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Pressure distribution measurement system PLANTOGRAF V12 and its electrodes configuration

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Abstract: This paper describes Plantograf V12, which is used for the investigation of the pressure distribution between an object, e.g. a foot sole or a tire tread pattern, and the transducer. It can be used for analysing steps, assessing the great joints and improving stability, as well as in the fields of sport medicine and car industry. The system processes variable time pressure signals in real time. The instrument has 16,400 sensors (with a diameter of 2.5 mm each in a matrix arrangement of 128 x 128) concentrated in the active area as large as 500 x 500 mm; it is able to sample and process up to 1,000 frames per second. A full frame is created by all 16,400 sensors. The pressure distribution frame is represented in 256 colour levels in a 2D or 3D model view and it is possible to post-process the measured data on a PC. The design of the electrodes, the properties of the transducers, the operating software and the pressure distribution measurements in biomechanics are presented in this article.

Key words: Plantograf, conductive elastomer, electrodes, pressure distribution, tactile transducer.

INTRODUCTION

Plantograf V12 is a tactile transducer that is able to pick up tactile information from a particular object and convert this information into an electrical signal. This sensor is used in the following applications: measurement of static and dynamic pressure distribution, human steps analysis, sitting position analysis, pressure distribution, the analysis of a flat human foot, and the analysis of the status of great joints (Volf et al., 1997; Volf et al., 2001). Plantograf V12 should fulfil the following conditions: the sensor should not affect the measured pressure distribution results, it should measure both static and dynamic load, and it should have sufficient sensitivity and accuracy in each point of the sensor matrix for the given application. These parameters are specified in a table of technical parameters of the Plantograf. This paper focuses on the description of the Plantograf V12 matrix design, the optimal electrode size determination, and the properties of the operating software.

MATERIALS AND METHODS

Transducer design

Plantograf V12 was designed with a view to minimizing the influence on the matrix measuring points and maximizing the matrix point sensitivity. The matrix design is shown in the patent application. Conductive elastomer CS 57–7 RSC is used as a converter between the force and electrical resistance (CS 57–7 RSC, 1980; Souza et al., 2005; Soares et al., 2006; Barman & Guha, 2006). Part of the Plantograf V12 cross-section is shown in Fig. 1. Both electrodes are corroded onto a single Cuflex film (the commercial name for elastic printed circuit) placed on the bottom part of the sensor matrix. Between the electrodes, changes in elastomer resistance are measured (Trinkl et al., 2011). The surface of each electrode is completely covered. The conductive elastomer and the electrodes are protected from mechanical wear by a non-conductive flexible material – the protective coating (Volf et al., 2012).

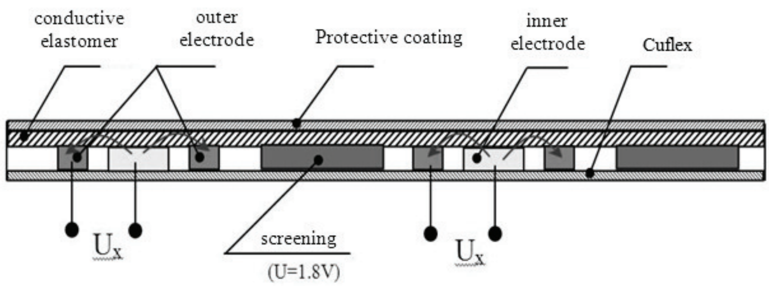

Figure 1. Cross-section of Plantograf V12.

Fig. 2 shows the principal layout of the electrodes at two adjacent sensors of the transducer. Real layout is more complex and it is realized by a multiply printed circuit. The arrow at the picture indicates the direction of the current between two circular electrodes of the sensor. It means that the current flows from the inner electrode through the conductive elastomer to the outer electrode. The common electrode, supplied by a voltage of 1.8 V, is used to mutual separation of individual sensors, which prevents – by hardware – the mutual interaction of the sensors.

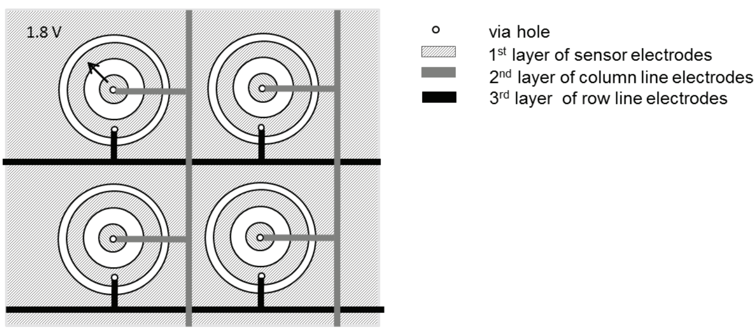

Figure 2. Four tactile sensors of the measurement matrix (the arrow indicates a change in sensor resistance).

Plantograf V12 uses new electronic circuits that are protected by a European patent (Novak & Volf, 2013). The electronic circuits consist of high-speed analogue-to-digital converters (ADC). Every ADC with an 8-bit resolution digitizes the signal from a simple RC circuit, where R represents sensor resistance. The counter measures the discharging period of capacitor C in the RC circuit. There are 128 such RC circuits – as many as the number of columns in transducer sensors. As a result, a full transducer line is converted at once. The converted samples are then processed for visualization (frames). All functions and control are integrated into a Xilinx Spartan 3 FPGA. These changes allowed the miniaturizing of the circuit and improved the speed of the whole system significantly. Currently the estimated rate is approximately 1,000 frames per second for a real time measurement. The sensors' resistance values correspond to a digitized signal using 8 bit ADC (i.e. 0–255 levels).

Software description

The device is designed to measure pressure (point value) from the contact forces' transducer, record it and provide a basic assessment. All previously measured data can be reverse-read to SW and processed (as if they were just measured), or they can be monitored and processed externally. The programme is not created as a closed unit; rather, it is a modular concept. SW is created by WIN 32 Microsoft NET C# (DirectX graphic output). The users can easily create their own (for example mathematical) blocks using the so-called libraries. The device can be easily run from a connected PC. During each measuring, several parameters can be set independently, e.g. visualization of the recording speed, change of transducer signal gain from 0.5x to 5x, zero set of the input signal, trigger mode of recording, and synchronizing with other recording devices. All the recorded data can be stored in several data formats, e.g. working DAT files, TXT text files, BMP pictures or DivX or XviD video records.

The operating software provides not only the monitoring and storage of the measured data, but also basic processing. During the monitoring, various operations are possible, such as displaying and rotating the frames, displaying the pressure centre and the histogram, creating custom horizontal and vertical cuts or selected regions and calculating their own pressure centres, creating a custom colour scale, making 2D and 3D visualizations, creating video files from the recorded values, and lastly exporting the measured data into EXCEL. Besides display operations, the software also allows mathematical processing, e.g. creating a file record for a selected cut or region and including the cut course in all the (selected) frames. The record may also contain additional statistical data (minimum, maximum, sum, average value, COP, histogram etc.).

RESULTS AND DISCUSSION

Optimal electrode size determination

A basic measurement task was carried out to determine the optimal electrode type for the application to give the sensors maximum measuring sensitivity. The measurement was performed automatically at a robotized workplace. All the measurements were performed in a static mode. The applied pressure was calculated from the diameter of the known electrode and the applied force was measured by the Hottinger transducer

DF2S-3. In this testing process the sensor's properties relative to the electrodes' design were measured; six different designs of the sensor electrodes were evaluated.

The sensor electrodes had the following sizes and names: Ø*E* = 2 mm, Ø*d* = 0.4 mm, *M* = 0.1 mm – ***LH***; Ø*E* = 2 mm, Ø*d* = 0.1 mm, *M* = 0.1 mm – ***PH***; Ø*E* = 2.5 mm, Ø*d* = 0.4 mm, *M* = 0.25 mm – ***LD***; Ø*E* = 2.5 mm, Ø*d* = 0.1 mm, *M* = 0.25 mm – ***PD***; Ø*E* = 3.5 mm, Ø*d* = 0.4 mm, *M* = 0.25 mm – ***OB***; Ø*E* = 3.5 mm, Ø*d* = 0.4 mm, *M* = 0.25 mm – ***SB***.

The sizes of the measured sensor electrodes are displayed in Fig. 3.

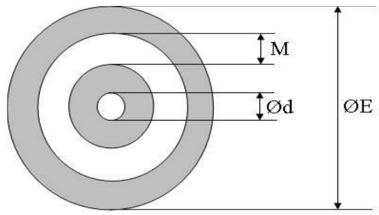

Figure 3. Sizes of the measured electrodes.

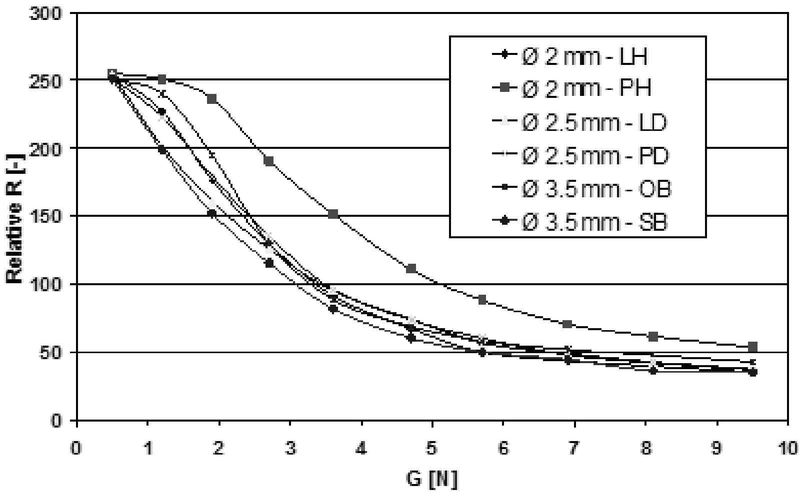

Figure 4. Relative dependence of sensor resistance on the loading force *G* for different electrode types.

Electrodes *OB* and *SB* have the same electrode size. Construction number 5 has placed the conductive elastomer separately only at the measuring sensor. Construction number 6 has got the conductive elastomer over its whole surface of the sensor matrix. Three different sensors for every design were selected for measurements. For the every selected sensor loading and unloading characteristic in the force range of 0.5 N – 9.5 N was measured 10 times. Uncertainties type A, B and C were calculated. Because of lucidity, only average values of the measurements are shown in Fig. 4.

Technical parameters and output of Plantograf V12

Electrodes of the type LD were selected for the final Plantograf V12 design. The following technical parameters were obtained:

Patient mass up to 150 kg; *rated pressure range* 5–100 kPa; *permissible overload (lower sensitivity)* 1.4 MPa; *tire loading* 3,000 kg; *permissible overload (higher sensitivity)* 14 MPa; *transducer active area* 500 x 500 mm; *number of sensors* 16,400 pcs; *sensor diameter* 2.5 mm; *transducer supply voltage* +5 V; *digital output* 256 levels; *frame frequency* 1 kHz.

Some of the areas of applications of the device are presented in Figs 5 and 6. Fig. 5 shows images of human soles in a biomechanical application of the system. Fig. 6 demonstrates a potential industrial usage of the system in analysing the pressure distribution between a tire and the road, as well as a further capacity of Plantograf – the determination of the centre of gravity using special computing software.

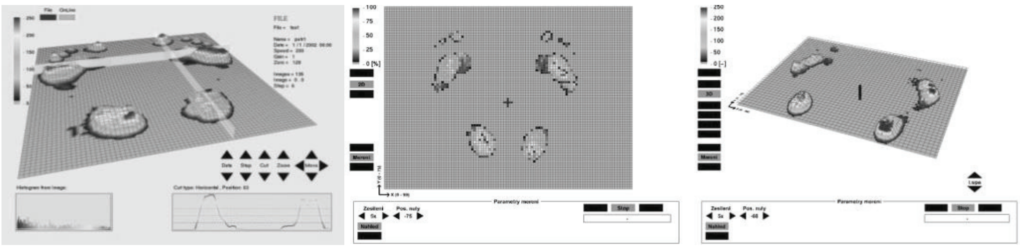

Figure 5. 2D and 3D images of human soles.

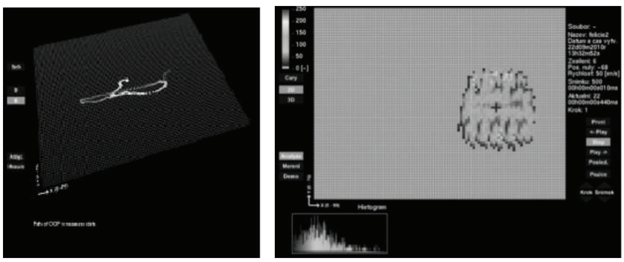

Figure 6. Determination of the centre of gravity and pressure distribution between a tire and the road.

The resulting frames have a 256 level colour scale. An unloaded sensor is indicated by the colour grey, while loaded sensors are coloured from blue to red, representing a fully loaded sensor.

Comparison with the competition

In comparison with PLANTOGRAF V12, the competing products TEKSCAN, RSSCAN and XSENSOR have the following drawbacks, among others:

- Limited recording period (buffer loading) – very short at high frequencies, longer at lower frequencies; one may not even manage to cross the sidewalk without the buffer already loading.

- Limited access to the data – measuring can be done in one walking direction only; the data are already pre-processed by software, RAW data (directly measured data) are unavailable; unstable software; the selection of arbitrary sections of the area is unavailable; one unanimous mask only; sometimes square regions. The software can analyse the sole of the foot only, it is unable to analyse other shapes.
- The number of sensors in the monitoring area is smaller, just 4,500 (each one measuring 5.0 x 7.6 mm). The specified maximum frame frequency of 300–500 Hz is comparable with that of Plantograf.
- In addition to sensor density and speed, the main advantages of our Plantograf include the SW modular concept, where SW can be arbitrarily extended depending on the needs of the user. Furthermore, the measured data export enables arbitrary data processing by the user.

CONCLUSIONS

This paper described the design, properties and technical parameters of Plantograf V12. The design of the tactile transducer Plantograf V12 is the newest in the Plantograf Vxx line.

Measurement results show that sensor sensitivity varies by the design of the sensor matrix. Design type PH has the lowest sensitivity (Fig. 1), while design type SB has the highest one. The results confirm the possibility of using miniature sensors in a Plantograf system to measure the pressure between a subject (e.g. a human sole, tire, etc.) and the transducer. The device can be utilized efficiently both in medicine and in the automotive industry.

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