mechanic-electronic measuring system with connected sensing probe, mechanical holding and driving system and mapping device connected to control computer. For software design of the measuring system in MATLAB software were designed scripts and control GUI. MATLAB environment offers a wide area for real-time processing and file post-processing of clinical data and graphical interpretation (similar to the system in [4]).

## 3. Pneumatic Matrix Electrode Probe Construction

There were designed, developed and realized several constructions of non-invasive sensing electrode probe, in our Research Laboratory of Biomechatronics. The whole probe consists of 64 electrodes placed into an $8 \times 8$ matrix on an isolative holding construction. Non-planar, bended and side areas of skin on the human body are not easily accessible and during the measurement exhibit non-stable and non-proper contact electrode-skin. In specific non-planar and complicated skin areas as fingers, ears and parts of face the problem with skin irritation occurs. The experimental laboratory system contains pneumatic sensing electrode probe that uses pneumatic telescopic electrodes with the complex driving mechanism (Fig. 3), externally controlled air compressor and device of pressed air pipe distribution subsystem (Fig. 4) with pressure distributing driving elements and measurement [7].

Detail of the connected pneumatic probe with air pipes and manometer in driving, holding and positioning mechanism can be seen in Fig. 4. In realized pneumatic probe are used electrodes with pistons and extended contact peaks of 0.5 mm tip diameter on a substrate square of 2.5 × 2.5 cm (Fig. 3).

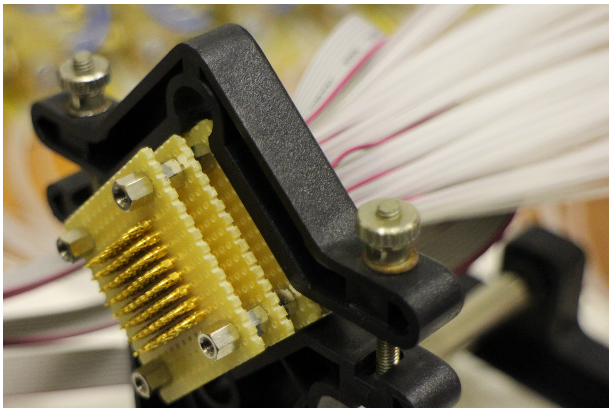


**Fig. 3:** Detail of pneumatic sensing probe in initial electrode position.

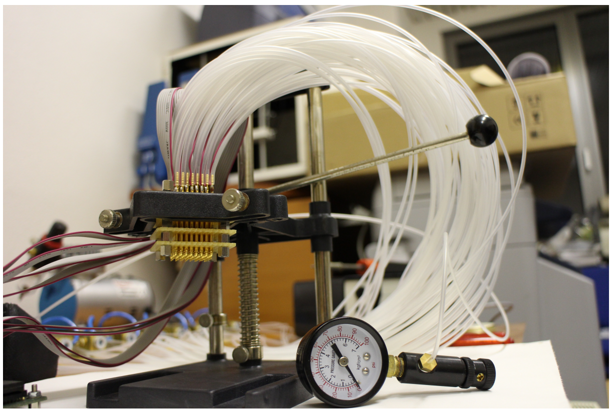


**Fig. 4:** Detail of the pneumatic probe with the air pipes and manometer in driving and holding mechanism.

## 4. Measurement of ACU-Points with Pneumatic Electrode Probe in Driving Pressure Progression

Most of the acupuncture points are situated on flat and good accessible skin areas. However, specific ACU-points are in hardly accessible parts of a human body. A skin area or acupuncture point is difficult to map, to visualize or to measure in the case it is situated on non-planar parts of human body or the acupuncture point is during the time of measurement smaller than the electrode probe resolution. Problems are also caused by the uneven skin areas of certain parts on human body, e.g. lateral side of fingers on hand or leg where specific active points of several meridians are situated. Performing a mapping skin measurement on the non-planar skin of lateral side of hand finger, the tips of all the electrodes have been touching the skin and pressing on it by the same lower and comfortable force, because of the same controlled constant air pressure in the system [8], [9]. Air in system is pressing on pistons of all the electrodes and invokes the same force pressing on the skin under the single electrodes (Fig. 5). That is why the skin irritation, perspiration and temporary change of electrical contact quality for all the measuring electrodes are the constant [8], [9]. Specific experimental measurements with pneumatic sensing probe were performed in our laboratory. We offer a representative set of measurements on an area described as "B" for this paper (see Fig. 6). It is significant mainly due to practical documentation of skin mapping measurement on complicated and uneven skin area. This is an operating space for a new pneumatic probe. Mapping skin measurements have been performed in specified parts on the lateral side of hand finger area.

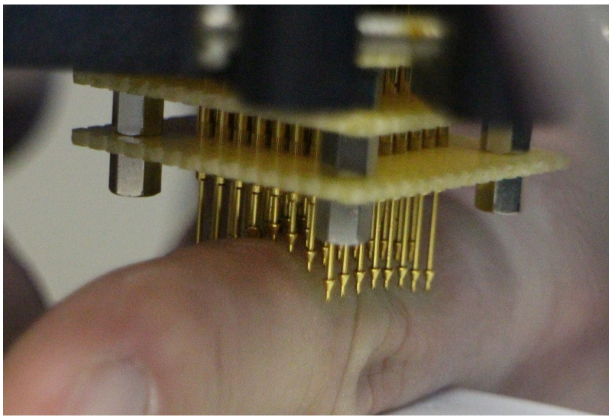


**Fig. 5:** Electrodes-skin detail of touching area in measurement by the pneumatic probe.

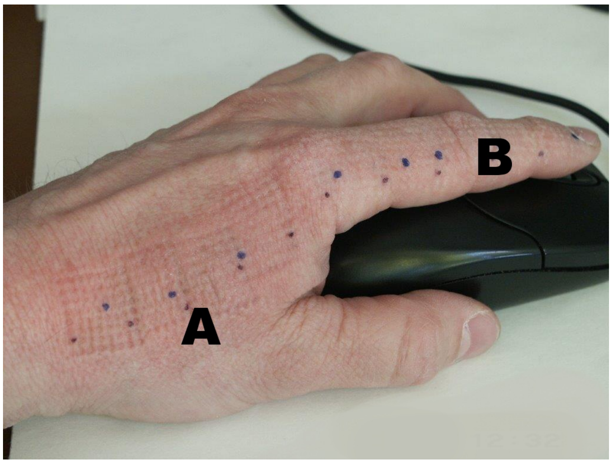



**Fig. 6:** Experimental object for measurement - hand and finger.

# 5. Experimental Results and Discussion

The first set of measurements was performed on the place of LI1b ACU-point (according to Voll description [10], between classical LI1 and LI2 ACU-points positions). This diagnostic point is situated on the area "B" (Fig. 6), respectively according to displayed location (Fig. 7).

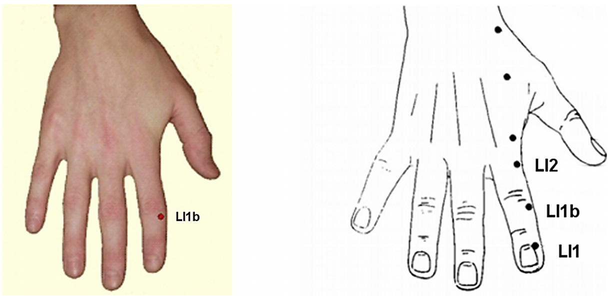



**Fig. 7:** LI1b ACU-point on LI meridian and next diagnostic points LI1 and LI2 according to Voll [10].

Measured graphical results are displayed on voltage-impedance maps below. In general, they contain the blue parts of map which are places on the skin with lower voltage/impedance drop (ACU-points), yellow or red places are surroundings with higher measured voltage or impedance, the voltage scale bar is situated on the right side of single maps.

## 5.1. Measurements of LI1b ACU-Point

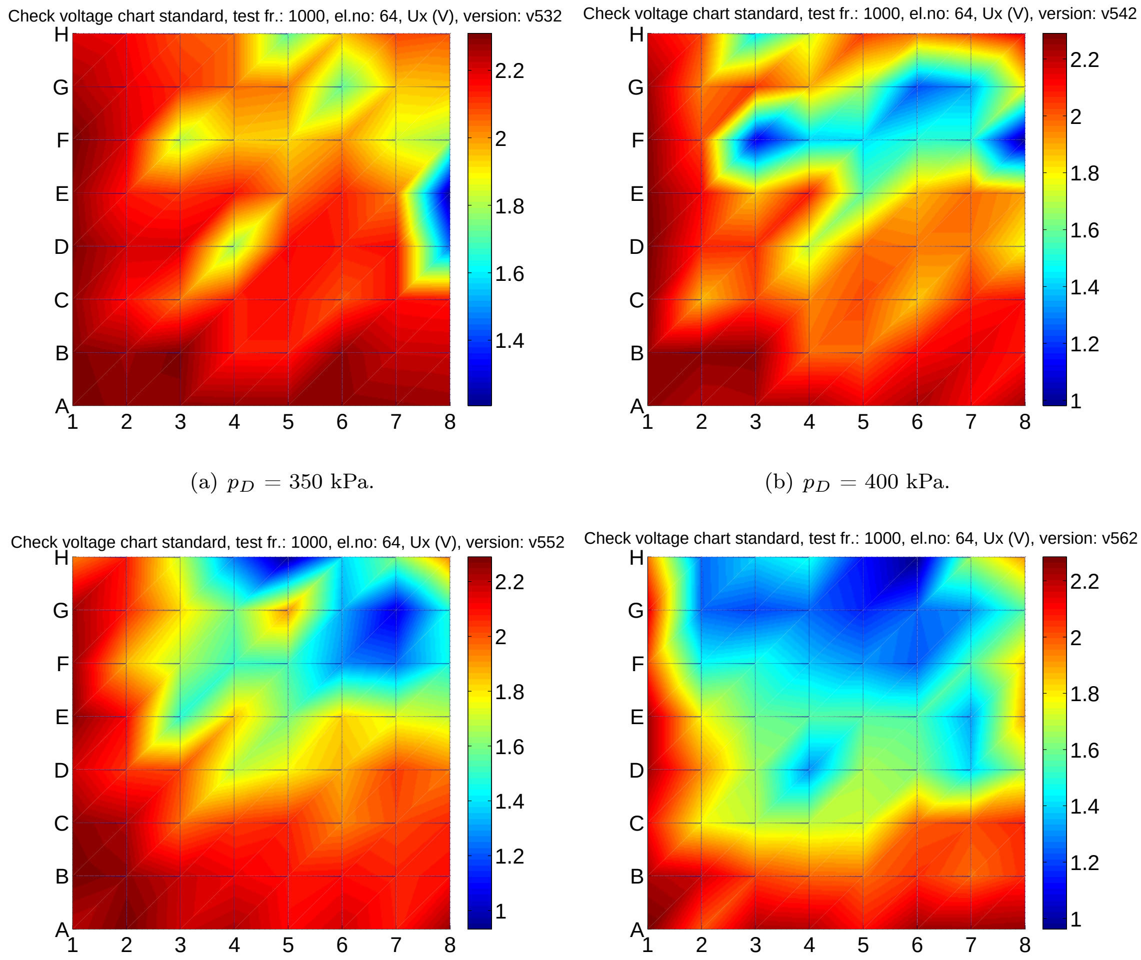
Results are presented in both tabular and graphical form. Both forms contain voltage drops values of measured voltage $Ux$ induced by harmonic driving current ($I = 1$ μA and $f = 1$ kHz ) flowing through the skin. The voltage drop is the measure of skin impedance under the measuring electrode. Measured maps of relatively uneven skin area "B" in the position of LI2 ACU-point obtained in four steps of driving pressure are shown in Fig. 8. Common consequence and shape relation of them all is apparent. Primarily the force of probe application in measurement process has been considered. The driving pressure $p_D$ of application was varied by choosing the pressure range between 350 kPa and 500 kPa in 50 kPa steps. According to the technical point of view, the air pressure 400 kPa and higher, ejects all the pistons in measuring electrodes (Fig. 3 and Fig. 5) in correct working position. The mechanical construction of some electrodes allows to push out them with higher driving pressure. The higher pressure, the better transition contact, and the lower transition impedance.

According to the measured human object, the lower pressure causes higher comfort of measurement and also lower skin irritation. While the maximal voltage drop measured on skin for driving pressure $p_D = 350$ kPa was $Ux_{\max} = 2.31$ V and $Ux_{\min} = 1.21$ V, for $p_D = 400$ kPa it was $Ux_{\max} = 2.29$ V and $Ux_{\min} = 0.98$ V, for $p_D = 450$ kPa it was $Ux_{\max} = 2.29$ V and $Ux_{\min} = 0.93$ V and for the driving pressure $p_D = 500$ kPa it was $Ux_{\max} = 1.36$ V and $Ux_{\min} = 0.96$ V. Maximal dynamic range of measurement was obtained with $p_D = 450$ kPa, $(Ux_{\max} - Ux_{\min}) = (2.29\text{ V} - 0.93\text{ V}) = 1.36$ V.

Considering all the influences and parameters, the optimum pressure for the recognition results in these measurements appears to be 450 kPa, as the compromise value because of the higher dynamic range of measurement (see also surrounded shape in the middle of single maps on Fig. 8).

## 5.2. Measurements of LI2 ACU-Point

During the measurement on selected area of LI2 ACU-point position the maximal voltage drop measured on the skin for driving pressure $p_D = 350$ kPa was $Ux_{\max} = 2.28$ V and minimal $Ux_{\min} = 1.26$ V, for $p_D = 400$ kPa it was $Ux_{\max} = 2.18$ V and $Ux_{\min} = 0.65$ V, for $p_D = 450$ kPa it was $Ux_{\max} = 2.09$ V and $Ux_{\min} = 0.72$ V and for the driving pressure $p_D = 500$ kPa it was $Ux_{\max} = 2.00$ V and $Ux_{\min} = 0.53$ V. Maximal dynamic range of measurement was obtained with $p_D = 400$ kPa and it was $(Ux_{\max} - Ux_{\min}) = (2.18\text{ V} - 0.65\text{ V}) = 1.53$ V (Fig. 9).




(a) $p_D = 350$ kPa.

(b) $p_D = 400$ kPa.

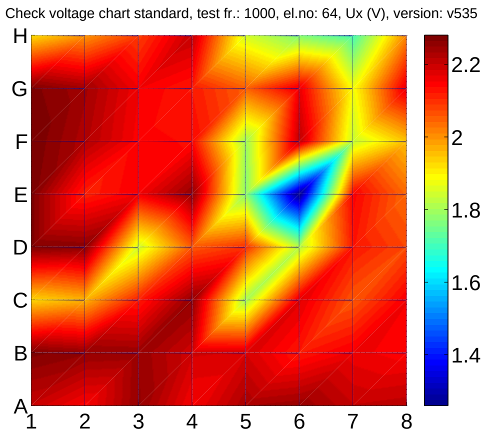
(c) $p_D = 450$ kPa.

(d) $p_D = 500$ kPa.

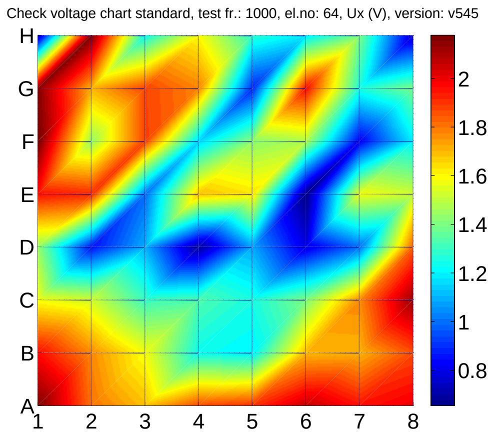
**Fig. 8:** Voltage map of skin on selected of LI1b ACU-point position (uneven skin area "B") measured with driving pressure $p_D$.

**Tab. 1:** Measured voltage map of skin on LI1b ACU-point position for driving pressure $p_D = 350$ kPa, $p_D = 400$ kPa, $p_D = 450$ kPa and $p_D = 500$ kPa in tabular form.

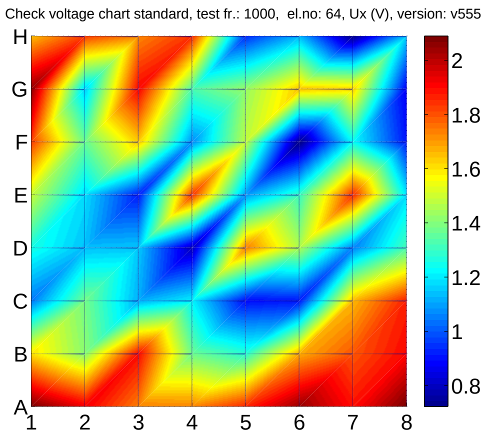
| $Ux$ (V) | $p_D = 350$ kPa | | | | | | | | $p_D = 400$ kPa | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| A | 2.31 | 2.28 | 2.29 | 2.28 | 2.28 | 2.29 | 2.28 | 2.27 | 2.26 | 2.21 | 2.22 | 2.23 | 2.14 | 2.23 | 2.11 | 2.24 |
| B | 2.30 | 2.27 | 2.14 | 2.30 | 2.13 | 2.13 | 2.22 | 2.22 | 2.25 | 2.26 | 2.27 | 1.98 | 1.98 | 2.11 | 2.15 | 2.08 |
| C | 2.28 | 2.15 | 2.04 | 2.13 | 2.15 | 2.08 | 2.15 | 2.14 | 2.27 | 1.88 | 2.03 | 1.94 | 2.02 | 1.86 | 2.08 | 2.10 |
| D | 2.30 | 2.21 | 2.20 | 1.79 | 2.16 | 2.13 | 2.15 | 1.44 | 2.29 | 2.07 | 2.06 | 1.71 | 1.98 | 1.96 | 1.96 | 1.78 |
| E | 2.29 | 2.14 | 2.10 | 2.14 | 2.02 | 2.13 | 2.02 | 1.21 | 2.28 | 2.12 | 1.86 | 2.08 | 1.58 | 1.88 | 1.98 | 1.90 |
| F | 2.31 | 2.20 | 1.81 | 1.94 | 1.92 | 2.00 | 1.85 | 1.78 | 2.27 | 2.02 | 1.10 | 1.41 | 1.43 | 1.52 | 1.52 | 0.98 |
| G | 2.26 | 2.19 | 2.11 | 2.04 | 2.03 | 1.72 | 1.94 | 1.95 | 2.24 | 1.95 | 2.05 | 1.88 | 1.69 | 1.24 | 1.35 | 1.79 |
| H | 2.20 | 2.17 | 2.08 | 2.04 | 1.71 | 1.95 | 2.09 | 2.07 | 2.15 | 2.02 | 1.45 | 1.73 | 2.05 | 1.96 | 2.03 | 2.14 |
| $Ux$ (V) | $p_D = 450$ kPa | | | | | | | | $p_D = 500$ kPa | | | | | | | |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| A | 2.20 | 2.29 | 2.17 | 2.22 | 2.10 | 2.17 | 2.08 | 2.25 | 2.29 | 2.00 | 2.22 | 2.21 | 2.09 | 2.24 | 2.24 | 2.25 |
| B | 2.29 | 2.26 | 2.18 | 2.13 | 2.09 | 2.10 | 2.07 | 2.09 | 2.22 | 2.17 | 2.03 | 1.98 | 1.97 | 2.05 | 1.97 | 2.05 |
| C | 2.27 | 2.22 | 1.96 | 2.03 | 2.06 | 1.93 | 2.01 | 2.06 | 2.10 | 1.78 | 1.70 | 1.70 | 1.72 | 1.99 | 2.01 | 2.07 |
| D | 2.17 | 2.04 | 2.01 | 1.68 | 1.77 | 1.87 | 2.03 | 1.94 | 2.23 | 1.92 | 1.66 | 1.31 | 1.67 | 1.62 | 1.40 | 1.67 |
| E | 2.27 | 2.11 | 1.48 | 1.84 | 1.60 | 1.83 | 1.74 | 1.69 | 2.23 | 1.77 | 1.59 | 1.56 | 1.57 | 1.55 | 1.33 | 1.90 |
| F | 2.25 | 1.86 | 1.67 | 1.50 | 1.52 | 1.28 | 1.23 | 1.46 | 2.01 | 1.46 | 1.49 | 1.38 | 1.31 | 1.24 | 1.56 | 1.85 |
| G | 2.24 | 2.06 | 1.81 | 1.59 | 1.91 | 1.32 | 1.04 | 1.47 | 2.14 | 1.25 | 1.21 | 1.25 | 1.16 | 1.25 | 1.31 | 1.56 |
| H | 1.93 | 2.08 | 1.70 | 1.25 | 0.93 | 1.38 | 1.60 | 1.94 | 1.95 | 1.25 | 1.40 | 1.47 | 1.13 | 0.96 | 1.67 | 1.91 |



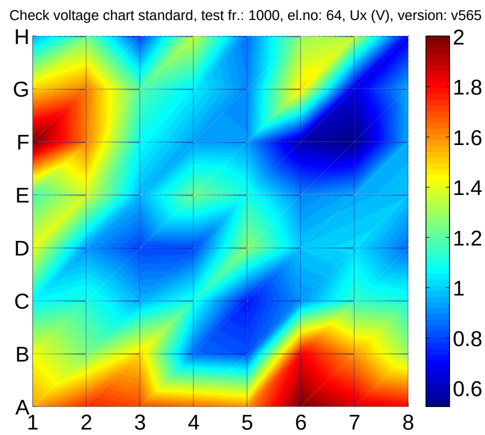

(a) $p_D = 350$ kPa.




(b) $p_D = 400$ kPa.




(c) $p_D = 450$ kPa.




(d) $p_D = 500$ kPa.

**Fig. 9:** Voltage map of skin on selected area of LI2 ACU-point position (left side of uneven skin area "B") measured with driving pressure $p_D$.

**Tab. 2:** Measured voltage map of skin on LI2 ACU-point position for driving pressure $p_D = 350$ kPa, $p_D = 400$ kPa, $p_D = 450$ kPa and $p_D = 500$ kPa in tabular form.

| $Ux$ | $p_D = 350$ kPa | | | | | | | | $p_D = 400$ kPa | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (V) | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| A | 2.20 | 2.14 | 2.25 | 2.15 | 2.23 | 2.25 | 2.20 | 2.21 | 2.17 | 1.80 | 1.68 | 1.87 | 1.90 | 2.06 | 1.95 | 2.00 |
| B | 2.27 | 2.25 | 2.25 | 2.19 | 2.18 | 2.12 | 2.16 | 2.14 | 1.96 | 1.76 | 1.58 | 1.24 | 1.20 | 1.70 | 1.70 | 1.86 |
| C | 1.93 | 1.96 | 2.11 | 2.25 | 1.80 | 2.17 | 2.06 | 2.15 | 1.58 | 1.53 | 1.30 | 1.33 | 1.25 | 1.41 | 1.77 | 2.13 |
| D | 2.27 | 2.26 | 1.85 | 2.06 | 2.09 | 1.82 | 2.12 | 2.07 | 1.44 | 0.86 | 1.10 | 0.69 | 1.08 | 0.79 | 1.01 | 1.84 |
| E | 2.27 | 2.11 | 2.15 | 2.25 | 1.78 | 1.26 | 2.14 | 2.04 | 1.95 | 1.91 | 1.00 | 1.68 | 1.63 | 0.65 | 1.58 | 1.52 |
| F | 2.28 | 2.22 | 2.14 | 2.13 | 1.80 | 2.21 | 1.84 | 1.95 | 2.18 | 1.45 | 1.88 | 1.16 | 1.43 | 1.48 | 0.83 | 1.20 |
| G | 2.27 | 2.24 | 2.15 | 2.12 | 2.05 | 2.16 | 1.88 | 2.17 | 2.15 | 1.70 | 1.87 | 1.77 | 0.89 | 1.95 | 1.26 | 1.40 |
| H | 1.92 | 1.99 | 2.08 | 2.20 | 1.85 | 1.77 | 1.71 | 2.01 | 0.72 | 2.16 | 1.24 | 1.59 | 1.28 | 1.19 | 1.40 | 0.76 |
| $Ux$ | $p_D = 450$ kPa | | | | | | | | $p_D = 500$ kPa | | | | | | | |
| (V) | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| A | 2.08 | 1.92 | 1.73 | 1.73 | 1.86 | 2.05 | 1.89 | 2.09 | 1.57 | 1.75 | 1.70 | 1.65 | 1.60 | 2.00 | 1.87 | 1.80 |
| B | 1.60 | 1.41 | 1.89 | 1.37 | 1.28 | 1.67 | 1.79 | 1.90 | 1.42 | 1.26 | 1.48 | 0.86 | 0.82 | 1.81 | 1.58 | 1.30 |
| C | 1.05 | 1.38 | 1.12 | 1.21 | 0.90 | 0.92 | 1.66 | 1.87 | 1.06 | 1.12 | 0.96 | 1.11 | 0.74 | 0.92 | 1.15 | 1.10 |
| D | 1.26 | 1.14 | 1.15 | 0.80 | 1.73 | 1.46 | 1.10 | 1.33 | 1.41 | 0.92 | 0.80 | 0.81 | 1.27 | 0.99 | 1.03 | 0.86 |
| E | 1.49 | 1.18 | 0.92 | 1.84 | 1.09 | 1.30 | 1.85 | 1.19 | 1.18 | 1.38 | 0.97 | 1.23 | 1.11 | 0.89 | 0.95 | 0.99 |
| F | 1.82 | 1.37 | 1.64 | 1.08 | 1.48 | 0.72 | 1.24 | 0.91 | 2.00 | 1.62 | 1.08 | 0.94 | 0.92 | 0.58 | 0.53 | 0.95 |
| G | 2.05 | 1.17 | 1.90 | 1.33 | 1.43 | 1.64 | 1.62 | 0.87 | 1.49 | 1.62 | 1.19 | 1.05 | 0.90 | 1.47 | 0.65 | 0.96 |
| H | 1.65 | 1.82 | 1.72 | 1.84 | 0.95 | 1.13 | 0.73 | 1.15 | 0.95 | 1.24 | 0.80 | 1.35 | 0.87 | 1.29 | 1.35 | 0.69 |

### 5.3. Measurements of LI1 ACU-Point

Very specific position for measurement and skin mapping is a position of acupuncture point LI1 at a lateral side of the distal phalanx of the forefinger. That position is very difficult to access (constantly by all the electrodes) and if we had a mechanical version of measuring electrode probe only, it would by practically impossible. The press of mechanical electrodes on the central part of measuring area would cause a strong skin irritation and false voltage drop. A pneumatic electrode probe construction allowed the uniform and non disturbing electrode contact with skin and the performance of the mentioned mapping measurement. The measurement of LI1 ACU-point position (Fig. 7) showed the maximal voltage drop measured on skin for driving pressure $p_D$ = 450 kPa, it was $Ux_{\max}$ = 2.30 V and minimal $Ux_{\min}$ = 1.20 V (measured voltage map of skin on Fig. 10) and for the driving pressure $p_D$ = 500 kPa it was $Ux_{\max}$ = 2.32 V and $Ux_{\min}$ = 1.00 V. Maximal dynamic range was obtained with $p_D$ = 500 kPa and it was $(Ux_{\max} - Ux_{\min})$ = (2.32 V − 1.00 V) = 1.32 V. A significant bordered blue area of the measured acupuncture point is visible in upper part of the voltage map on Fig. 10, also in Tab. 3, similarly on Fig. 11, also in Tab. 4.

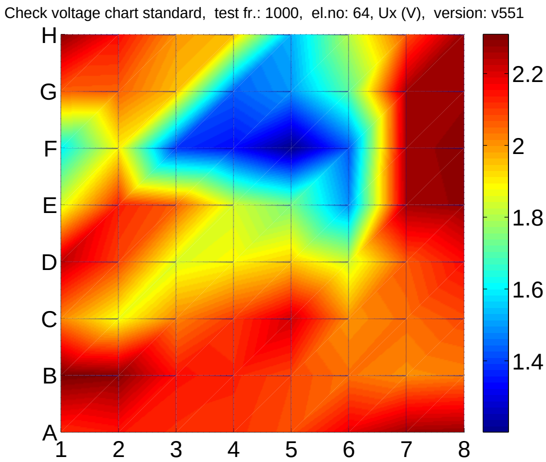



**Fig. 10:** Voltage map of skin on selected area of LI1 ACU-point position in 2D view (right side of uneven skin area "B") measured with driving pressure $p_D$ = 450 kPa.

The measured, described and recognized position and the shape of acupuncture point LI1 (Fig. 10) is possible to characterize numerically by the table of voltage drops values (Tab. 3) scanned on considered skin surface.

The position and the shape of acupuncture point LI1 (Fig. 11) are also possible to numerically characterize by the table of voltage drops values (Tab. 4) scanned on considered skin surface. An increased driving pressure on pneumatic electrodes in regard to the previous measurement (Fig. 10) caused higher skin irritation, a projection of the acupuncture point lost its clear contour (Fig. 11).

**Tab. 3:** Measured voltage map of skin on LI1 ACU-point position in tabular form measured with driving pressure $p_D$ = 450 kPa.

| $Ux$ (V) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| A | 2.11 | 2.14 | 2.11 | 2.11 | 2.08 | 2.19 | 2.27 | 2.28 |
| B | 2.31 | 2.29 | 2.14 | 2.12 | 2.08 | 2.04 | 2.01 | 2.02 |
| C | 2.01 | 1.87 | 2.02 | 2.10 | 2.21 | 2.00 | 2.04 | 2.08 |
| D | 2.24 | 2.08 | 1.85 | 1.89 | 1.94 | 1.84 | 2.07 | 2.15 |
| E | 1.85 | 2.13 | 2.06 | 1.84 | 1.74 | 1.49 | 2.26 | 2.28 |
| F | 1.60 | 1.89 | 1.39 | 1.34 | 1.20 | 1.42 | 2.27 | 2.29 |
| G | 2.06 | 2.06 | 1.95 | 1.44 | 1.50 | 1.71 | 2.26 | 2.27 |
| H | 2.29 | 2.15 | 2.00 | 1.95 | 1.53 | 1.81 | 2.07 | 2.28 |

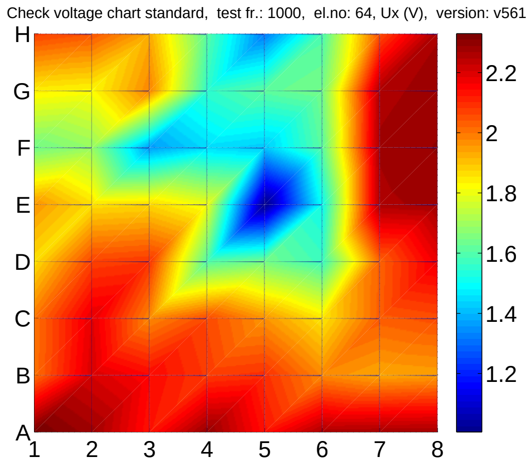



**Fig. 11:** Voltage map of skin on selected area of LI1 ACU-point position (right side of uneven skin area "B") measured with driving pressure $p_D$ = 500 kPa.

**Tab. 4:** Measured voltage map of skin on LI1 ACU-point position in tabular form measured with driving pressure $p_D$ = 500 kPa.

| $Ux$ (V) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| A | 2.33 | 2.28 | 2.12 | 2.29 | 2.13 | 2.26 | 2.27 | 2.27 |
| B | 2.01 | 2.20 | 2.14 | 2.08 | 2.09 | 1.97 | 1.93 | 1.94 |
| C | 2.00 | 2.19 | 1.97 | 2.06 | 1.96 | 1.85 | 2.03 | 2.05 |
| D | 1.86 | 2.07 | 2.08 | 1.60 | 1.65 | 1.57 | 2.03 | 2.18 |
| E | 1.96 | 1.86 | 1.87 | 1.80 | 1.01 | 1.51 | 2.26 | 2.28 |
| F | 1.64 | 1.69 | 1.37 | 1.45 | 1.43 | 1.62 | 2.27 | 2.29 |
| G | 1.84 | 1.83 | 1.98 | 1.56 | 1.62 | 1.65 | 2.26 | 2.28 |
| H | 2.07 | 2.04 | 1.93 | 1.60 | 1.32 | 1.60 | 2.05 | 2.27 |

Measured and described structure of skin surface voltage and impedance distribution obtained by the advanced pneumatic electrode matrix probe (controlled by mapping measuring device) [9] offers a relatively precious, rich and compact look on the skin surface, its structure and the position, the size and the shape of certain acupuncture points. Obtained density of measured voltage map realized by our pneumatic probe has greater resolution than results of authors [6], see Fig. 12 - the realized measuring probe of authors [6]. German researchers team led by Sybille Kramer published their research results in 2008 [6]. They performed their measurements and in the area of chosen acupuncture point GB34. They measured signals from the skin surface by they own designed and constructed flexible sensor, which consisted of he isolative plastic foil with regularly placed metal electrodes in array of 8 × 8 of the complex dimension 6 × 6 cm (Fig. 12).

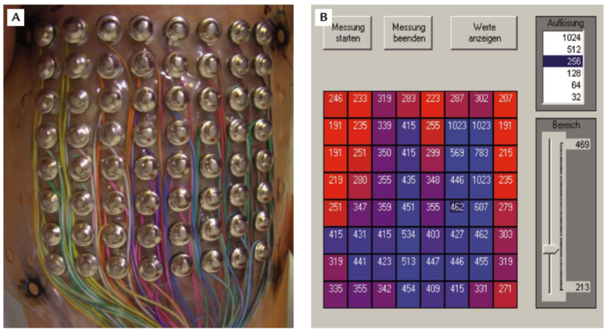



**Fig. 12:** Array of 64 metal touching electrodes on plastic foil (A) and graphic output of analyzing software with numerical and color-map outputs (B) [6].

A mapping resolution density of our pneumatic electrode probe is 20.24 electrodes per cm$^2$ in compare with the resolution of only 1.78 electrodes per cm$^2$ achieved by the realized probe of mentioned authors [6]. See Fig. 12 and Fig. 13.

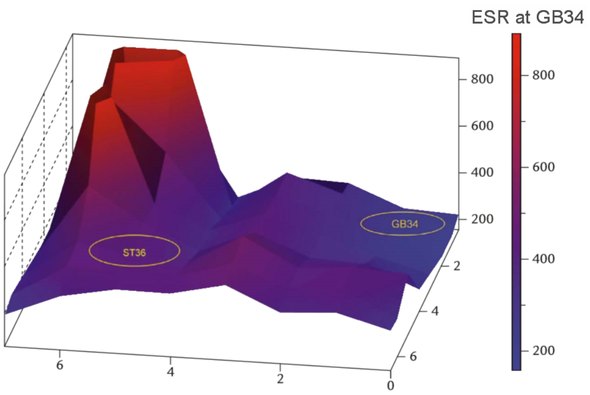



**Fig. 13:** Graphical 3D representation of the skin conductivity values measured on skin surface on acupuncture points GB34 and ST36 [6].

An ability to distinguish the position and the shape of certain acupuncture point on skin by measuring system of authors [6], (see Fig. 13) is smaller and not so effective as using our system Our effectivity is in the ability of the constructed electrode probe to cover chosen skin area and scan the parameters of skin in sufficient resolution. The driving pressure on measuring probe of authors [6] was guaranteed by mechanical fixation of plastic foil probe on skin or by the weight pressing on the probe in stable or lying position.

Specific parts of uneven skin area or small sections on certain parts of human body surface were immeasurable. Using a mechanical telescopic matrix probe or the probe with pneumatically driven electrodes from our laboratory team could also be an answer for these complicated areas. See an example of the especially difficult skin mapping the area between fingers realized by our mechanical matrix probe [5] and by our pneumatically driven electrode matrix probe [8], [9] (see Fig. 14 and Fig. 16).

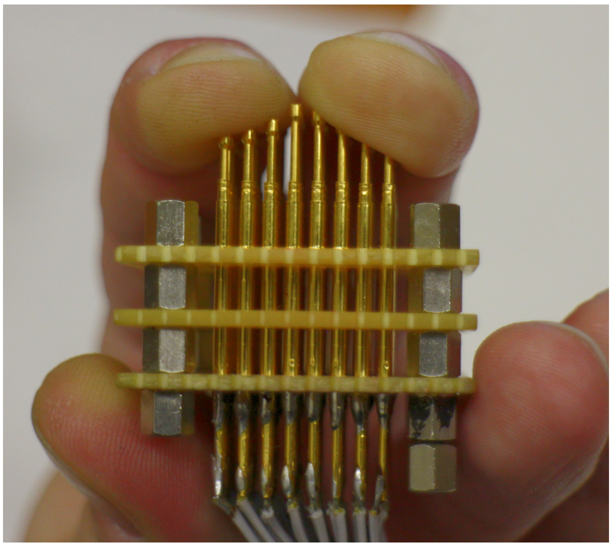


**Fig. 14:** Example of difficult skin mapping measurement realized by mechanical matrix probe - detail.

A driving pressure influence in mapping measurement realized by mechanical matrix probe cannot be additionally controlled. The impress of the mechanical telescopic electrodes is done by construction. Pressing force per one electrode is maximally 0.6 N, in maximal impress of the electrode. The quality of electric contact of touching electrodes differs by the depth of impress each of electrode. More pressed side electrodes of the probe (Fig. 14) achieve a better electric contact then less pressed central electrodes of the probe, also the level of skin disturbance is varying in the area of the matrix probe contact square. An ACU-point situated in the side area of the probe (measured blue parts on map, see Fig. 14) is then difficult to distinguish from the irritated skin on laterally from the measured square of skin (see Fig. 15).

A red like mountain chain part on map (Fig. 15) is the finger-side skin area between the fingers. A numerical representation of the voltage map on complicated skin area of LI-PC meridians measured by mechanical matrix probe can be seen in Tab. 6.

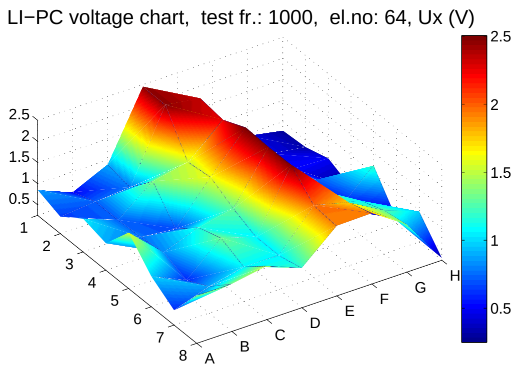



**Fig. 15:** 3D voltage map measured on area in between LI and PC meridians on fingers by mechanical matrix probe.

**Tab. 5:** Tabular form of voltage map of skin on area in between LI and PC meridians on fingers measured by mechanical matrix probe.

| $Ux$ (V) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| A | 0.85 | 0.65 | 1.04 | 0.89 | 1.57 | 0.97 | 0.60 | 1.39 |
| B | 0.52 | 0.73 | 0.73 | 0.76 | 0.83 | 0.60 | 0.88 | 1.38 |
| C | 0.90 | 0.79 | 1.36 | 0.67 | 1.13 | 1.32 | 1.07 | 1.52 |
| D | 2.46 | 2.46 | 1.54 | 1.61 | 1.30 | 1.06 | 1.05 | 1.19 |
| E | 1.62 | 2.33 | 2.25 | 2.50 | 2.48 | 2.49 | 1.96 | 1.91 |
| F | 0.54 | 0.82 | 1.15 | 1.25 | 1.26 | 1.28 | 1.74 | 1.92 |
| G | 0.45 | 0.46 | 0.53 | 0.70 | 0.45 | 1.07 | 1.28 | 1.38 |
| H | 0.29 | 0.33 | 0.50 | 0.25 | 1.19 | 0.37 | 0.97 | 0.30 |

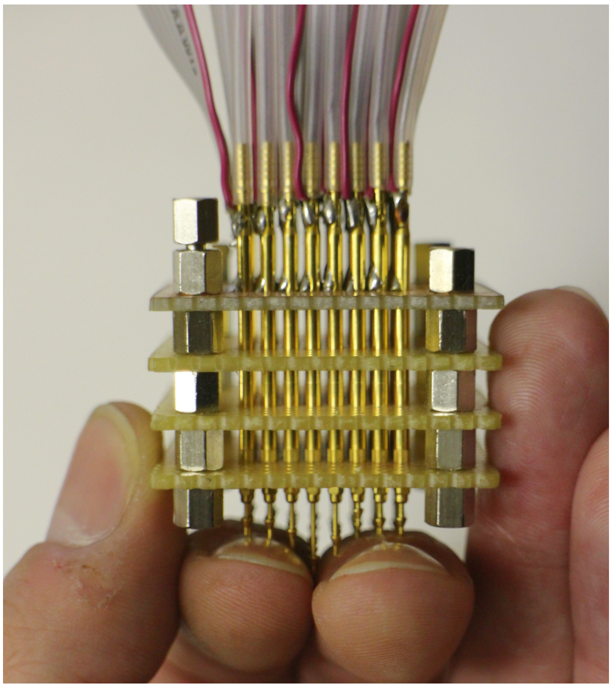


**Fig. 16:** Example of difficult skin mapping measurement realized by pneumatic matrix probe - detail.

A pressure controlled influence in mapping measurement realized by the pneumatic way causes the balanced impress of the pneumatic telescopic electrodes. A pressing force per one electrode is equal to pressing force in all the electrodes of the probe. The force pressing on the skin surface is regulated by the air pressure in driving pipes. The aim of regulation is to achieve the regular and constant electric contact for all the electrodes regardless the difficult and non planar surface of measured object.

The contact is not influenced by the depth of impress each of electrode. More pressed side electrodes of probe (Fig. 16) achieve the same electric contact as less pressed central electrodes of the probe, also the level of skin disturbance is the same in all the area of the matrix probe contact square

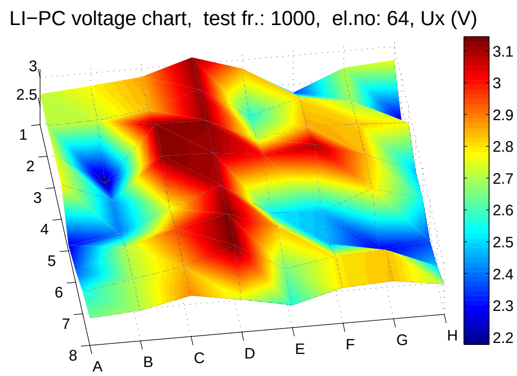



**Fig. 17:** 3D voltage map measured on area in between LI and PC meridians on fingers by sensitive pneumatic matrix probe.

A central red like mountain chain part on measured map (Fig. 17) is the lateral skin area between the fingers (Fig. 16). An ACU-point situated in side area of the measurement (blue parts of map, Fig. 17) becomes more significant and distinguishable from the rest of skin on side parts of the measured square of skin (see Fig. 15 and compare with Fig. 17).

**Tab. 6:** Tabular form of voltage map of skin on area in between LI and PC meridians on fingers measured by pneumatic matrix probe.

| $Ux$ (V) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| A | 0.68 | 0.61 | 0.88 | 0.75 | 1.00 | 0.58 | 0.46 | 2.36 |
| B | 0.61 | 1.29 | 1.40 | 1.03 | 1.06 | 1.32 | 0.44 | 2.13 |
| C | 1.70 | 1.65 | 1.60 | 1.84 | 1.60 | 1.04 | 1.01 | 2.01 |
| D | 2.41 | 2.28 | 1.61 | 2.21 | 2.07 | 2.27 | 2.22 | 2.29 |
| E | 1.88 | 1.55 | 1.86 | 1.93 | 2.03 | 1.92 | 2.00 | 1.93 |
| F | 1.50 | 0.88 | 1.39 | 1.72 | 1.58 | 1.74 | 1.68 | 0.74 |
| G | 1.51 | 0.71 | 0.52 | 1.48 | 1.52 | 1.79 | 1.86 | 0.65 |
| H | 1.25 | 1.19 | 1.76 | 1.71 | 1.91 | 1.63 | 0.92 | 1.26 |

A numerical representation of voltage map on complicated skin area of LI-PC meridians, mentioned above, measured by pneumatic matrix probe can be seen in Tab. 6.

### 5.4. Conclusion

Achieved mapping results measured using the pneumatic probe construction driven by various pressure range for the piston-electrode movement, impress on the skin surface and the constant electrode-skin electrical contact proved the hopeful and perspective results. Voltage-impedance maps show electrical skin structure, positions and shape of acupuncture points and can serve acupuncture physician as a useful tool for medical diagnostics and therapy. As we have mentioned above, the skin conditions are changing in time and weather conditions, but these changes are not contraindication of successful measurement and an acupuncture point successful recognition. Thereforeour mapping measurement is based on relative and not on absolute values of the voltage-impedance measured results. For active point on skin position recognition is not crucial the final map offset or lower dynamic range if the surrounded position of the measured active point on mapped skin is explicitly visible and recognizable. The acupuncture voltage/impedance mapping of the skin, unfolding the position and the shape of certain active points on the human skin surface, basic gradual research and unfolding of their properties has a tradition in our Research Laboratory of Biomechatronics at the Institute of Automotive Mechatronics and at the Institute of Electronics and Photonics FEI SUT (Faculty of Electrical Engineering and Information Technology of Slovak University of Technology) in Bratislava.

## Acknowledgment

The paper has been created as a part of a research and education process at the Institute of Automotive Mechatronics and the Institute of Electronics and Photonics, FEI SUT in Bratislava, Slovak Republic and is supported by the Grant VEGA 1/0987/12, VEGA 1/0823/13, VEGA 1/0937/14, KEGA 011STU-4/2015 and VEGA 2/0138/16.

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