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Investigating the Pressure Distribution on Uneven Surfaces Using an Educational Robot for Development of Ergonomic School Furniture

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The article presents the method of investigating the pressure distribution on uneven surfaces, used for the development of a new, modern series of school furniture that meets the relevant health, pedagogical and legal requirements. During the examination of pressure conditions on school chairs with a flexible tactile sensor, which was primarilly developed for this purpose, exact data on the immediate differences in contact pressures between the person sitting and the seat are obtained. Based on this information, it is then possible to optimally shape the seats during their design and subsequent production according to the age of the sitters and the needs of the organizational form of teaching from the point of view of the specific character of the teaching environment. Technical parameters of the flexible tactile sensor depend on the shape and number of electrodes, as well as on the conductive inks used, they are stated and discussed within the article. Due to the large number of collected data, a robot, otherwise used in teaching, was used for obtaining of individual loading characteristics of the proposed sensor. At the end of the article, the results obtained by the statistical processing of the measurements are summarized and discussed.

Keywords: teaching process, school chair, flexible tactile sensor, pressure distribution, educational robot

1 Introduction

Pupils and students spend approximately a third of their daily time at school. The basic equipment of every school facility includes school furniture. Given that children and adolescents spend the majority of their time at school sitting, special attention must be paid to the ergonomic parameters of school chairs in classrooms, which have a significant impact on their health. The teaching process is associated with stress factors that, in addition to negative effects on one's own education, can also cause a whole range of health consequences. In addition to health requirements, school furniture must also meet pedagogical requirements that result from the specifics of the educational process at different types and levels of schools, e.g. ergonomic workspace, variability for different types of classes, or ergonomy requirements. Finally, the the construction of school chairs should respect the anthropometric characteristics of the sitters, too.

Health and pedagogical requirements result in legal requirements, enshrined in laws, decrees and technical standards. Law No. 258/2000 Coll., On the protection of public health [1], deals with the conditions for the upbringing and education. The § 11 paragraph 1 of the Executive Decree No. 410/2005 Coll., On hygienic requirements for the premises and operation of facilities and establishments for the upbringing and education of children and adolescents [2], school furniture must take into account the different body heights of pupils and students and promote healthy posture. Chairs and tables for children and teenagers must also meet the prescribed values of the Czech technical standard ČSN EN 1729-1, which regulates the size indicators of furniture according to age categories [3].

To optimize the shapes of school chairs, it is necessary to investigate the pressure conditions in the space between the seated persons and the chairs. For this purpose, we have developed an original flexible tactile sensor, named SITSCAN CS, enabling detection of differences in contact pressures at individual points of the seats for all age groups of youth. Special attention was paid to the measurement of the transfer characteristic between the pressure acting on the individual sensing sensors and the corresponding electrical resistance. Due to the large scale of measurements and the high demand for accuracy, a robot was used for these purposes, which is available at the faculty and is commonly used in teaching. The obtained measurement results were then statistically processed and evaluated. Basing on the results, a specific combination of electrode dimensions and used ink layer was selected for the development of the flexible tactile sensor.

There have been researched several technologies to act as a transducer between applied pressure on a surface and output electrical quantities. Among the most important technologies used in such pressure mapping systems belongs the piezoresistive, capacitive, triboelectric and piezoelectric technology. Each of them has its specific sensor construction, available pressure range, sensitivity, fabrication demands and other individual properties, limitations and advantages. An extensive overview about the topical research in this field can be found in [4, 5, 6]. As a follow-up to this, we developed a prototype of the new flexibe tactile sensor and we performed some introductory measurements to verify the ability of the sensor to obtain load maps on different types of school chairs, which are the basis for manufacturers in the development and subsequent production of new types of school chairs and the shaping of their contact surfaces.

2 Materials and methods

The proposed measuring system should be primarily able to adapt to uneven surfaces. The base of the sensor board is a sufficiently elastic film on which the sensor matrix of electrodes is placed, the possibility of manufacturing the sensor matrix using PCB technology (printed circuit board) will be preferred. Based on the expected use, the pressure of a sitting person on the seat of the chair in the area of the pelvic bones was roughly calculated (2 x contact area 40 x 40 mm, weight acting on the seat of the chair 38 kg). The calculated value is approximately 120 kPa, on the basis of which a basic measuring range of 30 - 200 kPa was determined in order to cover areas of lower pressures, as well as possible peak pressure values. For the given purposes, the relative distribution of pressure will be sufficient, and especially the detection of the places of maximum contact pressure values. This purpose should be achieved by means of an A/D converter and the display of relative pressure on a color scale, with the possibility of amplifying or shifting the zero-reference signal. The sensing plate for the given use should have dimensions of approx. 500 x 500 mm with a minimum required resolution of 1 sensor per 1 cm^2.

Basing on our previous research and contribution of other authors, the sensor will be based on the piezo-rezistive technology [7, 8], i.e. changing the resistivity of the material under the applied pressure, the technology enables sufficient flexibility and manufacturing with the PCB method. The electrode matrix will be printed on a deformable PET plate, which exhibits appropriate mechanical properties for the given purpose; more about mechanical properties of different polymer materials see in [9]. The entire measuring system SITSCAN CS consists of the sensing plate, of electronic circuits to evaluate and process the data of individual rows and columns of the tactile matrix and of PC control program. It includes basic tools for capturing, storing and displaying data with expansion options for further analysis. The program allows you to save individual images and record video sequences. The pressure on the pad is displayed in the color scale gray (no measurable load) - blue - green - yellow - red from the lowest to the highest load in 256 levels, red color (value 255 of the 8-bit A/D converter) represents the maximum pressure value in the given range. The tactile system SITSCAN CS including the sensing plate, electronic circuits and a laptop running the control program are depicted in Fig. 1.

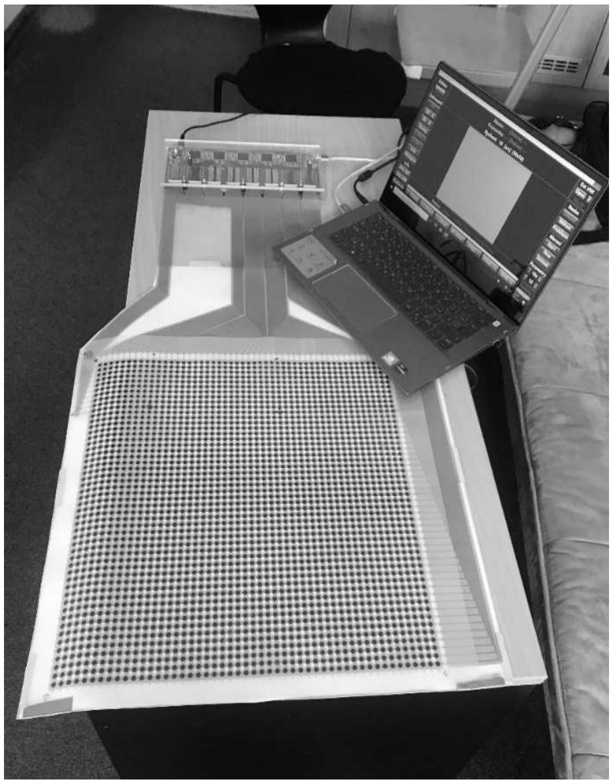

Fig. 1 *Flexible tactile system SITSCAN CS*

The basic requirement for the developed sensor is to convert the pressure to another quantity suitable for further processing, in the given case to electrical resistance. Similar research of electrical conductivity with different materials (rubber and conductive carbon particles) is described e.g. in [10], another example of using a mat to force measurement in automotive industry is stated in [11]. The sensor should be able to record the pressure caused by the sitting of large groups of the population - from the youngest pupils to university students, while the optimal course of its loading characteristic would be linear. Its course depends on the shape of the electrodes, their surface and the conductive ink used. For this purpose, a large number of measurements had to be made at various magnitudes of pressures on the sensor; this requirement was best met by the use of a robot. The methodologies for various types of measurements of mechanical quantities are described e.g. in [12, 13], general advantages of robotization in research and production are stated in [14]. The block diagram of the measurement chain is displayed in Fig. 2 below.

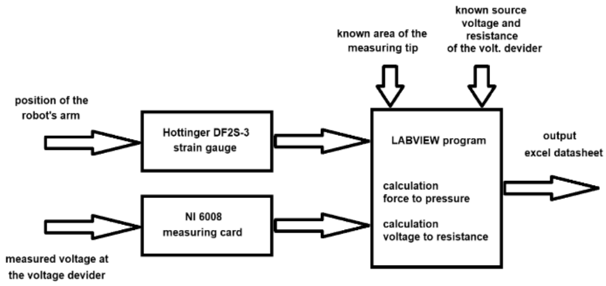

Fig. 2 *Block diagram of the measurement chain*

In view of this, a Bosch TurboScara SR 60 robot (Fig. 3) was used for the measurements in conjunction with a Hottinger DF2S-3 strain gauge force sensor (Fig. 4). The loading force from the robot arm was exerted in the range from 0.4 N to 18 N. The pressure acting on the electrodes was calculated from the known surface area of the measuring tip (D = 4 mm, i.e. S = 12.56 mm²) and the applied force, which corresponded to range of pressure values from approx. 30 kPa to approx. 1,400 kPa for a specific measuring tipentire measuring system consisted of a PC running the LabVIEW application for visualization and data storage, an NI 6008 measuring card for capturing the electrical voltage, and an ALMEMO 2890-9 measuring center that evaluated the signal from the strain gauge force sensor.

Fig. 3 *Robotized workspace with the Bosch TurboScara SR 60 robot*

Fig. 4 *Hottinger DF2S-3 strain gauge force sensor placed at the robot's arm*

To determine the characteristics of the sensor, i.e. the relationship between the applied pressure and electrical resistance, original measurements were made of a total of 162 samples of various sizes of electrodes and mixtures of conductive inks Loctite NCI 7002 and ECI 7004. For each individual combination of the electrode size and ink layers, the robot's arm performed an automatic movement in the vertical direction divided into 20 steps of 20 μm, with a time interval of 19 s between each step, so that the measurement application could take 5 separate readings of voltage values, corresponding to the electrical resistance values. This way we obtained several loading characteristics, i.e. the relation between the applied pressure and electrical resistance.

The course of the dependence of the electrical resistance on the load met the general assumptions according to the literature and previous research [15]. A significant drop in electrical resistance in the initial phase was followed by a less steep drop, and then the saturation region, when the electrical resistance drops very little or not at all. This is because the microparticles in the material are already compressed to the maximum level and their electrical conductivity does not increase any further. This phenomenon generally occurred in the range of pressures above 500 kPa, however, this limit varied greatly for individual combinations of electrodes and inks.

After assessing all the individual courses of electrical resistance in dependency on the applied pressure, the most convenient electrode - ink combination was selected and measured again with finer, 10 μm step. The resistance characteristic of this electrode measured in 10 μm steps with uncertainties is shown below on the graph in Fig. 5, this electrode is characterized especially by its stable behavior in the area of lower pressures, without fluctuations in the course.

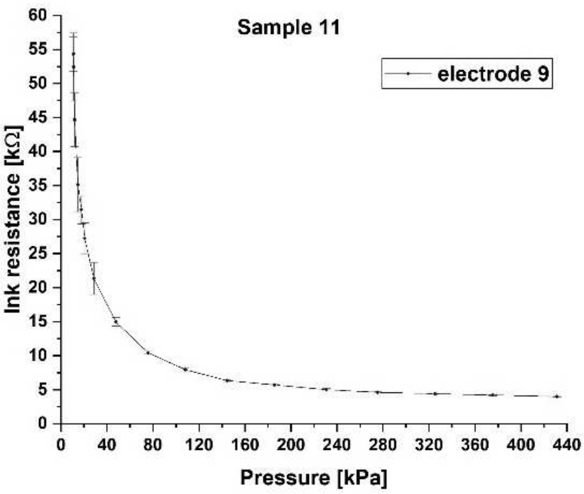

Fig. 5 *Dependency of the electrical resistance on the applied pressure, step 10 μm*

3 Results and discussion

The tactile system SITSCAN CS has been subsequently tested to see if it meets the specified requirements. As part of the initial testing measurement, we compared the properties on five different chairs, see Fig. 6. Of these, there were three older VQ-type constructions currently delivered to schools and two, as part of the project, newly developed PINNA-type chairs, which will begin to be delivered to schools. For comparison, we measured the distribution of pressures when sitting on all five types of chairs. The measured pressure distributions are shown in Fig. 7 and Fig. 8.

Fig. 6 *Tested chairs. 1 – VQ big; 2 – VQ medium; 3 – VQ small; 4 – PINNA big; 5 – PINNA small*

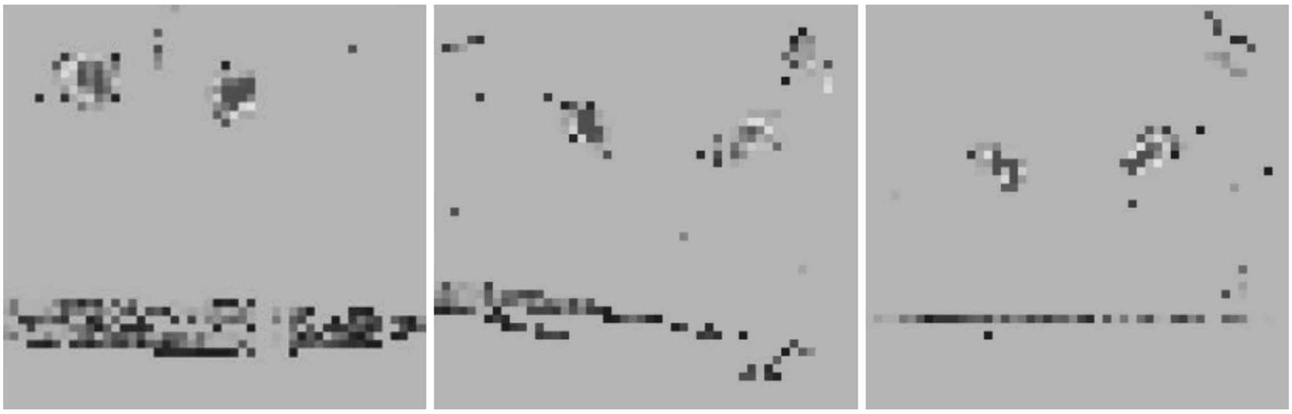

Fig. 7 *Pressure distribution on the chair seats (from left: VQ big; VQ medium; VQ small)*

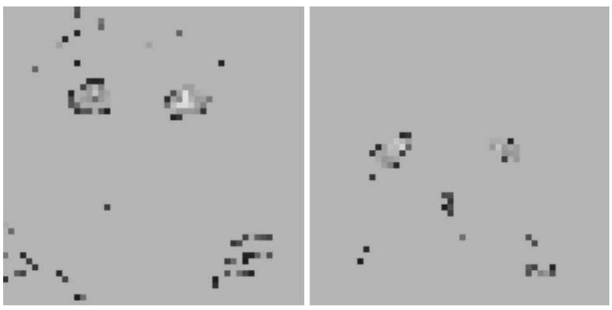

Fig. 8 *Pressure distribution on the chair seats. From left: PINNA big; PINNA small*

In general, the new developed tactile sensor proved its ability to measure the pressure distribution on uneven surfaces, specifically on chair seats. However, there are minor deficiencies of the tactile sensor, namely limited flexibility and insufficient sensitivity in low pressure ranges. Both issues will be disposed by appropriate technological improvements during the further development.

If we look closely at the pressure distribution on the seats for individual types of chairs, we can see a significant difference between the old (VQ) and new (PINNA) chair construction. The seats of the VQ chairs are made of shaped plywood, while the new design of the PINNA chairs is a solid molding. On the VQ chair seats, there is a significant load on the pelvic bone (red color), and thus a relatively uncomfortable seat, when pain occurs in this area when sitting for a long time, so the sitting person searches for a position where these areas do not hurt; it is known situation on the seats in the auditoriums. With the new design of the chairs, the peak pressures are limited and spread over larger area, so this situation does not occur anymore, and the sitting position is much more comfortable from the point of view of longer sitting.

On the pictures it can be also seen the limited sensitivity on the lower pressure ranges. While the areas with maximal pressure are depicted well (pelvic bones), other areas with lower contact pressures are not visible. This issue can be altered by choosing different settings of the amplification or the zero-shift within the control software. If the sensitivity will be still insufficient, a new sensing plate, with different, more conductive ink mixture, can be manufactured. The creation of a "spurious" response at the edges (blue line in Fig. 7, where the sensor bends) is inherent in a given material and cannot be eliminated within the given design.

4 Conclusion

The main goal of our research was to provide technical data for the design and production of a new range of school furniture, which would not only meet all the requirements of legal regulations and technical standards, but also respect the opinions of experts - mainly from the ranks of doctors for children and adolescents - on health suitability, safety, ergonomics and design. The newly developed flexible tactile sensor enables objective testing of the seats of school chairs by sensing the instantaneous values of the contact pressure distribution between the seated person and the seat. The differences in individual types of school chairs can be seen from the measured load maps.

For this purpose, it was developed an original flexible tactlile sensor that can adopt uneven surfaces; the whole tactile system including the electronic interface and control PC program was subsequently tested in real conditions. After some minor adjustments and improvements, the tactile system will find practical use at the company Santal, s.r.o., where the measured load maps will serve as one of the bases for the development of a new series of school chairs.

In conclusion, it should be mentioned that thanks to the chosen concept and the PCB production technology, the developed sensor can also find application in several areas in the technical, agricultural and medical fields. The measuring range of the sensor for different applications can be changed to a smaller extent through the user software, if a larger change is necessary, a sensor of other dimensions or with a different ratio of conductive inks can be produced at minimal costs. The printing technology enables a fast and cheap method of manufacturing the sensor plate according to the specified requirements, including the desired size and resolution of the sensor matrix.

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