VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

FACULTY OF MECHANICS

DEPARTMENT OF MECHANICS, ROBOTICS AND DIGITAL MANUFACTURING

Rokas Dvarvytis

HUMAN SITTING POSTURE ANALYSIS USING LOW COST PRESSURE SENSING MATRIX

ŽMOGAUS SĖDĖSENOS ANALIZĖ NAUDOJANT NEBRANGIĄ SLĖGĮ MATUOJANČIĄ MATRICĄ

Final Master’s thesis

Study programme MECHATRONIC SYSTEMS,
Code 6211EX053

Vilnius, 2021

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

APPROVED BY
Head of Department

____
(Signature)
____
(Name, Surname)
____
(Date)

Student's Name and Surname

HUMAN SITTING POSTURE ANALYSIS USING LOW COST PRESSURE SENSING MATRIX

Final Master's thesis

Study programme MECHATRONIC SYSTEMS,
Code 6211EX053

Supervisor: ____________________ ________ _______
(Title, Name, Surname) (Signature) (Date)

Vilnius, 2021

Vilniaus Gedimino technikos universiteto egzaminų sesijų ir baigiamųjų darbų rengimo bei gynimo organizavimo tvarkos aprašo
2 priedas

(Baigiamojo darbo sąžiningumo deklaracijos forma)

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Rokas Dvarvytis, 20146763

(Studento vardas ir pavardė, studento pažymėjimo Nr.)

Mechanikos fakultetas

(Fakultetas)

Mechatroninės sistemos, MSfm-19

(Studijų programa, akademinė grupė)

BAIGIAMOJO DARBO (PROJEKTO)
SĄŽININGUMO DEKLARACIJA

2021 m. gegužės 10 d.

Patvirtinu, kad mano baigiamasis darbas tema „Žmogaus sėdėsenos analizė naudojant slėgį matuojančią matricą“ patvirtintas 2021 m. balandžio 19 d. dekano potvarkiu Nr. 87me, yra savarankiškai parašytas. Šiame darbe pateikta medžiaga nėra plagijuota. Tiesiogiai ar netiesiogiai panaudotos kitų šaltinių citatos pažymėtos literatūros nuorodose.

Parenkant ir įvertinant medžiagą bei rengiant baigiamąjį darbą, mane konsultavo mokslininkai ir specialistai: daktaras Andrius Dzedzickis. Mano darbo vadovas daktaras Inga Morkvėnaitė-Vilkončienė.

Kitų asmenų indėlio į parengtą baigiamąjį darbą nėra. Jokių įstatymų nenumatytų piniginių sumų už šį darbą niekam nesu mokėjęs (-usi).

(Parašas)

Rokas Dvarvytis

(Vardas ir pavardė)

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS
MECHANIKOS FAKULTETAS
MECHATRONIKOS, ROBOTIKOS IR SKAITMENINĖS GAMYBOS KATEDRA

TVIRTINU
Katedros vedėjas

Gamybos inžinerijos studijų kryptis

Mechatroninės sistemos studijų programa, valstybinis kodas 6211EX053

(Parašas)
Vytautas Bučinskas
(Vardas, pavardė)
2021-04-01
(Data)

BAIGIAMOJO MAGISTRO DARBO
UŽDUOTIS

2021-04-01
Vilnius

Studentui Rokui Dvarvyčiui

Baigiamojo darbo tema: Human sitting posture analysis using low cost pressure sensing matrix

Patvirtinta 2021 m. balandžio 19d. dekano potvarkiu Nr. 87me

Baigiamojo darbo užbaigimo terminas 2021 m. gegužės 14 d.

BAIGIAMOJO DARBO UŽDUOTIS:

1. Baigiamojo darbo tema atlikti mokslinės literatūros apžvalgą ir analizę;
2. Sukurti slėgį matuojančią matricą, sudaryti eksperimentinio tyrimo metodiką, atlikti eksperimentinius tyrimus ir ištirti žmogaus sėdėjimo pozicijas;
3. Pateikti atliktų bandymų rezultatų analizę, išvadas ir rekomendacijas.

Baigiamojo darbo rengimo konsultantai: dr. Andrius Dzedzickis.

Vadovė .... dr. Inga MorkvėnaitėVilkončienė
(Parašas) (Moksl. laipsnis/pedag.vardas, vardas, pavardė)

Užduotį gavau
....
(Parašas)
.......Rokas Dvarvytis..............
(Vardas, pavardė)
2021-04-01
(Data)

Vilniaus Gedimino technikos universitetas
Mechanikos fakultetas
Mechatronikos, robotikos ir skaitmeninės gamybos katedra

ISBN ISSN
Egz. sk. ....
Data ..........-.....-.....

Antrosios pakopos studijų **Mechatroninių sistemų** programos magistro baigiamasis darbas 4

Pavadinimas **Žmogaus sėdėsenos analizė naudojant slėgį matuojančią matricą**

Autorius **Rokas Dvarvytis**
Vadovas **Inga Morkvėnaitė-Vilkončienė**

Kalba: anglų

Anotacija

Nuolat besiplečianti IT ir kitos sritys pritraukia daugumą kvalifikuotų specialistų dirbti įmonėse, kuriose vyrauja biuro tipo sąlygos. Pastovus sėdėjimas žymiai padidina darbuotojų nusiskundimus nugaros skausmais, maudimu, kurie yra pirminiai ženklai vedantys link stuburo traumos – skoliozės. Atsižvelgiant į tai šio tyrimo tikslas – padėti identifikuoti pagrindines žmogaus anatomijos charakteristikas, atsakingus už tinkamą kūno masės paskirstymą ir išskirti žmonių grupę, kuri turi didžiausią riziką patirti stuburo traumą. Šiam tyrimui buvo sukonstruota 8x8 matrica. Velostat® yra šios matricos pagrindas, kuri pasižymi lankstumu, reagavimu į apkraunamo slėgio pokyčius ir žema kaina. Išvesties rezultatams surinkti naudojamas multiplekseris. Po kalibravimo biuro aplinkoje buvo ištirti 9 dalyviai. Įvertinant dalyvių kūno masės paskirstymo matricas galima pastebėti, kad dalyviai su mažu BMI koeficientu, pasižymintys mažu aktyvumu turi didžiausius šansus sukelti kraujo tekėjimo ir stuburo srities problemas. Efektyviam kūno masės paskirstymui yra reikalingas tinkamas raumeninio ir riebalinio sluoksnio santykis. Šis tyrimas padės labiau stebėti ir įvertinti biuro aplinką, kad būtų galima išlaikyti gerą darbuotojų sveikatą ir padidinti produktyvumą. Darbuotojams suteiks daugiau informacijos koks gyvenimo būdas yra jiems labiau tinkamas ir kokias sėdėjimo pozicijas rekomenduojama labiau vengti.

Prasminiai žodžiai: sėdėjimo pozicijos; stuburo trauma; matrica; Velostat®; multipleksersis, BMI indeksas.

Vilnius Gediminas Technical University
Faculty of Mechanics
Department of Mechatronics, Robotics and Digital Manufacturing

ISBN ISSN
Copies No. ....
Date ..........-.....-.....

Master Degree Studies **Mechatronics Systems** study programme Master Graduation Thesis 4

Title	**Human Sitting Posture Analysis Using Pressure Sensing Matrix**
Author	**Rokas Dvarvytis**
Academic supervisor	**Inga Morkvėnaitė-Vilkončienė**

Thesis language: English

Annotation

Booming IT, industrial fields attract many new employees to change their working place to an office environment. Prolonged sitting has increased complains about back pain, soreness, which can lead to spinal trauma – scoliosis. Therefore, the purpose of this research is to help identify main human body characteristics responsible for good body mass distribution and identify specific category, which have the highest change having spinal trauma. For this research 8x8 pressure matrix was built. For this were used key material – Velostat®, which is well known for its flexibility, pressure sensing and low price. For data gathering a multiplexer was used. After calibration 9 participants were evaluated in an office environment. After participant matrix map analyzation can be noticed, that subjects with small BMI index, low physical activity have the highest risks for blood supply distortion and spine, muscular disorders. For sufficient body mass distribution an appropriate muscle and fat ratio in the buttock area is required. This research will help to monitor office environment and increase worker’s healthiness and productivity. For employees would give good information what lifestyle is the best for a health and what sitting postures should be avoided.

Keywords: sitting posture; spinal trauma; matrix; Velostat®; multiplexer, BMI index.

CONTENTS

ILIUSTRATION LIST

TABLE LIST

GRAPH LIST

LIST OF ABBREVIATIONS

IT – Information Technology

LED – Light Emiting Diode

ADC – Analog to Digital Converter

CS – Compressed Sensing

I/O pins – Input/Output pins

EMFi – Electro-Mechanical Film sensor

BMI – Body Mass Index

PHR – Photoresistor

HS – Hall‘s Sensor

FSA – Force sensing arrays

PCB – Printed Circuit Board

USB – Universal Serial Bus

Force DI – Force Dispersion Index

STDEV – Standard Deviation

Min-BMI – Participants with smallest BMI from 20 to 22.4

Avg-BMI – Participants with BMI, which is closest to overall BMI average, from 24.1 to 25.4

Max-BMI – Participants with Highest BMI from 25.6 to 29.8

Min-Active – Subjects with monthly steps per month between 184320-247435

Avg-active – Subjects with monthly steps per month between 247435-310551

Max-Active – Subjects with monthly steps per month between 310551-373666

INTRODUCTION

Research problem. Daily work in IT field, in an office, monotonous sitting posture can lead to upper extremity disorders – pain and functional impairment, deformation of soft tissues, disturbance of local blood supply and lymphatic circulation. Inappropriate sitting can lead to spine, muscular disorders, hospitalisation, or inhalable trauma. For that reason, many measuring methods as facial recognition or vocal expressions were used, but they do not give scientific indisputable results. For that reason, various sensors are used – they give measurable results, which are more understandable and can be visually shown in graphs.

Research object. 9 office workers, sitting positions next to workstation analysis using built pressure sensing matrix.

Aim of the thesis. Analise human body anatomy, responsible for body mass distribution, identify category of people who have the highest risks to have spinal disorders.

Tasks of the thesis.

1. Based on scientific literature identify usable types of sensors, pressure matrix architecture and working principal.
2. Gather knowledge what parameters are identified in pressure matrixes.
3. Build low-cost pressure matrix, complete calibration.
4. Measure office worker's sitting postures in their task environment.
5. Categorize participants according to specific criteria.

Master thesis structure. in the first chapter of master thesis, the importance of human posture evaluation is raised, pressure matrix application capabilities, system structure schemes and working principles are explained. In the second chapter, low-cost pressure matrix construction explanation, calibration process and analysed matrix parameter identification. Pressure matrix results and patrial conclusions are presented in the last chapter. At the end is identified human body characteristics responsible for human mass distribution and category of people, who have the greatest risk of spinal trauma while sitting in an office environment.

Research methodology:

Analysis of scientific literature.

Design and manufacturing of low-cost pressure sensing matrix.

Calibration of pressure sensing matrix.

Sitting posture identification and human posture analysis based on matrix data observation.

1. LITERATURE REVIEW

1.1 Relevance of pressure sensing system

In previous decade nurses and doctors evaluated human postures – used visual evaluation and questionnaires to determine spinal cord disease. It is easy to carry out and gives fast results. But this kind of subjective analysis does not give any kind of numbers to prove diagnosis. Sometimes these primitive analyses can correctly diagnose disease improper curvature of the spine can be seen by the eye. If there are doubts, an X-ray can be taken. However, the patient then receives hazardous rays. When cameras were starting to be used for diagnosis, hospital personnel felt, that despite improved evaluation of human posture they violate human rights for privacy (J. Heinrich, 2004). Human body movement can be evaluated using cameras in different angles that way creating 3D projection, or attach sensors where joints are. But this kind of method is complex, needs time for data processing and training additional personnel that could use it.

As alternative for these tests had been developed various pressure sensing planes. For example, rigid force plates, which use accelerometer to analyse human in standing or sitting position. That type of measure is inaccurate and does not give mass distribution map, so it not used often. As a solution other, more flexible systems were created. Today new pressure sensing systems are so advanced technology that they can be integrated to our clothing, cushions and chairs to analyse pressure distribution (W., Xu, et. al., 2013, M. Huang 2017), amplitudes and even respiration, sleeping posture (V. Casey, 2011, R. Zemp 2016, J. Meyer 2010). Moreover, systems can be installed with sitting supporting surface to correct wrong sitting position, alarm person and reduce risk to have ulcers on buttocks (C. Sun, 2017, H. C. Yu, 2014). But these ,,intelligent“ systems have several huge disadvantages: they are expansive due to requirements for medical equipment and presented data is complex, which is difficult to interpret (R. Barba, 2015). For that reason, scientists are focused on cheaper alternatives, which could digest collected data and present in a way, that won't need doctor 's interference.

The system can be applied to number of different fields: from medicine (J. Heinrich 2004, W. Xu, 2013, D. Jun, 2016) to psychology (S. Anderson 2013, J. Bao, 2013, M. Huang 2017). The system can be adjusted for these features:

Trauma diagnosis – the system can not only measure pressure sensing map, calculate amplitudes, classify it and objectively label sitting positions. This classification principle can be adjusted for trauma diagnosis in medicine field. This system saves doctors time and provides essential information about encountered trauma.

Posture surveillance and control – the pressure measurements can be useful in rehabilitation field. In hospitals people, who must stay in bed or in wheelchair have a higher chance for ulcer emergence due to bad posture. For that reason, pressure sensing systems can not only identify bad sitting position but adjust it with supporting planes. In this system can be implemented an audio alarm signal or LED lights to inform person or hospital personnel about inappropriate patient position.

Human psychology's analysis – pressure sensing in real time can be applied analysing human behaviour while sitting and participating in conversation. As result people, who more often change their sitting posture participate in conversation more. Moreover, from pressure distribution map you can determine when a person is bored or exited (M. Huang 2017). This kind of system is useful for danger prevention – it can recognise stressful people in a public, like terrorists and alarm policeman for incoming danger (B. Zhou, et al. 2014).

1.2 Pressure sensing system – working principle.

Pressure sensing system is made of conductive planes (outer, inner), sensors, hardware and software. The main goal of every pressure sensor is to measure inner layer deformation in one small area. In whole plane are many sensing areas, which combined form a matrix. This kind of system is capable to present the data using computer.

Deformation of inner layer can be measured by sensors. They can be of various types and measure different characteristics. Systems measured values are voltage drop or rise in one area. Voltage changes depend on sensors resistance. This phenomenon is called pieziorеsistive behaviour (R. Barba, 2015, B. Zhou, et al., 2014). When the force is not applied the sensor's resistance is very high. When the force interacts with plane the resistance drops, and voltage increases accordingly (Fig 1.1).

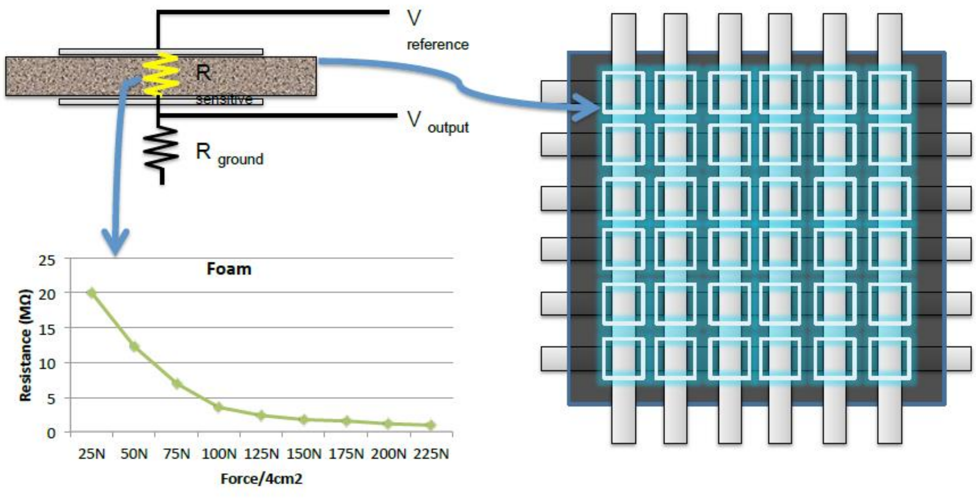


Fig. 1. 1 Pressure sensing principle. (R. Barba, 2015)

The basis of this system is a large area of material with high resistive characteristics that can be locally reduced by applying force (Huang 2017). The force vs. resistance is shown in fig 1.1 bottom left. When resistive material was chosen, array of conductive lines were attached to the upper and lower side in such way that the lines on the lower side are perpendicular to the lines on the upper side. Each sensing element can be read by measuring the resistance between the respective horizontal and vertical line.

Designing pressure sensing system needs to reconsider required inputs, that system could present needed outputs (results). For that are raised main requirements for processing electronics (M. Huang 2017):

Settling time. It is property to react in applied external forces. The reaction time depends on used sensors – appproximally it can be from 1ms – 2 min.

Spatial resolution. Appropriate pixel density is essential for recognizing shapes of objects. Higher density would give a more detail view, but it also significantly increases the amount of data. Density depends on sensors matrix scale. The quality of resolution depends on used number of bits.

Measurement sensitivity and dynamic range. Studies have shown that different tester masses have an impact to different results. Measurable mass limits are 100 g - 100 kg.

Sample rate. To collect data sampling frequency is needed. Appropriate frequency gives important data without requiring large amount of memory. In this article was taken 10 Hz, 50 Hz within respect of relative studies.

1.3 Pressure matrix architecture scheme

According to article (M. Huang 2017) in this scheme (Fig. 1.2), X and Y lines are interacting. The sensor node between each conjunction can be abstracted as a block with an enable input, pinned to the corresponding Y wire, and an analogue output, connected to the X direction. During the scanning procedure, one Y wire is powered each time, enabling the nodes with the same Y to generate output on the X wires. A completed frame is done by sweeping the Y axes to address all the sensor nodes.

High analogue precision always requires low noise level. To achieve this were separated the digital and analogue parts, equipped the analogue part with ultra-low noise power supply ICs. The X electrodes need to be connected to ADC input channels for sampling. In this system multiplexers are used to route analogue signals, but by implementing this update the output has bigger noise levels and settling time.

A master control unit coordinates the scanning sequence, reads the output after ADC sampling, processes the data and sends it to computer. The data transmission method has several options: a serial port, Universal Serial Bus (USB) etc. The choice could be made based on data bandwidth and complexity of information development.

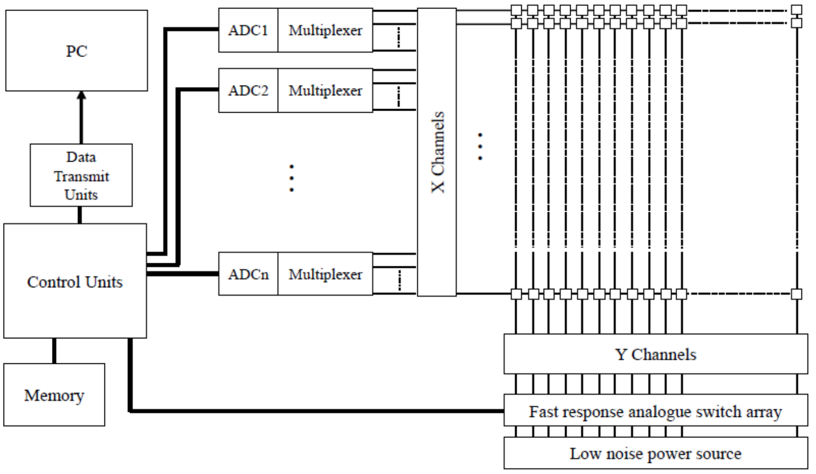


Fig. 1. 2 Matrix data acquisition system architecture. (M. Huang 2017)

As result pressure measuring plane was constructed with 32x32 channels with 16-bit ADC. 1 multiplexer was used for 32 channels, which was integrated to microcontroller. Experiment studied three cases when the sensors plane was used: doing physical exercise, sensing body shapes changes with tight fitting garments, sitting on the table. The research purpose was to create a system that can be applied in different situations and as the result obtain the data (M. Huang 2017).

1.4 Software MATLAB

Signal digital representation needs software, which can read that type of data. According to article (V. Casey, 2011) many have made their own program software, but despite them in several research MATLAB was used as well (D. Jun 2016, J. Bao 2013, R. Zemp, et al. 2016). This program is widely used, has many functions and commands to process data and represent it to audience.

Firstly, when the system is turned on, the MATLAB must read all sensor values, then in function window describe all values as zeros, determine sampling frequency. Then a program collects all sensor data – that is one sampling time. When sampling period is finished system wait while second sampling period have to occur. The results are written as matrix. The matrix size depends on how many sensors are displayed on sensing systems plane. Results are shown in numbers and figures. The bigger the matrix, the higher resolution and number of pixels.

Another function can be written for posture classification. According to articles the system itself recognises the key posture arrangement and can determine if you are healthy or have disease.

1.5 E- textile based pressure sensing system.

E-textile is fibre with coated conductive polymer (J. Heinrich, 2004). It is flexible and biocompatible. It could be used for pressure, strain, stretch measurements. But this material is not studied well yet and what is known now that there are many unstable factors as:

- **Environmental noise –** brings uncertainty to measured values.
- **Offset –** it depends on how thigh the layers are assembled. The more loose the layers are, the less offset would be in the system.
- **Scaling –** it happens when two sensors interact with each other and the voltage value goes up more than usual.

Fig. 2.1 represents the main system ‘s design scheme (J. Meyer 2010). It can have 5 and more layers: two outer and several electrode array planes, conductive material planes (R. Zemp 2016, J. Meyer 2010, A. Fathi. 2017). Outer plane hold system together while the pressure is applied. The plane can be made from silicone or other material – are many options to choose. Second electrode plane can be printed with 3D printer or built from separate electronic parts (V. Casey 2011). The electrodes are in square form, placed all over the plane. Their task is to send electric signal back to electrode through conductive layer. This layer has electric current supply chain. The smaller the distance, the higher value are transmitted. Conductive layer transfers electric current from the top to the bottom electrodes. The signal value depends on how much conductive layer is deformed. Sensitivity range in every article is written differently: it is about 100 g – 100 kg (M. Huang 2017) or 100 – 500 mmHg (R. Barba 2015). The system responds to pressure changes in milliseconds, can measure values in real time.

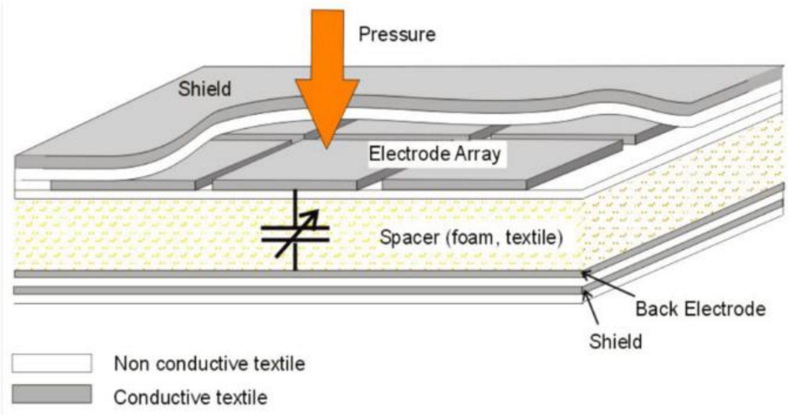


Fig. 1. 3 E– textile working principle (J. Heinrich, 2004)

Pressure measuring system is composed of smart mat embedded with a pressure sensor array, the hardware circuit for acquiring the pressure values and the software for signal processing (V. Casey, 2011). The sensor ‘s initial resistance is very high, when the pressure is not applied. However, the resistance greatly decreases in milliseconds when the force is actuating the sensor plane. Resistance can be changed from 50 Ω to 250 KΩ for a single resistor. According to article (V. Casey, 2011), human applied pressure ranged from 1500N to 4000N.

According to other research (V. Casey 2011) the data was gathered by generating voltage from 1024 sensors. Simultaneously sensors send 1024 voltage values to software, where are converted to 32x32 matrix pressure matrix. The voltage from 0V to 5V is applied to the system and the analogue signals are divided to 255 values, which are represented from blue to red colours. This kind of data extraction is called Compressed sensing (CS) method – the large amount of data can be collected and processed be compressing it. The data is sampled below Nyquist frequency and still gives high quality information. Collected information are processed as fallows: small values from 1024 sensors bin removed because they have less importance and require more time to analyse. For those small signals 1% - 5% from biggest recorded voltage are removed. Of course, smaller percent gives more accurate information.

E – textile according to article (J. Heinrich, 2004) was integrated into system called ,,Smart Cushion system“. The Smart Cushion system is composed from textile sensor array, data aggregator, data analysis module. Author notice, that sensor squares can be any size: this time it is 1.6 cm in 25 cm plane. Data transfer module is based on Arduino hardware. In this case the Bluetooth system was integrated. Data sampling frequency was taken 10Hz, because sitting posture does not vary than other human parts as respiration.

The sensors arrays are divided in two planes, between them are high initial resistance. Working principle is the same as in other articles: when the force is applied to plane, it initiates resistance decrease. For proper work with two sensor layers the third one, conductive must by inserted for pressure sampling. That way for this system only need 2 I/O pins – analogue signal is easy to gather.

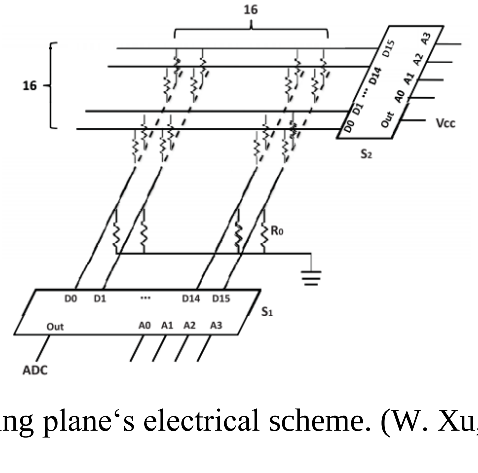


Fig. 1. 4 Sensing plane‘s electrical scheme. (W. Xu, 2013)

Lower layer is connected to ADC from analogue switch module S_1 and to ground via an offset resistor R_0. Every array at the top layer is connected to a voltage supply V_{cc} - S_2. Both S_1 and S_2 are used together to determine which sensor is selected. The scanning sequence is synchronized by a microcontroller. For example, when S_2 connects bus *i* on the top layer to a voltage supply and S_1 connects bus *j* to ADC, Smart Cushion will read the sensor located in row *i*, column *j*, which is denoted as V_{ij} . Therefore, this peripheral circuit has random accessibility for an arbitrary sensor in the system.

The cushion – system can take voltage from only one pair of sensors at the time, and it takes time to register all of them. Because of scaling the values can be unreasonable, so the threshold function was made to calculate probability density function.

1.6 Other sensors-based pressure sensing systems.

Other recommended types of sensors: photoresistor, Hall ‘s and capacitor (EMFi) sensor. Both, photoresistor and Hall’s sensor components change circuit resistance, but photoresistor due light stream (A. Fathi. 2017) and Hall ‘s sensors due changes in magnetic field (R. Zemp, et al. 2016). Changes occur due silicone’s cylinder deformation. These types of sensors rarely had been used before, so several tests must be applied to determine, if sensors could satisfy systems requirements.

Photoresistor and Hall ‘s senor matrixes have pieces of silicone cylinders that would be pushed several times. For Hall ‘s sensor additionally magnet would require. The monometer is used to measure voltage changes. The results would show how voltage change in mV occurs during force presence in the area. Other analysed characteristic would be voltage settling time. It would show how the system can adjust to external forces. Required characteristics would be settling time in milliseconds because human cannot sit always still.

Before photoresistor (PHR) and Hall ‘s sensor (HS) matrix construction, the sensors must be tested for optimization. Both change circuit resistance and photoresistor dependents on light stream density and Hall ‘s sensors on magnetic field. To examine their performance electric circuit constructed in one case with PHR and in other with HS. In first circuit case to evaluate sensor ‘s response was used normal chamber lamp light and later turn on a flashlight. Consequently, the systems voltage must drop accordingly. Most important variables are voltage drop difference, value and time, when the new voltage settle down. After that, the same test is tried when silicone plate is placed on sensor. The same values are measured. In second case for HS optimization additionally would need a magnet. Most important values as mention before are voltage values and time when it settles down. The test again is repeated with silicone plane and placed on senor. The magnet is pushed on silicone plane.

If the photoresistors would be used on the system, then LED light for every PHS must be connected to circuit. Moreover, the light must not interfere to other sensor results because the data accuracy percentage would drop exponentially. To avoid this every matrix unit must be isolated with black tape or paints. If the Hall ‘s sensors would be used, then additionally magnets would be implemented. The magnet must be strong enough that sensor could measure magnetic field changes but weak enough that could not interfere to other matrix unit sensors. That way is kept high system ‘s measurement accuracy.

Capacitor EMFi sensor main advantage is several layers of polypropylene separated by the voids – the force will change the thickness on the polypropylene & void interfaces as result moving to each other, that way charging proportionally to the applied dynamic forces. This type of senor helps to evaluate static (mass) and dynamic (heart rate, breathing) human generated forces (S. Skatch, 2017).

1.7 Human posture research in a literature

Table 1. 1 Human posture research methods & conclusions

Sitting posture classification			
Method	**Participants**	**Conclusions**	**Reference**
8 pressure sensors must be on specific chair locations.	15, male and female	System could classify postures with 98 % accuracy.	(G. Liang, 2017).
Participants asked to sit on three different office chairs. Were used 8x8 textile pressure sensor matrix.	20, (7 females and 13 males) of age 27–57 years, height of 1.60–1.89 m	Specific accuracy of 83%. Participants 45 % of their time was sitting by leaning forward compared to other postures.	(R. Zemp, et al. 2016), (W. Xu, 2013), (G. Liang, 2017)
Analysed from seven, eight to fifteen postures. Eight main sitting postures on a chair.			
240 electrodes (15x16 matrix) built with conductive textiles are arranged on both sides of compressible spacer, forming a variable capacitor	50 participants	After classification, the system’s measuring accuracy became 85.9%. Number of sitting postures are similar to each other and harder to be differentiated from each other.	(J. Meyer. 2010), ,(R. Zemp, et al. 2016), (D. Y. Jun, 2016), (W. Xu, 2013).
The wooden stamp is placed on a sensor with several weights (0.6 kg, 1.1 kg, 1.7 kg, 3kg, 4.3 kg), generated sensors value versus applied force curve.			
Between each measurement, subjects were asked to stand up to reset the pressure sensors as well as to avoid influence of the previous sitting positions on the following one.			

Using accelerometer, gyroscope, magnetometer, human posture evaluated while participant daily works in office environment. Using Naive Bayes method was calculating these elements: 1)Sensor value from each sensor element, 2) Centre of force, 3)Pressure applied to aggregated areas of the seating area	16 females and 25 males with average 38 years age.	Data bin classified with 90 % accuracy. The author of this research highlights the importance of supporting the upper body using the arms to reduce spinal loads.	(R. Zemp, et al. 2016), (J. Meyer. 2010).
Data transferred to software MATLAB with sampling rate of 50Hz, 100 Hz. Data digested using 6 methods: • Support Vector machines, • Multinomial Regression, • Boosting, • Neural Networks, • Random Forest, • Combination of Boosting.	24 males, some of them had muscle or nervous system abnormality; 9 subjects	Using Machine learning and different calculation methods, the data was classified in accuracy from 78 % to 98 %.	(Y. Jun 2016), (J. J. Bao 2013), (R. Zemp 2016), (J. Roh et al. 2018), (J. Meyer 2010)
Other method for data, human postures classification is done by machine learning.		Learning algorithm shows that back sensors have the highest impact to classification accuracy.	
Analysing cushion influence for human mass distribution on different surfaces.			
Participant was asked to sit on three different surfaces: bare floor, office chair, car seat. For research were used Xsensor X3, 48x48 matrix.	1 participant, male 30 years old.	Seat pressure was more even distributed by 7%-41%. The average pressures around coccyx (bone at the base of spinal column) with cushion decreased by 74%, 58%, and 82%.	(D. Y. Jun, 2016)
Pressure distribution analysis by changing angle tilt and back angle in car seat & simulator chair.			
For this research were used Force sensing arrays (FSA). 15x15 matrix at seat level & 15x16 sensors matrix at backrest level.	10 participants.	As result pressure distributed most evenly when back of the chair was in 45° angle from nominal position.	(R. Aissaoui, 2001)
The Arms placed on armrest, back in 90° angle. This first position is determined as nominal. Then the angle was changed with step of 10°. The data compared to nominal position was determined as positive and negative.			
Determining human psychological behaviour			
Research experiment had three chairs with installed pressure sensing system: 8x8 matrix, textile sensors were made from conductive fabric and resistive foam	9 groups of 3 people (11 females and 16 males). The age of participants was between 20 and 40	Sensors show that different patterns of pressure changes across the chair are associated with the different dialogue states. The most sensible pressure sensors were when participant laugh. The pattern of pressure changes found across thighs, buttocks and waist, shoulders.	(B. Zhou, et al., 2014).
Participants had to sit next to a table and solve common dilemma and find an agreement. Conversation time limit was 15-20 minutes. The analysis is focused on three key behaviours: speaking, laughter and backchannels.			
Research purpose – observe human movements in conversation focused on analysing people's leg and torso movements.	9 groups with 3 participants in each. 11 female and 16 males	The results showed that registered different sensor patterns and values are related to specific dialog state. Sensors	(O. Postolache, 2010)

Used microcontroller – Teensy 3.2, 8 piezoresistive sensors.	between 20-40 years old.	mostly were sensitive in talking state, when person leans forward – sensors register higher pressure in tights and reduced interaction in buttocks area. In laughing state results were different, hence sensors on the tights showed lower values and buttocks much higher.	
Eight sensors were arranged in chair seat (1 sensor on one edge, 4 sensors total) and back corners (1 sensor for each edge) to register shoulders, waist, buttock and thigh's movements. Chosen sampling rate – 4Hz.			
Research purpose to quantify specific human behaviour when he is highly, lowly interested in conversation and when taking brake while learning tasks via computer.	8 participants for behaviour classification, 2 subjects to identify his personal interest in conversation.	Data processing and using automated recognition algorithm 6 sitting postures were identified with accuracy 88 %.	(S. Mota. 2003).
2 matrixes made by Tekscan. One matrix resolution 42x48, covering 41x47 cm area			
Sensor matrix placed on seat-pan and on the backrest.			
Posture evaluation with additional observation			
Workers were watched be trained observer, which measured posture load and registered time, spent sitting next to computer.	162 computer workers	32% of all participating computer workers experienced at least four risk factors for postural load. Most frequent risk factors were mouse use with a stretched arm (45%), no support of forearms during typing (41%), hands bend backwards during typing (39%), and illumination problems (39%). The workers with upper body pain simultaneously changed posture to reduce aches in particular body parts.	(S. Anderson, 2013)
Other measured variable was time, spent on using mouse and keyboard while working.			
The data between the testers with and without upper pain was compared.			

For human posture classification analysis was chosen eight sitting postures on a chair: upright sitting (P1), slumped sitting (P2), leaning forward (P3), leaning backward (P4), leaning left (P5), leaning right (P6), right leg crossed (P7), left leg crossed (P8). Having different number of participants, points on a matrix, data processing techniques was reached different accuracy percentage between 78% - 98%.

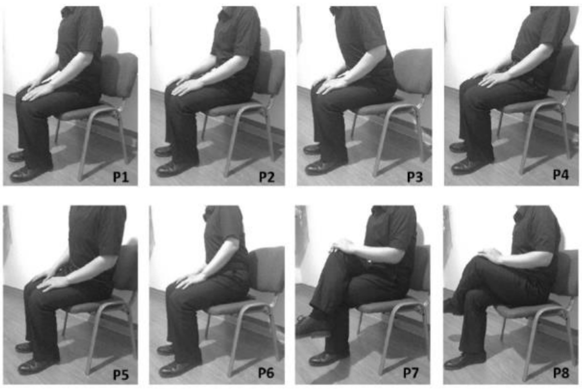
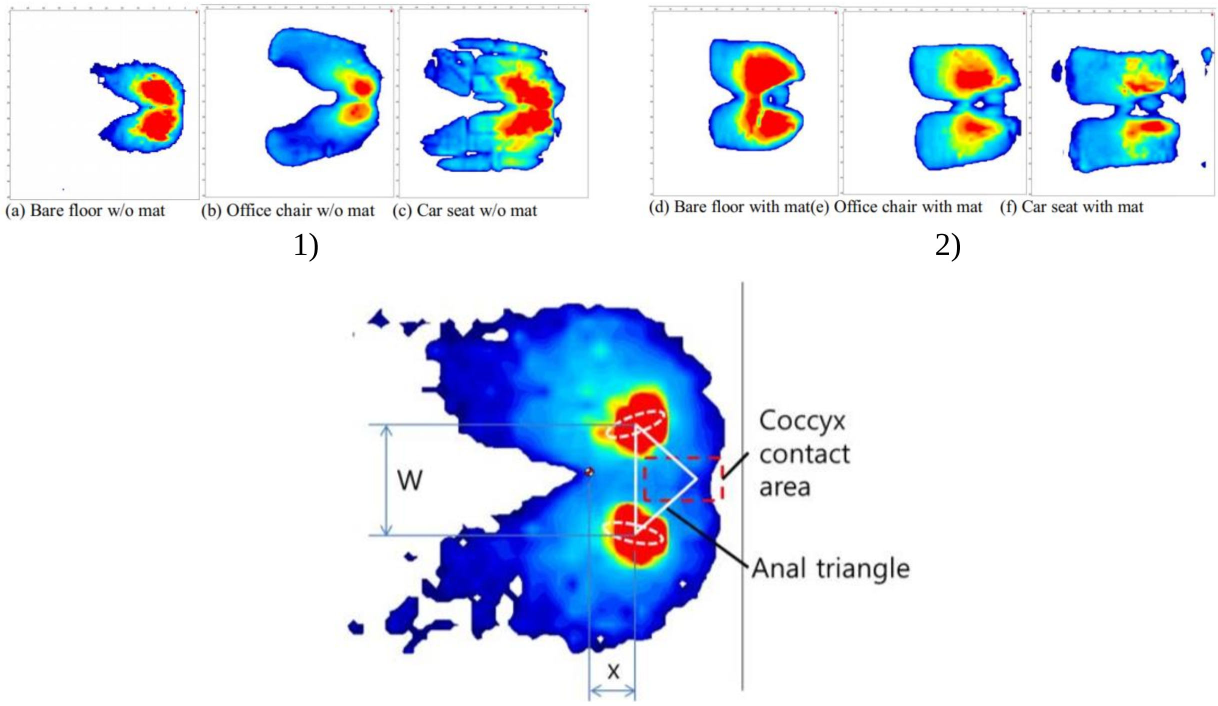


Fig. 1. 5 Different sitting positions (J. Roh, et al. 2018)

According to article (D. Y. Jun, 2016) system can by applied for posture evaluation, because new seat designs at work, car, home have different influence on our posture. For sitting softening the mat was placed below buttock. Two cases analysed – sitting posture with and without mat. What is important to notice that Xsensor X3 PX100:48:48 was used to measure body pressure. Sensor's plane had 48x48 matrix with measurable range about 0.14 N/cm^2 – 2.7 N/cm^2. As test subject were chosen three types of surfaces: bare floor, an office chair and car seat. The results were taken firstly without and secondly with mat.



3)

Fig. 1.6 Pressure distribution without (1) and with (2) mat (D. Y. Jun, 2016)

Main key characteristics seen in pressure distribution map (3).

1.8 Summary of Literature review

Literature review exposed main pressure sensing matrix usage purposes: Trauma diagnosis, human posture & psychology's evaluation. Pressure sensing system is made of conductive planes, sensors, hardware and software. When the inner layer is deformed the pressure is measured by sensors. After every point evaluation is generated pressure distribution map.

Designing every system must be considered main systems requirements: settling time, when the system starts to react to applied force, special resolution as pixel density for object recognition, measurement sensitivity, sampling rate.

Pressure matrix architecture is based on X and Y interacting lines. During scanning faze one Y is powered up each time. From Y flows as output current to X wires. After all X have registered the output, then is powered second Y channel. To achieve high precision must be separated digital and analogue parts, X channels must be connected to ADC input channels for sampling. The master control unit coordinates the scanning process, reads output, digests the data and sends it to computer.

Most common software used for data management and presentation – MATLAB. With program defined sampling rate, digested calibration values, chosen calculation methods and generated final matrix curves, graphs.

Scientific literature proposes sensors with several different measurable characteristics: resistance, capacitance, light intensity, magnetic field. To measure these characteristics are implemented in system different type of sensors: E-textile, Velostat, photoresistor, Hall's sensor.

E-textile based pressure matrixes are priced as low-cost systems. They are known for their biocompatibility and sensitivity for strain and stretch measurements. E-textile is most sensible to environmental noise, offset and scaling. The matrix consists of 5 layers, more can be embedded if necessary. The key layer is conductive one in the middle, which change output voltage as result of applied pressure in that area. At the beginning of measurement process, initial sensor's resistance is high, during applied force on the matrix the sensor's resistance can drop from 250K Ohm to 50 Ohm.

Photoresistor and Hall sensor are used with silicone cylinders. During silicone deformation changes light beam intensity or magnetic field, sensor measured change of resistance and the output transfer to microcontroller. For every Hall's sensor would need additional magnet.

Pressure matrix is suitable for human posture analysis, characterization, optimisation and observing human behaviour – emotions. All research done on an office chair. Before the research is determined a number of sitting postures, from normal to laying position. The data were collected using various size and types of matrixes for better resolution (8x8 textile sensors, 15x15 FSA etc.). Before using the pressure matrix, it must be calibrated, for that purpose various weights were used 0.6 kg – 4.3 kg. Gather data after calibration, sitting posture results can be processed using different calculation methods: Naive Bayes method, Neural Networks, Machine Learning etc. following these methods can be achieved human posture classification with accuracy between 78% - 98%. For human posture optimisation, emotion observation used higher resolution, commercially available matrixes. Participants were asked to turn daily behaviour, that way trying not to change nature human reaction. The results showed that matrix patterns were associated with human emotions as laughing & talking.

2. RESEARCH METHODOLOGY

2.1 Pressure sensing plate design

Constructed pressure sensing plate is 8x8 matrix, made of 35x35cm 0,5mm thick sticky tape (1), 0,5cm copper tape (2), 30x30cm Velostat® (Adafruit Industries) (3). Velostat®, also known as Linqstat, is a packaging material made of polymeric foil, impregnated with carbon black to make it electrically conductive, can change resistance while flexed or pressed. The main advantages of this material are flexible range of dimensions, mechanical and chemical stability and relatively low price (A. Dzedzickis, 2020).

The matrix relates to multiplexer CD74HC4051E and Arduino Uno microcontroller using wires (4) (Fig.2.1 a)). The pressure plate consists of three layers. At the top of the plate the copper tapes are wired horizontally, at the bottom the copper strips are in vertical position. Between the stripes are 3mm distance. The junctions where horizontal and vertical stripes meet can be called sensor points, where the pressure is measured. In the middle section of the plate is added Velostat® pad. The Velostat® is a key material in this project hence it can change his resistance when the pressure is applied.

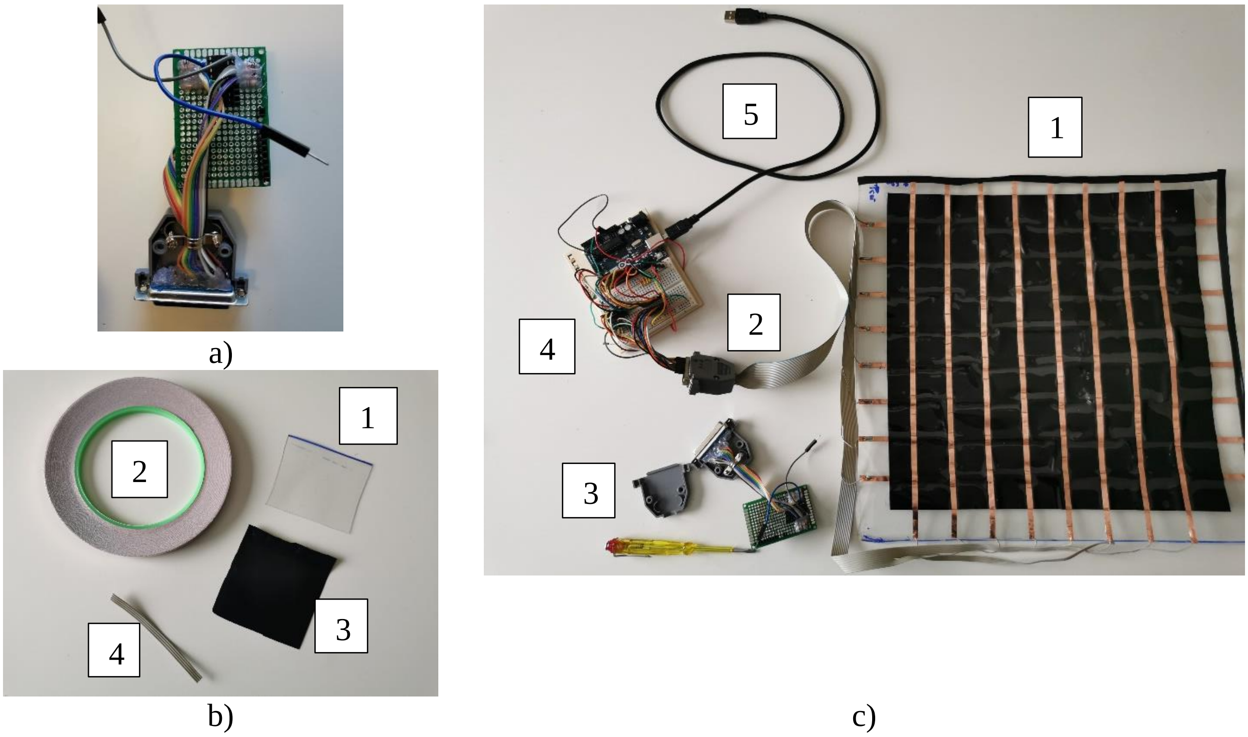


Fig. 2. 1 Parts of pressure sensing matrix. a) Multiplexer PCB board b) Piece of materials used to build a matrix, c) main parts of matrix system.

Matrix system (Fig.2.1, b)) consists of matrix plate (1), 25-pin port (2), multiplexer PCB board (3), layout board with Arduino Uno (4), USB cable to connect microcontroller with computer for data extraction. Data read and pressure sensor control is done using multiplexer. Microcontroller benefit is availability to read many sensor points using several microcontroller pins. Multiplexer was integrated into layout board (4), after successful matrix plate read was soldered smaller version PCB board (3) according to scheme (Fig.2.2).

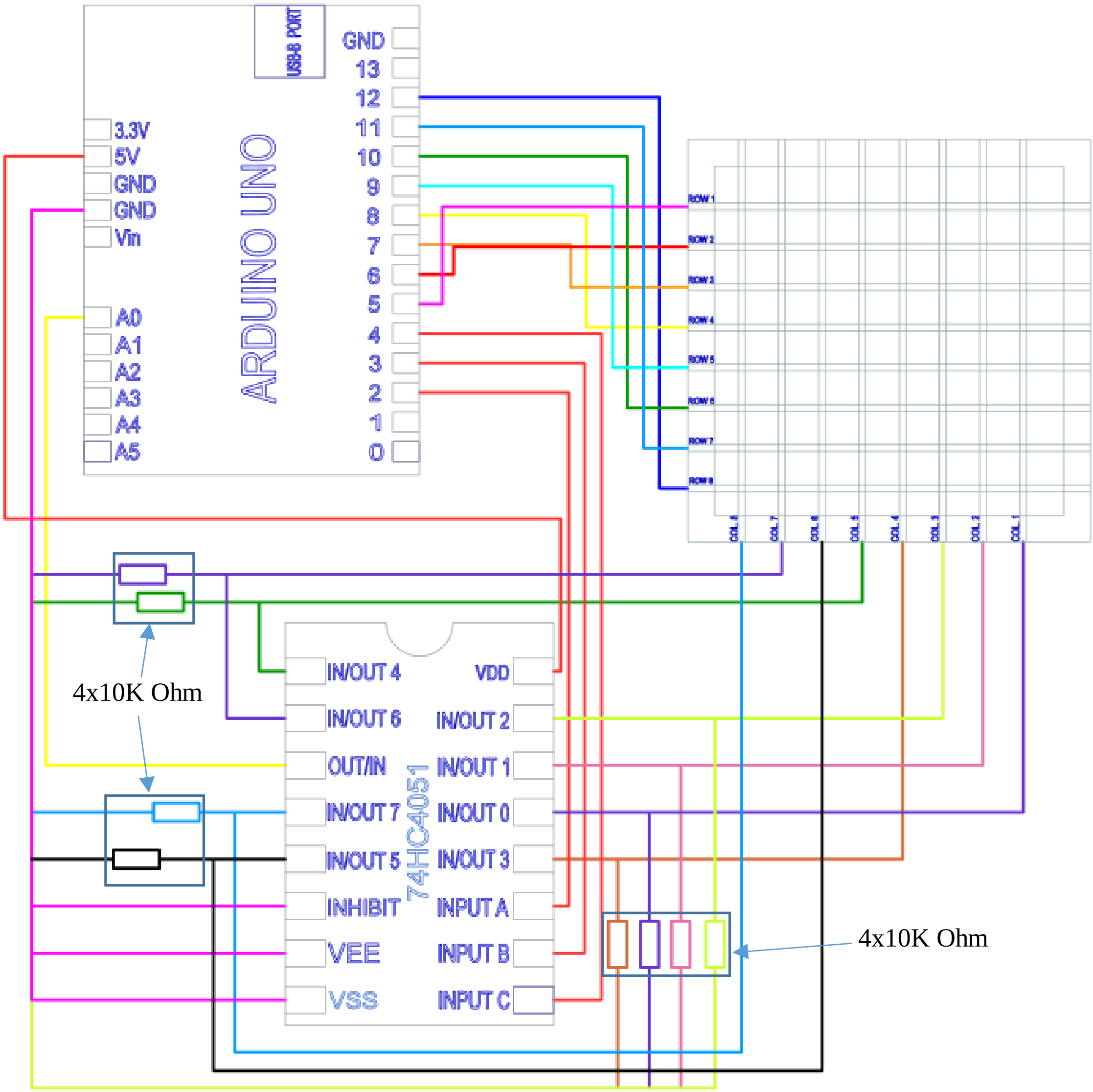


Fig. 2. 2 Matrix system schematics

Pressure sensor's working principle: one row is open (HIGH), and others are closed (LOW). Multiplexer is responsible for column control. The multiplexer has one pin HIGH, others are LOW. When the 5V voltage starts to flow from the open row it goes to the output which has least resistance – where the column is HIGH. When the output reaches multiplexer, it closes first channel and opens the second. 5V voltage then flows through channel 2. The process repeats until channel 8, then counting starts again from channel 1. All eight column values are transmitted through multiplexer's analog pin to Arduino pin A0. At the same time, when channel 8 is closed (LOW), the first-row pin

(HIGH) is closed (LOW) and second is opened from LOW to HIGH. As result 5V flows from row 2, the multiplexer starts the counting and gathers the data by changing all 8 channels LOW-HIGH-LOW. The process repeats when are read all eight rows. When all eight rows from HIGH had been LOW, the Arduino program is completed – the program runs again where it started.

2.2. Calibration

Sensor calibration is done by measuring output voltage response after applied force. To evaluate how the system will respond to applied force 5x5cm width weights for each sensor point were used. Different output voltage values were achieved using different weights: 1-20N. During calibration pressure sensing plate is on flat surface. Output value has been measured 2 minutes after load application, to make sure voltage measurement is in steady state. The sensor calibration curve has been measured by converting 10-bit ADC value to resistance by the following equation:

$$R_{(velostat)} = R_{(reference)} \frac{1024 - V_{(ADC)}}{V_{(ADC)}} \tag{2.1}$$

where $V_{(ADC)}$= 10-bit ADC value, $R_{(reference)}$ = resistor reference on voltage divider (10K Ohm), $R_{(velostat)}$ = sensor matrix resistance.

3.3 Research method

The research purpose was to analyse human posture in office environment. 9 participants: 6 male and 3 females between age of 24-42 years were asked to sit in 7 most common posture positions to reflect different human behaviours next to their desk. 7 different sitting postures were:

1. **Standard:** back support, sitting back with the feet completely flat. This posture is characterized by the body exerting pressure on the back and seat.
2. **Lying:** a posture denoting boredom, where subjects sit up on the air, sitting on the edge of the chair. The body exerts strong pressure on the upper part of the back and the front of the seat.
3. **Tilt forward:** It denotes attention. Subjects sit back, leaning forward, feet under the chair. The body exerts a strong pressure on the front of the seat, without pressure on the back.
4. **Normal position, feet under the chair:** This posture denotes attention, where subjects sit with their back supported, sitting back with their feet completely flat. In this position, the body exerts very little pressure on support and strong pressure on the front of the seat.

5. **Sitting on the edge:** stance denoting attention, where the subject sits on the edge of the chair, back and flat feet completely on the air. No pressure is observed on the back, showing a homogeneous distribution on the seat.
6. **Legs Crossed:** posture denoting peace, subjects sitting normally with legs crossed. Depending on the crossed leg, the weight is concentrated on the right or left of the seat and slightly on an edge of the back.
7. **Lying:** posture denotes fatigue. Subjects sit in are clinging position. In this position a lot of pressure is exerted on both the seat and the backrest.

Between every sitting posture was asked for a participant to empathize into emotion, how he would act in defined sitting situation. With every posture the data was registered by Arduino, raw data digested & reflected with colored matrix map using program MATLAB. The participants were categorized by:

- Sex.
- Health (person with no spinal traumas compared with participant who have sclerosis).
- Body mass index (BMI).
- Lifestyle activity.

Using calibration data values will be generated posture pressure distribution matrix. Using all information from every participant were calculated these parameters (W. Li., 2020):

- **Average pressure –** matrix mean average.
- **Max pressure –** matrix map maximum identified value.
- **Total surface area –** the area of matrix points which reacted to applied force.
- **Mean contact area** – the area of matrix points which reacted to average pressure in a range of deviation of 1 sigma.
- **Max force gradient** – max pressure vector in matrix representing biggest change of pressure between points.
- **Pressure dispersion index (DI) –** statistical coefficient explaining scale of mass dispersion.

Max force gradient was calculated using MATLAB software. Force gradient is a vector which identifies the direction where value increases – the summary of vectors on one point. The vectors are calculated for each point. Pressure distribution index calculated with equation:

$$DI = \frac{Variance}{F_{AVG}} \tag{2.2}$$

where Variance – variance based on the entire matrix, F_{AVG} – average matrix force.

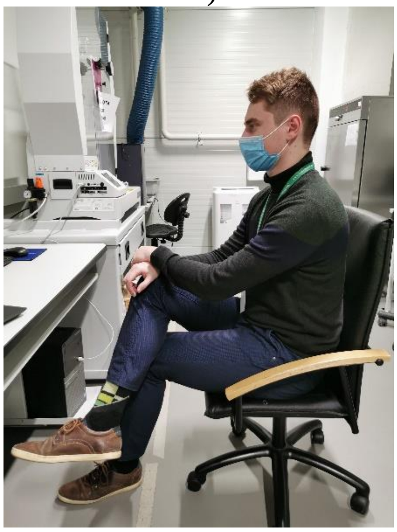

1)


2)


3)


4)


5)


6)

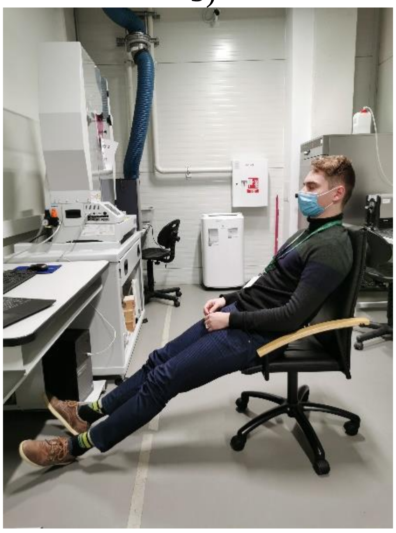
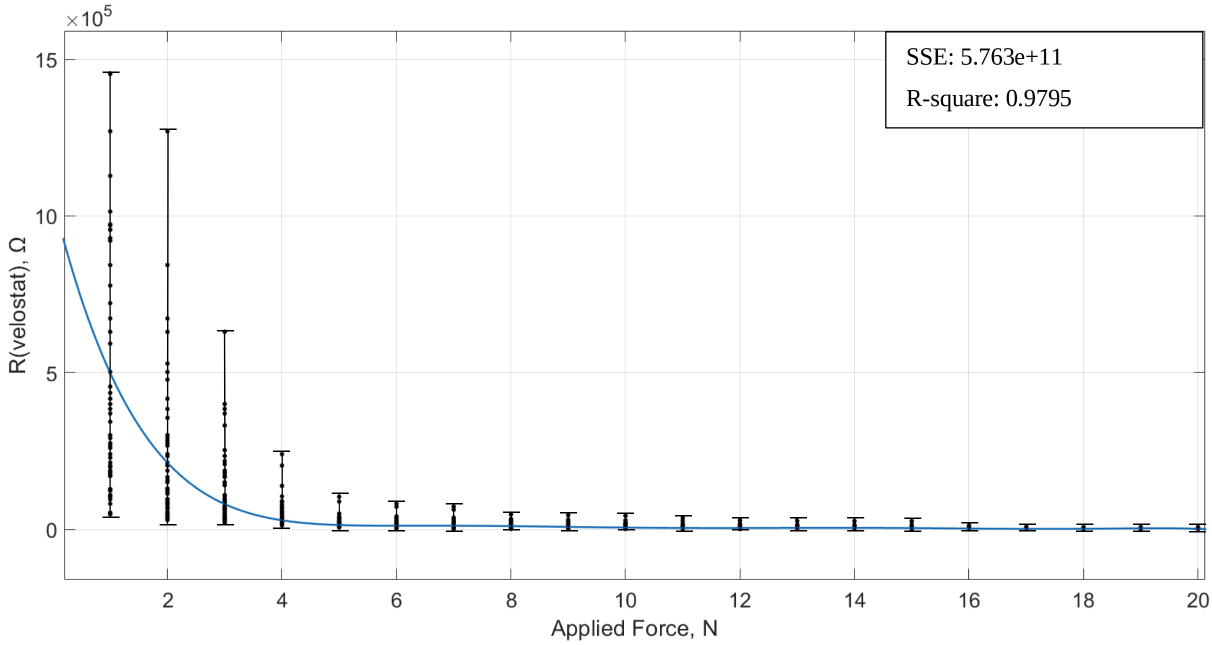

7)

Fig. 2. 3 Seven sitting postures

3. SITTING POSTURE RESULTS

3.1 Calibration results

During calibration were measured Velostat® dependency of applied force. The force linearly increased from 1N to 20N for one point at the time. The results presented in graph 3.1 and were used for raw data converter to final results. The final graph corresponds to resistance curve found in a literature fig. 1.1 (R. Barba, 2015).



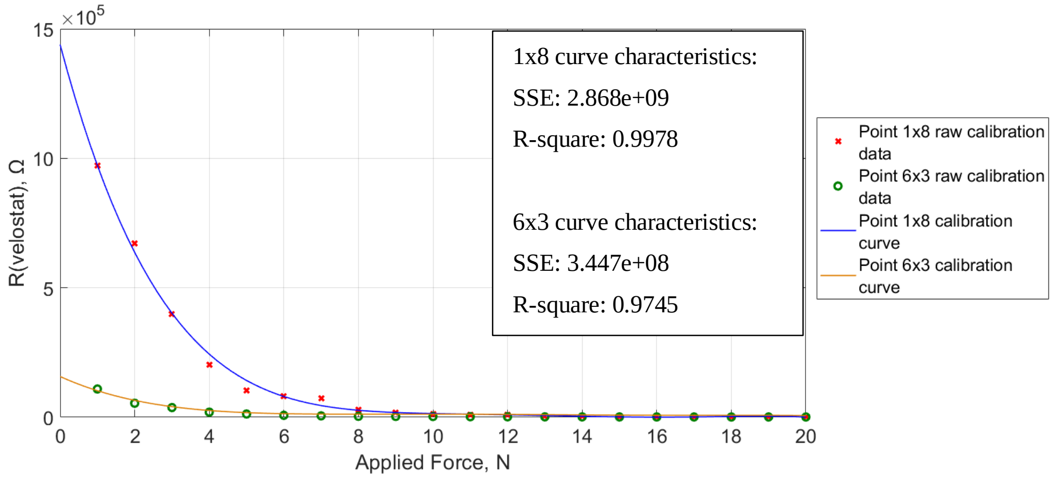
Graph 3. 1 Velostat resistance versus applied force results (calibration curve). SEE – data's accuracy, or the scatter of point about the line for a given value; R-square – statistical measure of fit that indicates how much variation of a dependent variable is explained by the independent variable(s) in a regression model.

Graph 3.1 shows the wide deviation of the sensor results. this wide deviation value is possible because of hand-made manufacturing. Although deviation of 32 samples on sensor matrix is wide, the percentage tends to reduce as the force increases. Manufactured matrix is more reliable to sense high forces.

After calibration, the data were used to generate differential 7-degree polynomial Velostat® resistance equation:

$$R(\mathrm{x}) = (-0.04982) \cdot x^7 + (4.335) \cdot x^6 + (-156.5) \cdot x^5 + (3028) \cdot x^4 + (-3.379\mathrm{e}+04) \cdot x^3 + (2.168\mathrm{e}+05) \cdot x^2 + (-7.41\mathrm{e}+05) \cdot x + (1.054\mathrm{e}+06) \quad (3.1)$$

Due wide deviation of overall sensor calibration curve SEE, to begin with was created one-point calibration curve matrix (two matrix point results can be found in Graph 3.2). One point calibration curves could reduce the deviation for a better accuracy.



Graph 3. 2 One-point calibration curves.

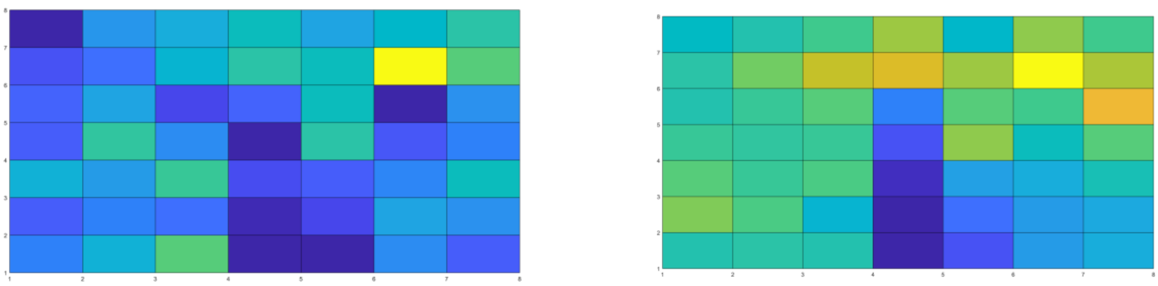
1x8 curve force equation:

$$R(\mathrm{x}) = (-3.237)\cdot x^5 + (225.3)\cdot x^4 + (-6142)\cdot x^3 + (8.216e+04)\cdot x^2 + (-5.428\mathrm{e}+05)\cdot x^1 + (1.439\mathrm{e}+06) \tag{3.2}$$

6x3 curve force equation

$$R(\mathrm{x}) = (-0.5572)\cdot x^5 + (36.66)\cdot x^4 + (-927.2)\cdot x^3 + (1.121e+04)\cdot x^2 + (-6.499\mathrm{e}+04)\cdot x + (1.572e+05) \tag{3.3}$$

All calibration curves were created using program MATLAB application "Curve fitting". After obtaining 32-point calibration curves for comparison were created pressure distribution maps. Two maps show that by increasing system's accuracy it becomes less understandable and readable, when making experimental conclusions (Fig.3.1). For that reason, decided to create one calibration curve using all gather point results.



a) Calibration done using one-point calibration curves

b) Calibration with one general calibration curve

Fig. 3. 1 Human mass distribution maps.

3.2 Research methodology results and analysis of different sitting posture

In this research participated 9 people with the age between 25 – 33 years old, 1,58 – 1,93 m height, 56 – 93,5 kg weight. For this research one participant was chosen as nominal: man, 25 years old without any spinal trauma. Other participant matrixes, conclusions partially will be referenced to his results. The data for each subject were grouper according to specified criteria and compared accordingly. The chosen person as nominal results presented in fig. 3.2 – fig. 3.8, calculated statistical results for each posture in table 3.1.

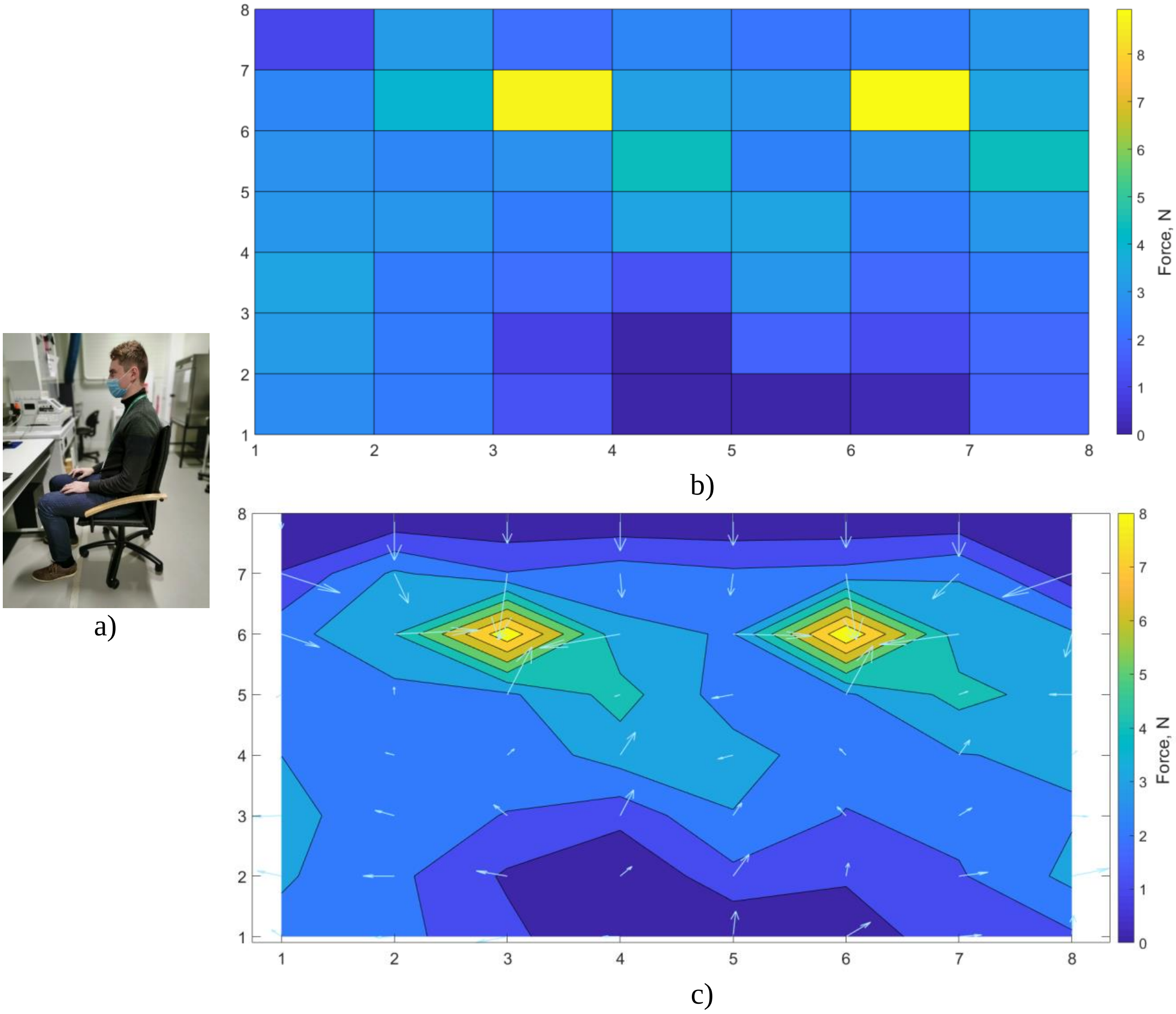
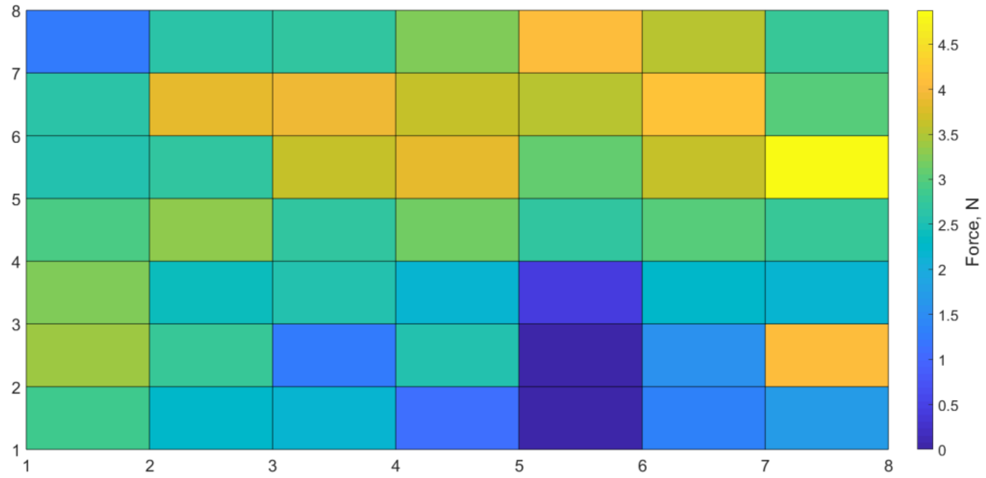
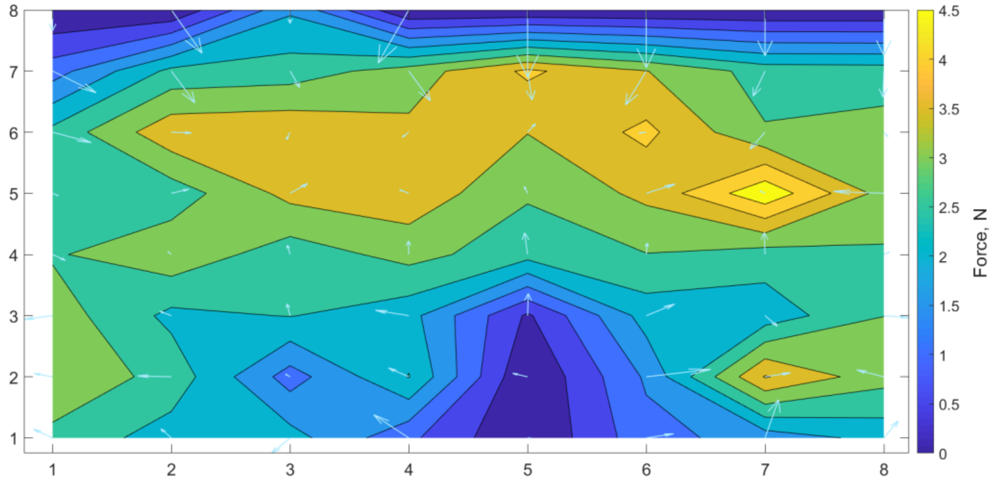


Fig. 3. 2 Standard sitting position.
a) sitting posture; b) raw data after calibration; c) final results.

a)



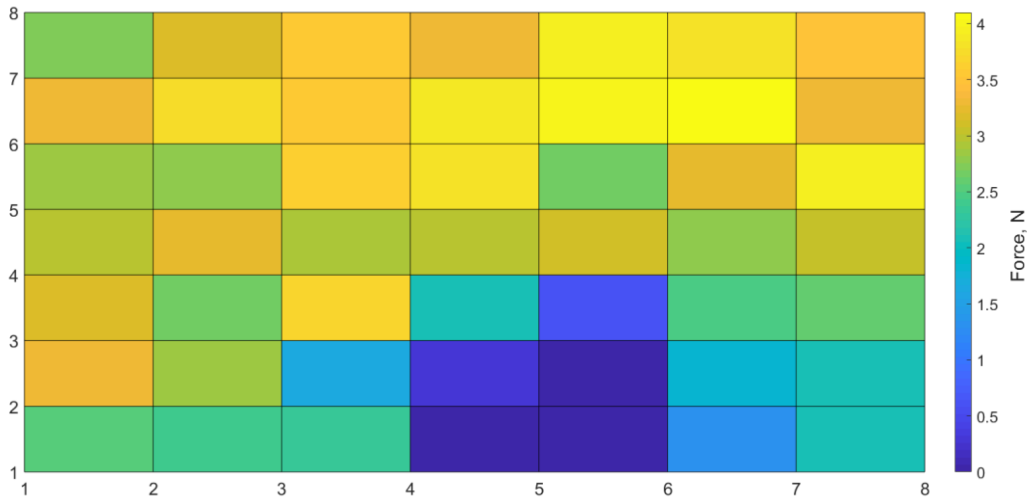
b)



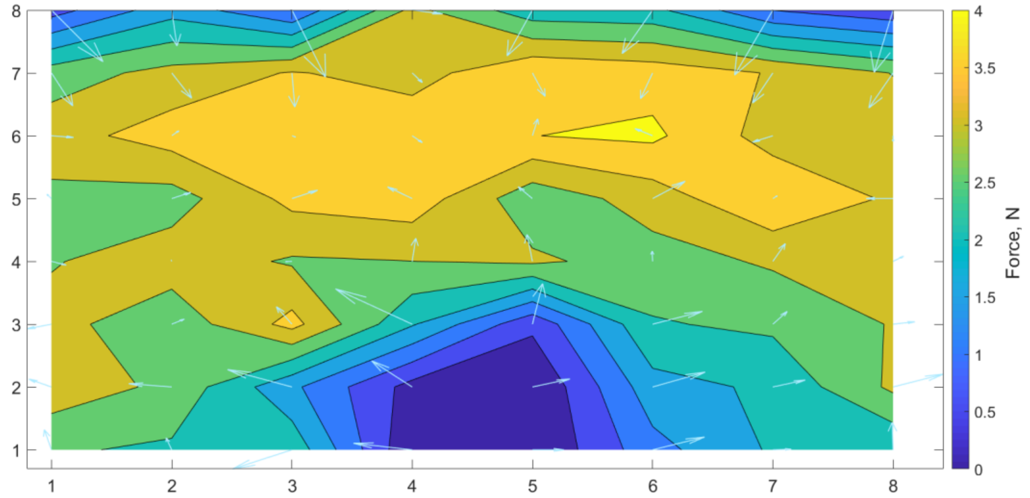
c)

Fig. 3. 3 Lying sitting position.
a) sitting posture; b) raw data after calibration; c) final results.

a)

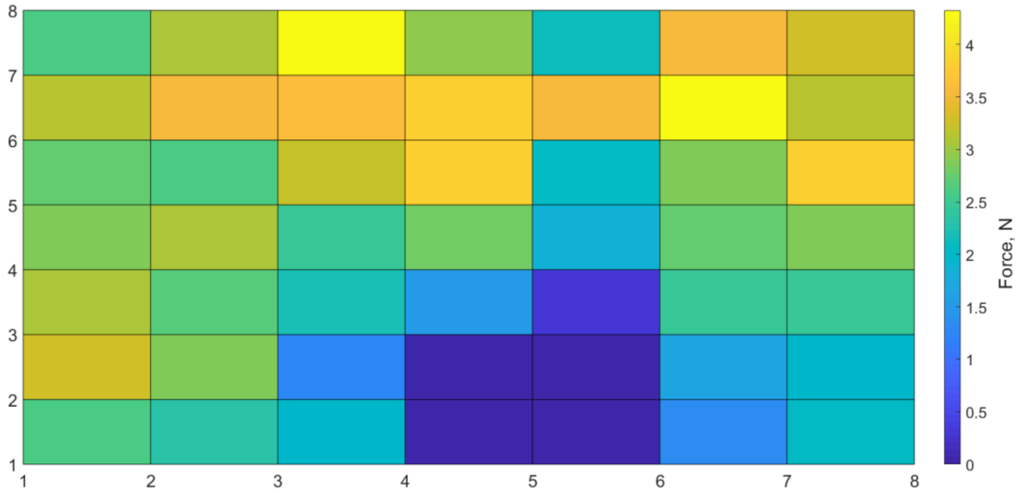


b)



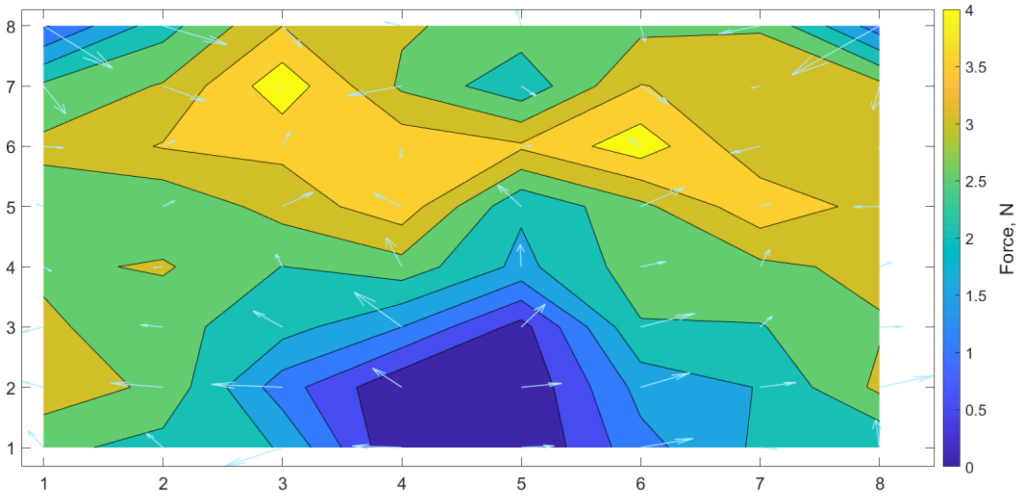
c)

Fig. 3. 4 Tilt forward sitting position.
a) sitting posture; b) raw data after calibration; c) final results.



b)

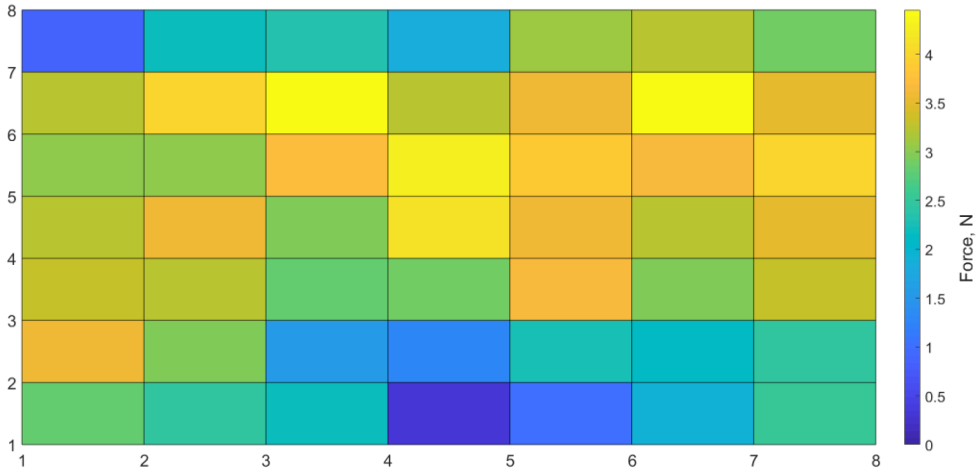
a)



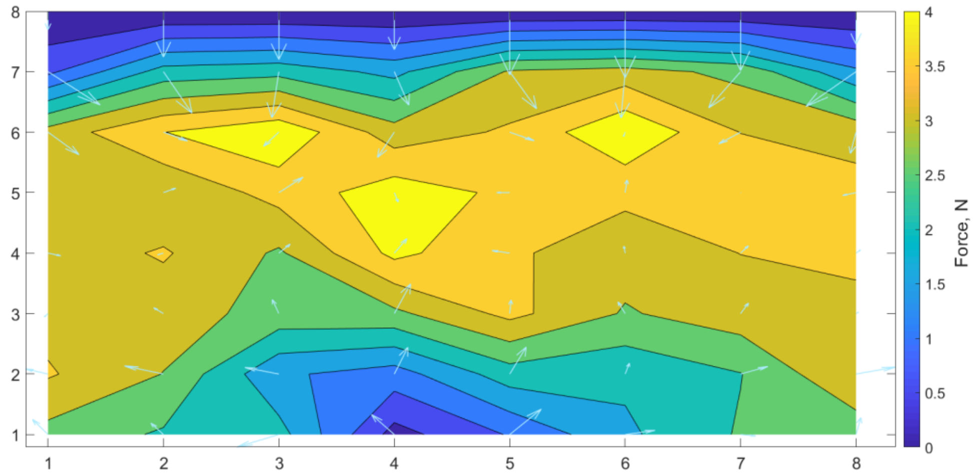
c)

Fig. 3. 5 Normal position, Feet under the chair sitting position.
a) sitting posture; b) raw data after calibration; c) final results.

a)



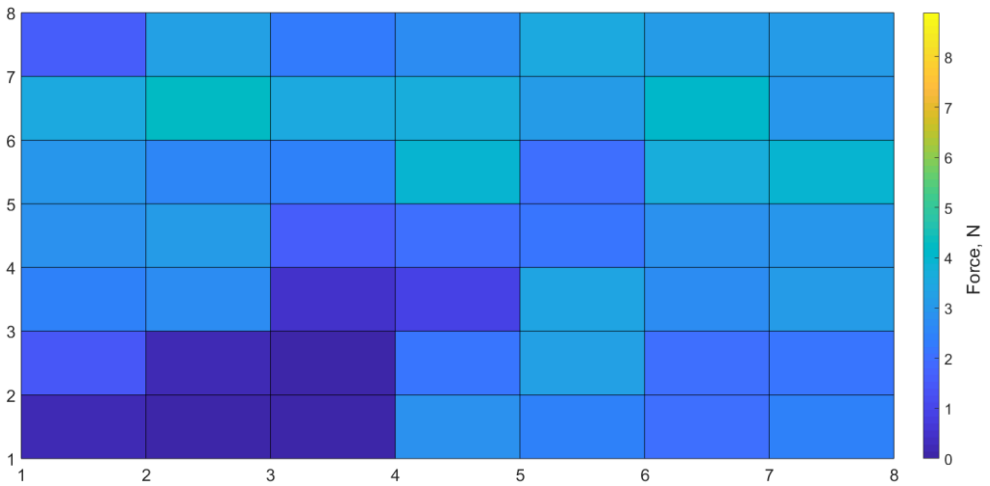
b)



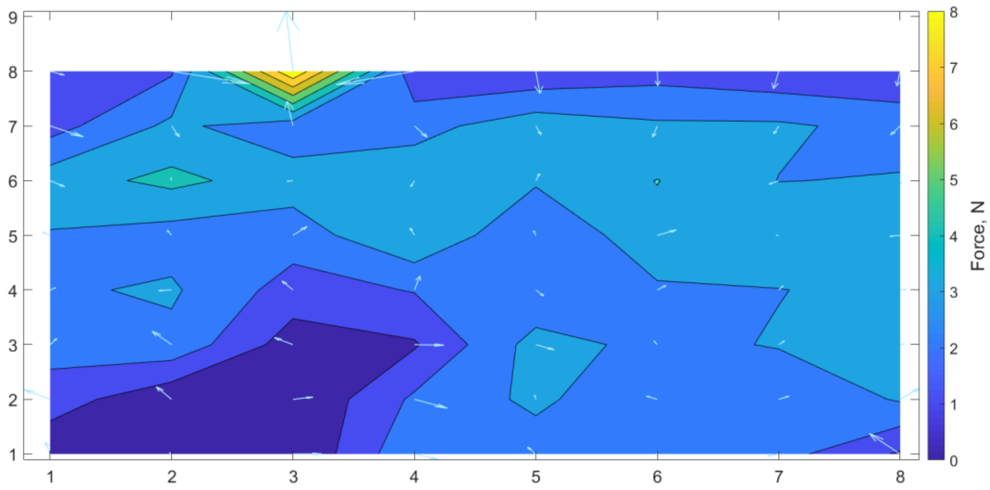
c)

Fig. 3. 6 Sitting on the edge sitting position.
a) sitting posture; b) raw data after calibration; c) final results.

a)

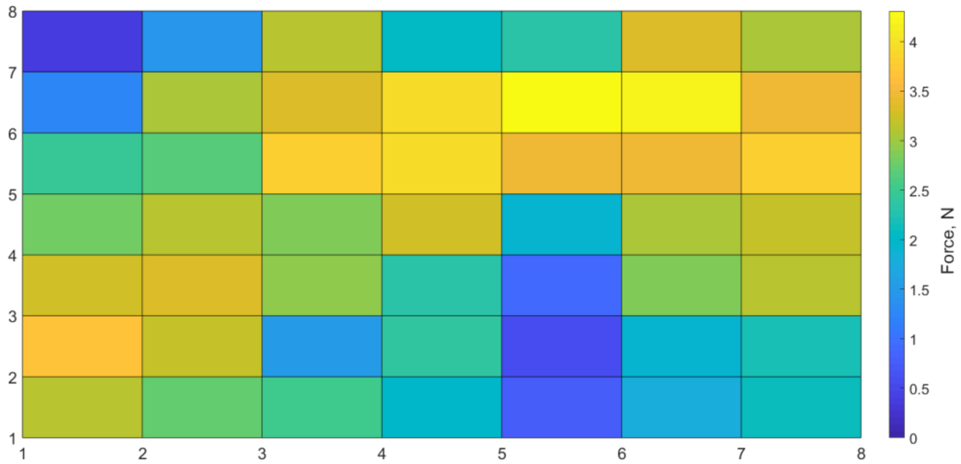


b)

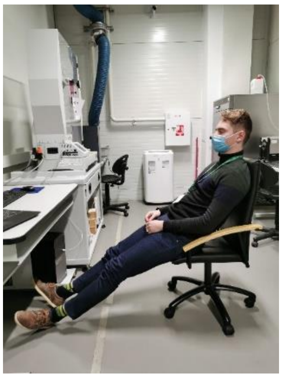


c)

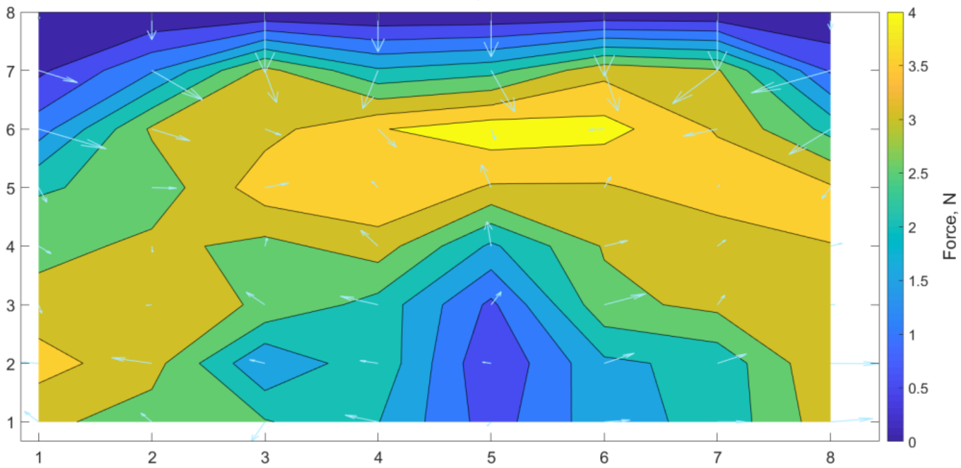
Fig. 3. 7 Legs Crossed sitting position.
a) sitting posture; b) raw data after calibration; c) final results.



b)



a)



c)

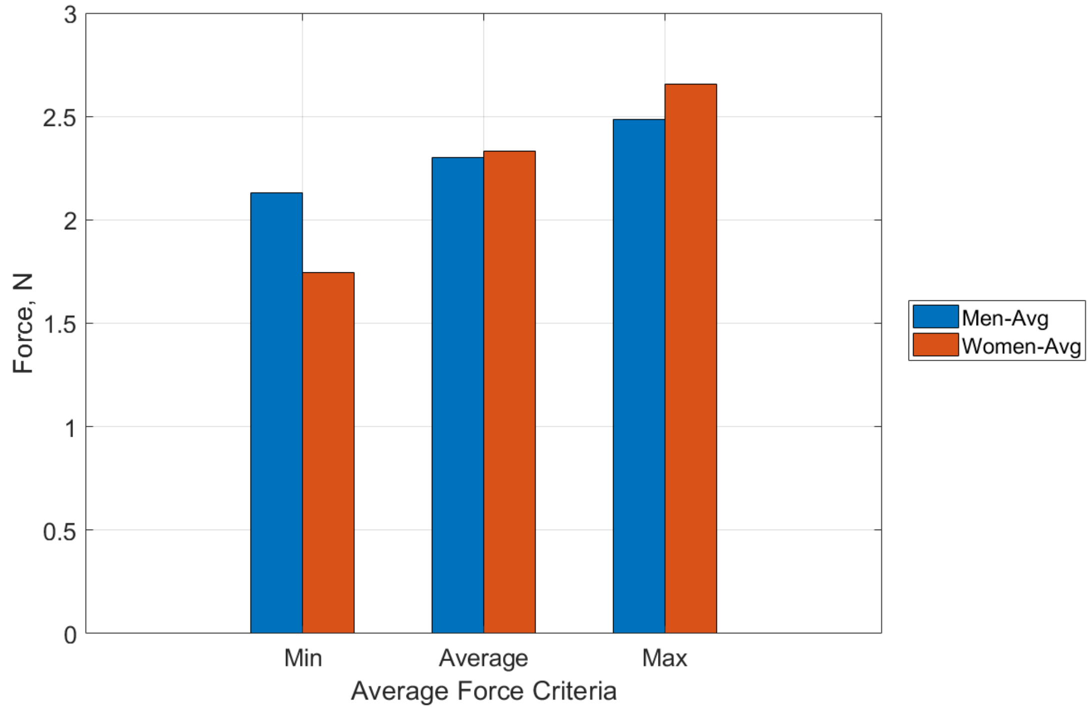
Fig. 3. 8 Lying-2 sitting position.
a) sitting posture; b) raw data after calibration; c) final results.

Table 3. 1 Participant defined as nominal sitting posture results

Sex	Age, years	Height, m	Mass, kg	Human Mass index		Steps per month	Positions	Average Force	Max Force	Total surface area, Max (64)	Mean contact area	Max force gradient	Pressure dispersion index (DI)
Man	25	1,93	78	20,9	Normal	187500	1	2,292	8,947	53	48	21,966	3,744
							2	2,417	4,876	55	47	20,470	1,019
							3	2,620	4,100	62	46	12,951	0,491
							4	2,554	4,326	62	49	13,026	0,400
							5	2,591	4,452	56	45	16,030	1,039
							6	2,483	8,879	61	50	32,725	1,340
							7	2,385	4,309	56	44	16,720	1,035
							Average	**2,478**	**5,698**	**58**	**47**	**19,127**	**1,296**
							Min	**2,292**	**4,100**	**53**	**44**	**12,951**	**0,400**
							Max	**2,620**	**8,947**	**62**	**50**	**32,725**	**3,744**
							STDEV	**0,119**	**2,209**	**3,716**	**2,160**	**6,898**	**1,129**

3.3 Research results – sitting posture analysis between ganders.

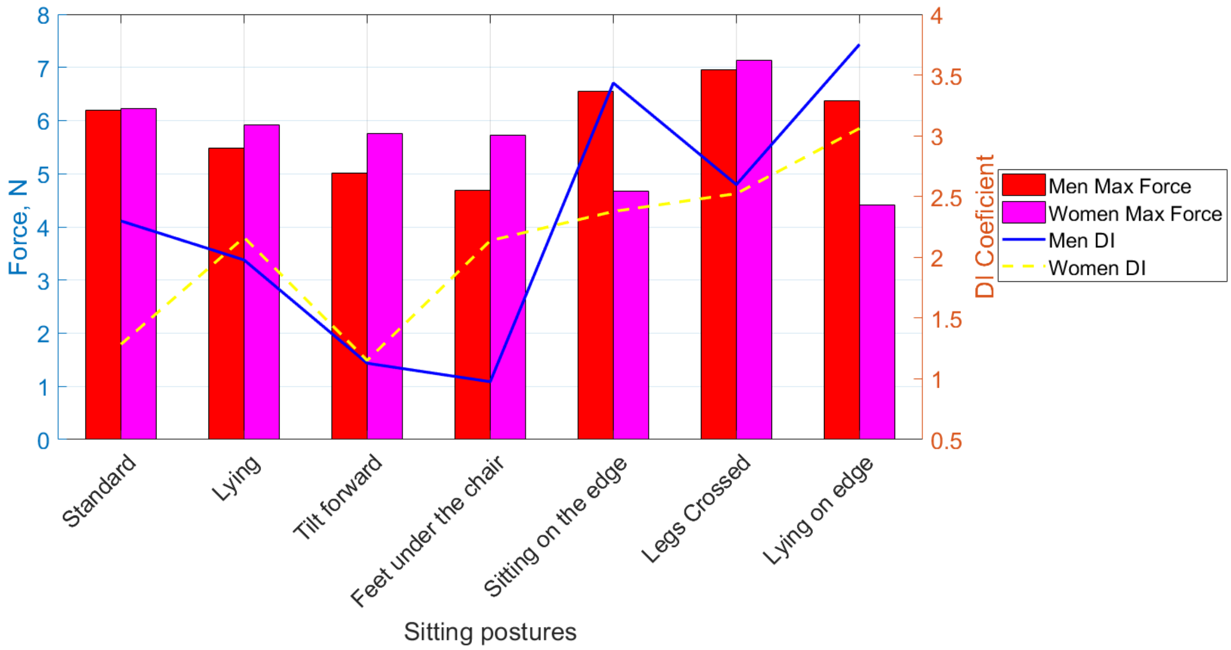
In first case was completed collected data comparison between man and women matrices. The data of each gender was summed and compared using graphs 3.3 & 3.4.



Graph 3. 3 Men & Women average force results

Looking at the average matrix force results it can be noted that the max and average force of women is bigger than men. The results may look illogical as women weight less and Women-Avg Min collum in graph 3.3 proves that. The Women force results are related with Max force matrix results (graph 3.4 & table 3.2). When men sit on a chair, they manage to distribute force more evenly, from matrix maps it is more difficult to tell where the Anal triangle is. When the siting posture is based on the edge of the chair, where the mass must be concentrated in one area, the men then surpass women with max force results – force distribution index (DI) values are the highest. But despite that, women manage to create the highest force on the matrix with the value of 7.14N (men 6.95 N).

Looking at graphs 3.3 & graph 3.4 have been made two assumptions: during specific sitting postures (sitting on the edge, legs crossed, lying on the edge) the human weight is focused more in one area, where hip bones are generating higher force values. With this comes another assumption – women generate bigger values hence the body is not able to distribute mass evenly due low muscle and fat layer in buttock area.



Graph 3. 4 Men & Women Max force & distribution index results

For comparison women, sitting feet under chair results presented in fig. 3.9. The matrix results approve, that women mass is not distributed as even as for men (man nominal, fig 3.5), most of the weight goes through bones. It can be seen a slight weight transfer to human left side.

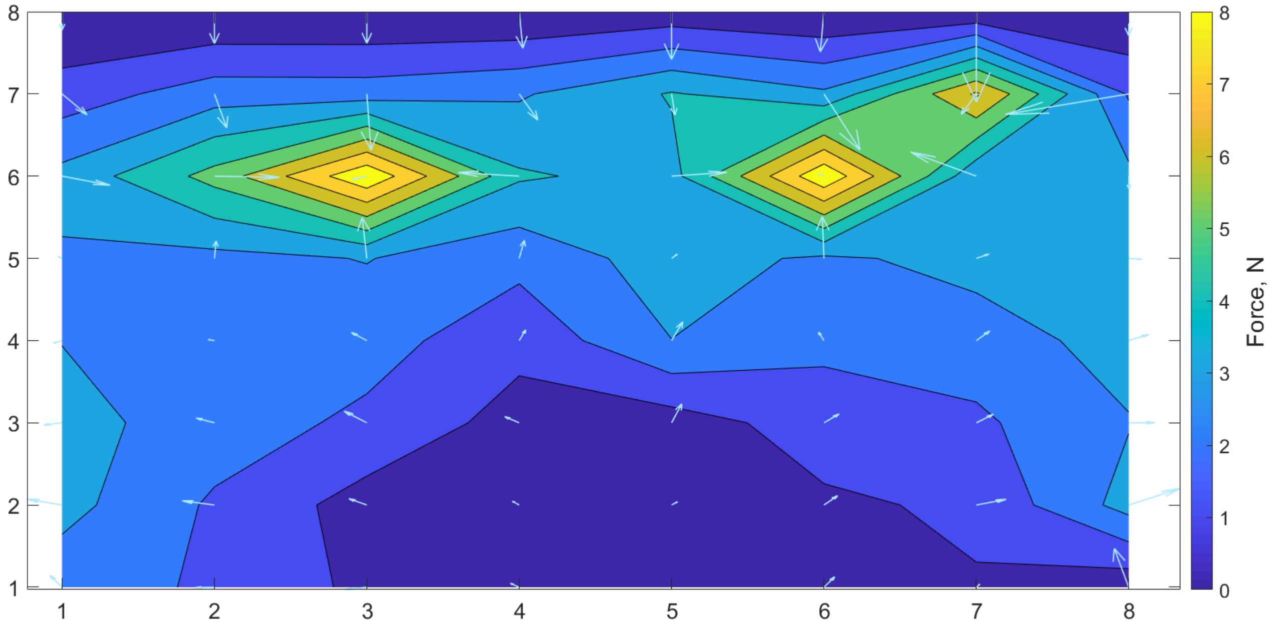


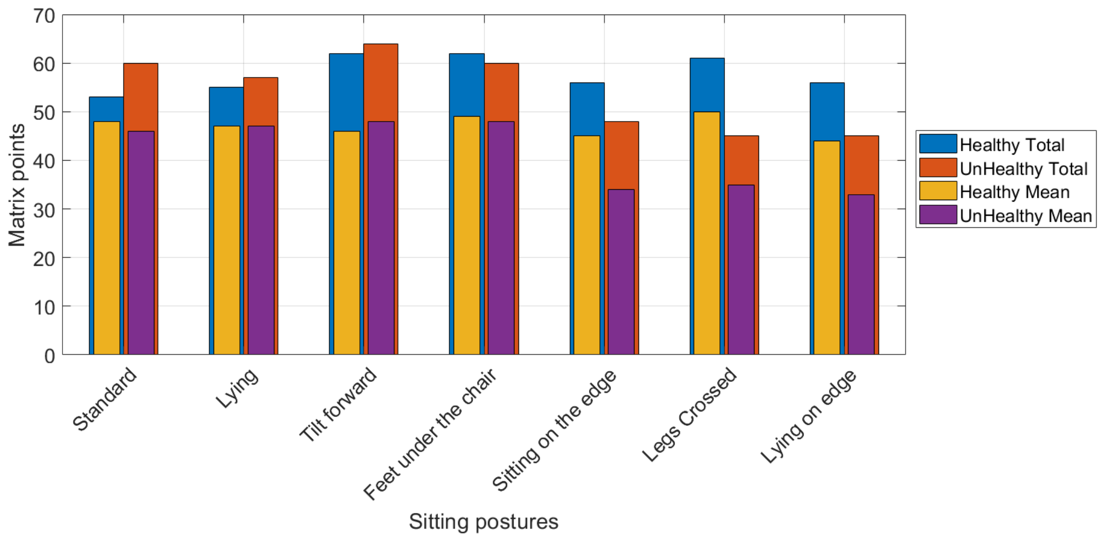
Fig. 3. 9 Women, sitting feet under chair

Table 3. 2 Sitting feet under chair force results

Gander	Average, N	Max, N
Man (nominal)	2.554	4.326
Women	2.253	8.859

3.4 Sitting posture analysis between healthy and scoliosis.

In this section analyzed one person with scoliosis trauma in contrast with healthy human posture (nominal man). Firstly, side by side were placed matrix contact area results. The graph show how much of matrix area were taken for data gathering and how much sensors were close to average force results. With mean contact area was removed matrix points with very small values and points with too high forces. The results of healthy (man) and person with scoliosis (women) presented in fig 3.7 and in table 3.4.



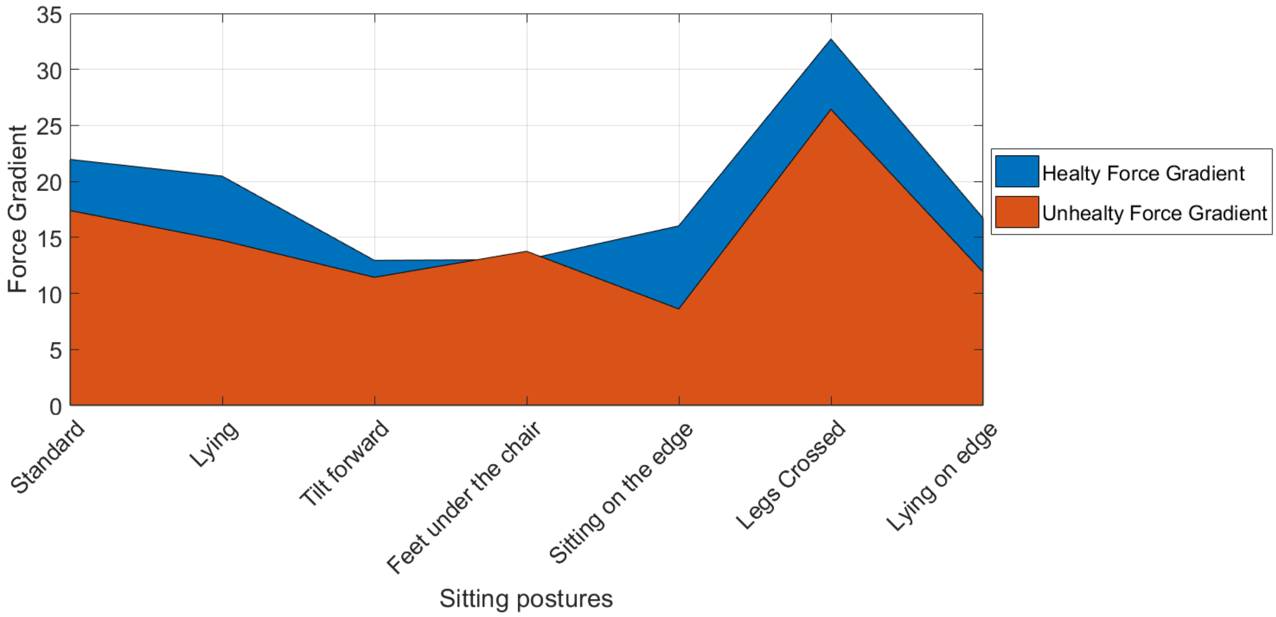
Graph 3. 5 Matrix point occupancy

Table 3. 3 Healthy (men – nominal) and person with scoliosis summary data

Participants		Average Force	Max Matrix Force	Total surface area, Max (64)	Mean contact area	Max force gradient	Pressure dispersion index (DI)
Healthy	**Average**	2.478	5.698	58	47	19.127	1.296
	Min	2.292	4.100	53	44	12.951	0.400
	Max	2.620	8.947	62	50	32.725	3.744
Unhealthy	**Average**	2.285	5.118	54	42	14.896	1.752
	Min	1.879	4.040	45	33	8.608	0.079
	Max	2.996	8.684	64	48	26.432	4.515

In this section can be noticed, that here is compared man and women results – with mass generated forces cannot be relied upon. At first glance the healthy person's average total surface area is higher (58) in contrast with unhealthy person (54). In standard sitting posture women total surface area is higher (60 to 53), but mean contact area for unhealthy participant is smaller in contrast with healthy one (46 to 48). During legs crossed can be seen the biggest difference in total surface & mean contact area.

Another analyzed sitting posture aspect was the Max force gradient graph 3.6. In thi plot, the peak force gradient was at the 6th sitting posture. It is possible that in other sitting postures man's results are always higher (except fourth sitting posture) than women's due to BMI difference. For a detail matrix review were chosen standard & legs crossed sitting postures (table 3.4)

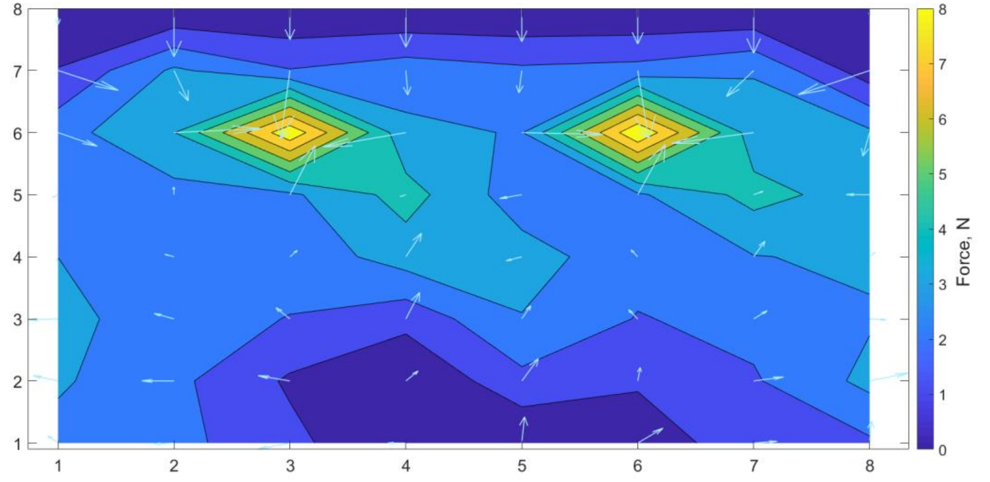
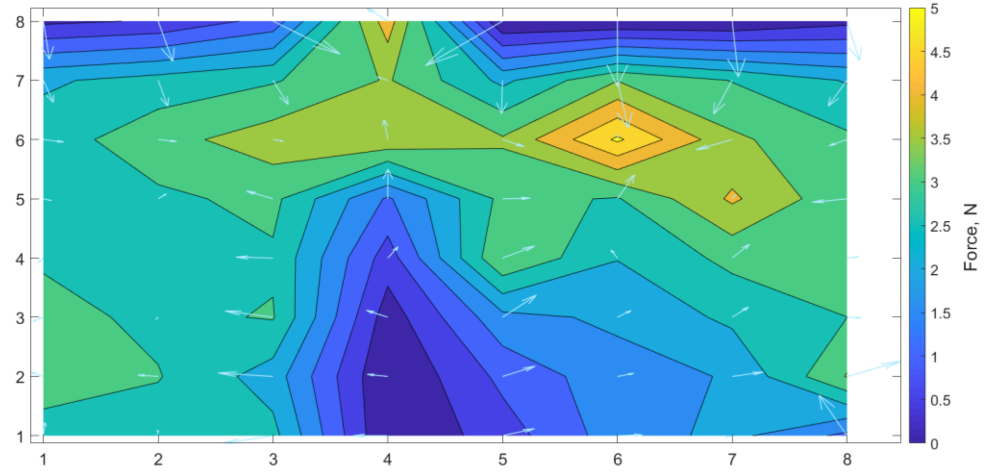
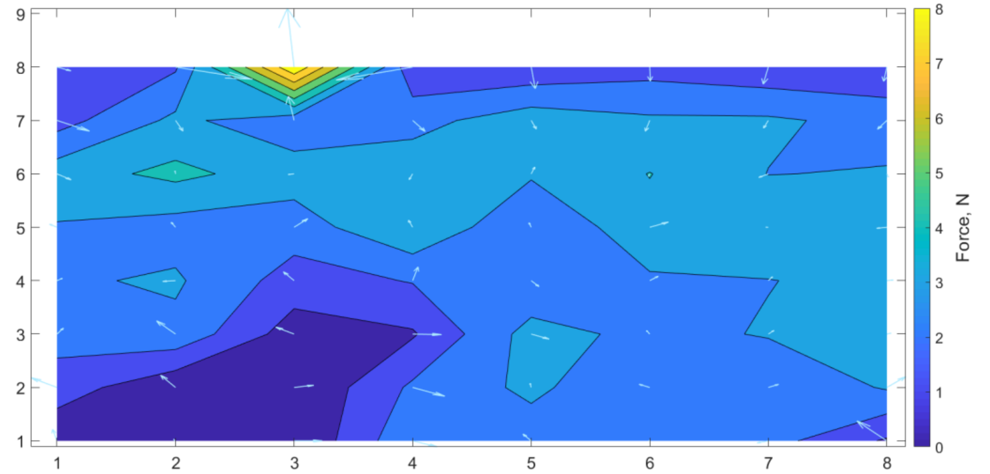
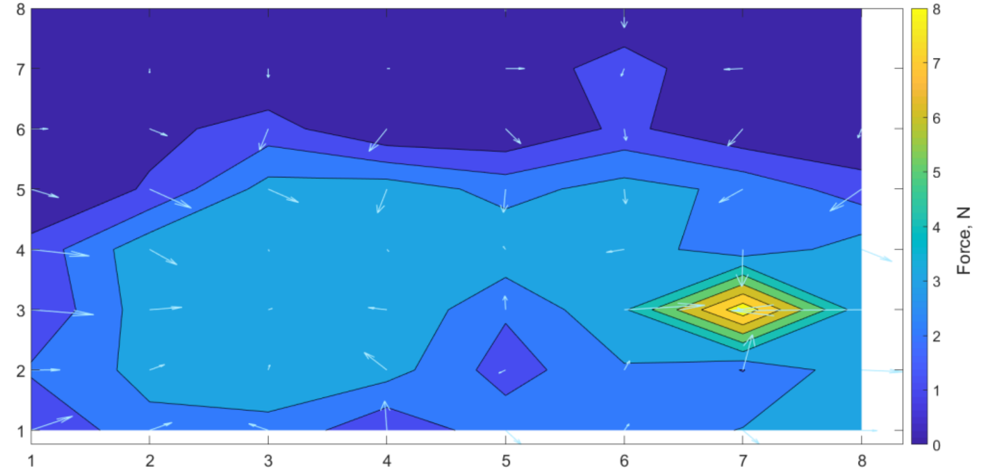


Graph 3. 6 Max force gradient

Matrix results show that person with scoliosis body weight max forces are distributed more on left side than nominal man. Nominal person's mass during standard sitting posture is spreaded more evenly than women's having a scoliosis. During legs crossed (right leg on the left) man‘s force density increased on right hip area while women mass stayed focused on the left hip side.

In legs crossed sitting posture person's with scoliosis matrix is not fully covered. Explanation as follows – during sitting posture for participants were asked to cross right leg on the left. While women stayed in the same position the man changed his posture to standard and then crossed legs. He changed his posture that he could use a seat back for additional back support. The matrix contact area results can be seen in graph 3.5.

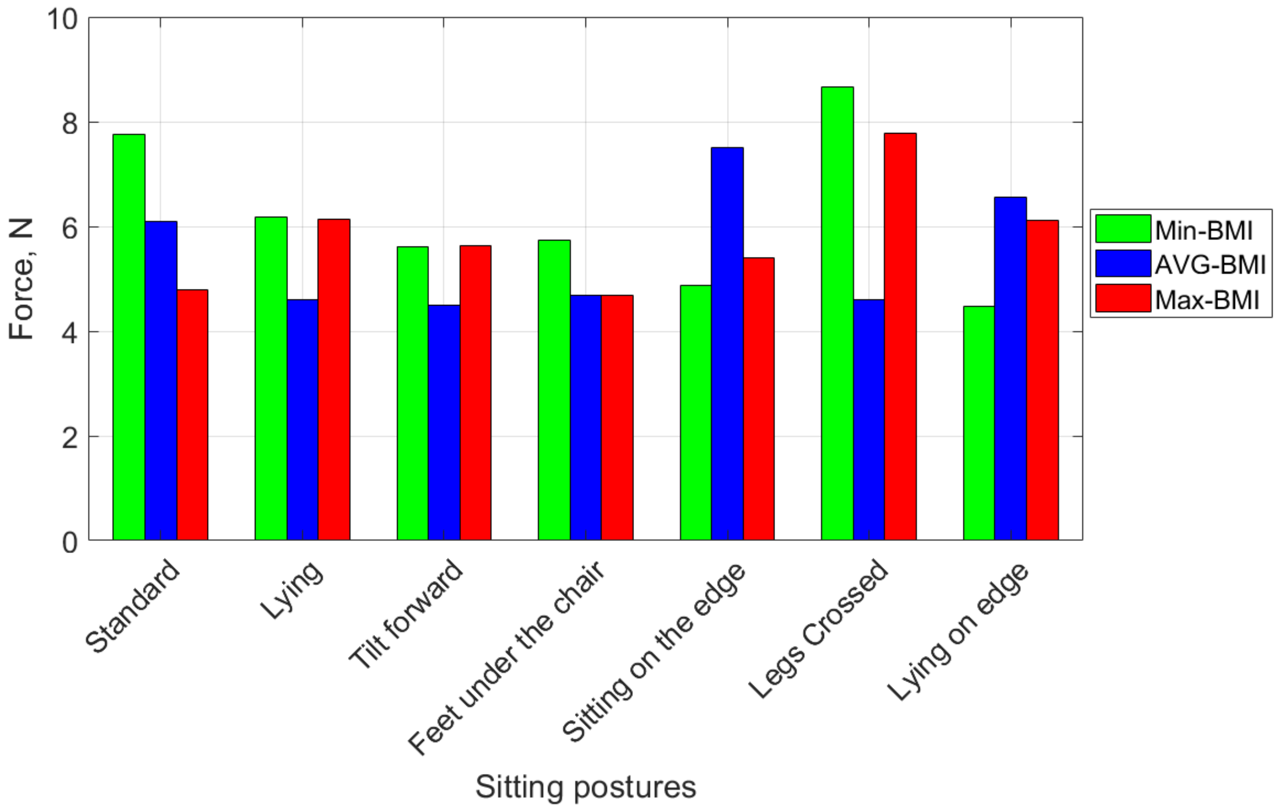
Table 3. 4 Sitting posture comparison between healthy and scoliosis trauma having person

Healthy Person (Nominal)	Person with scoliosis
Standard sitting posture	
 	
Legs crossed	
 	

3.5 Sitting posture analysation between participants with different BMI index.

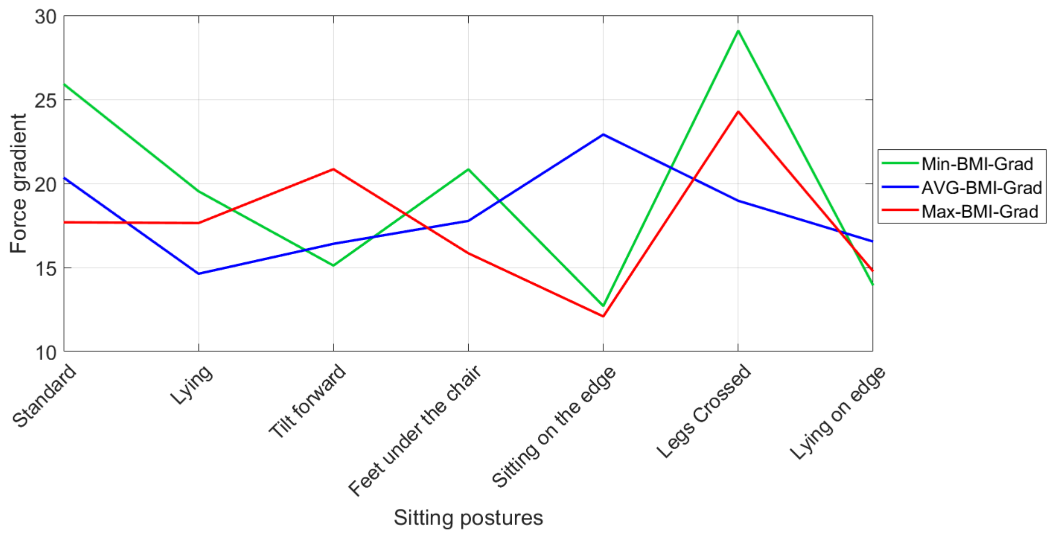
Sitting postures compared between participants with different BMI index. 9 participants were grouped by three: Min-BMI, Avg-BMI, Max-BMI. After categorization at first was created max matrix force graph (graph 3.7).

To begin with, Standard sitting posture presents strong explanation how body mass distributes with different BMI coefficients works. Participants with small BMI should produce the smallest force results, but it is not the case. During standard and legs crossed sitting postures the values are higher than other BMI's. It can be explained by small muscle and fat layer in buttock area – most of the force is produced by hip bones. On the contrary, participants with high BMI coefficient managed to maintain relatively low max forces due to larger density of fat layer. The best performed participants with average BMI – while keeping max force in standard and lying on the edge postures close to total average max force of Avg-BMI, four sitting postures produced lowest forces compared to others. Exception is sitting on the edge posture – probably due occupied too small chair area and insufficient fat layer where the force could be distributed more, as result generating the highest forces. Min-BMI results were lowest because the participants weight the least, Max-BMI participants have a high fat ratio which helps to use a wider area on the chair to distribute hip mass more.

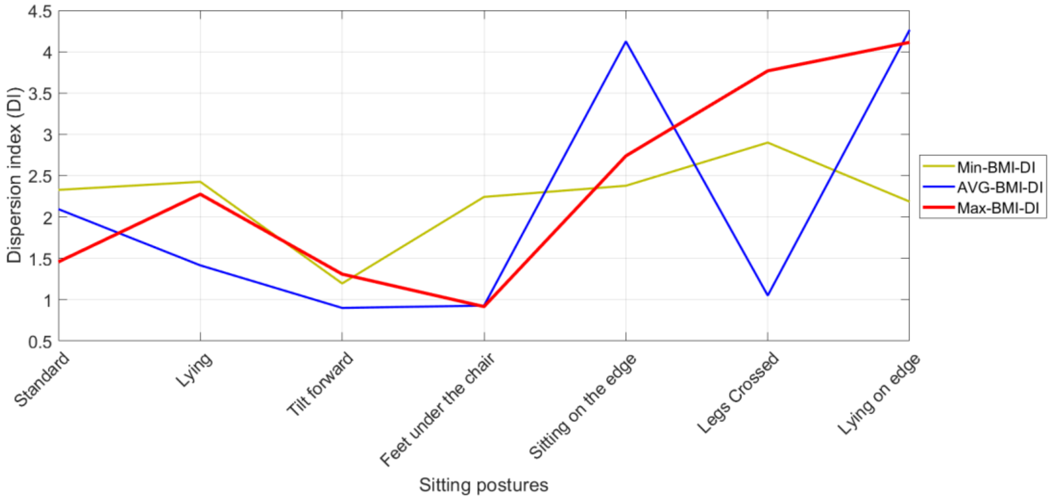


Graph 3. 7 Max Matrix Force graph

Max force gradient (graph 3.8) and force dispersion index (DI) (graph 3.9) improve the understanding how hip bones interact with muscles and fat. Min-BMI participants in standard and legs crossed sitting postures produced the highest gradient due lack of sufficient fat and muscle layer. Sitting on the edge the value is smallest due small weight. Avg-BMI showed the smallest deviation between sitting postures. Sitting on the edge produced the highest results (graph 3.8-3.9) as participants lacked fat layer, muscle layer is not enough for proper mass distribution. During tilt forward, feet under chair and legs crossed DI is lowest – assuming muscles stretched more, used additional leg support to spread the force more evenly. Max-BMI subjects produced lowest gradient in fifth pose (sitting on the edge) due to a likely large fat layer and high body mass. During legs crossed max gradient peak is reached. DI graph shows that putting feet under chair the force deviation was the lowest, as the participants were able to use legs (legs have their own muscle and fat layer). From sitting on the edge to lying the DI index increases due to high force values in a small area.

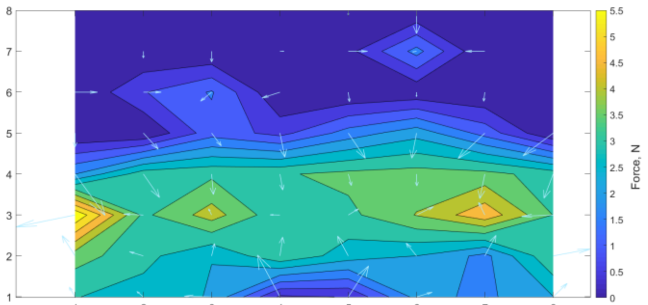
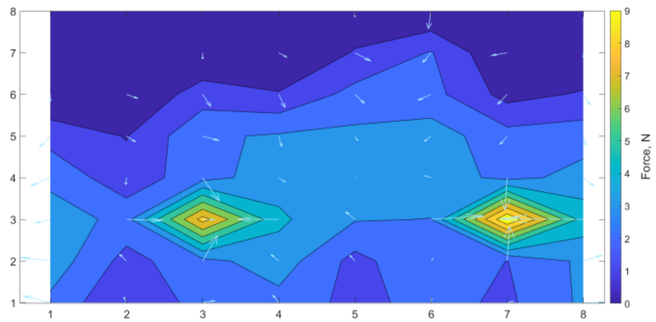
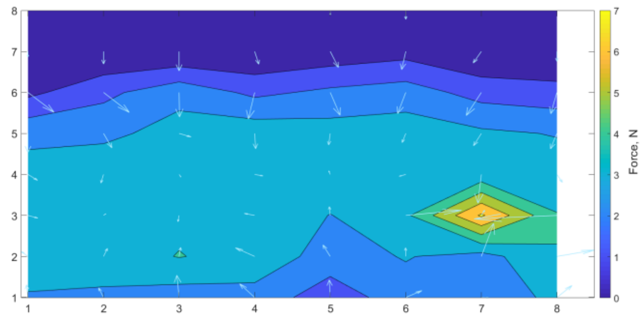
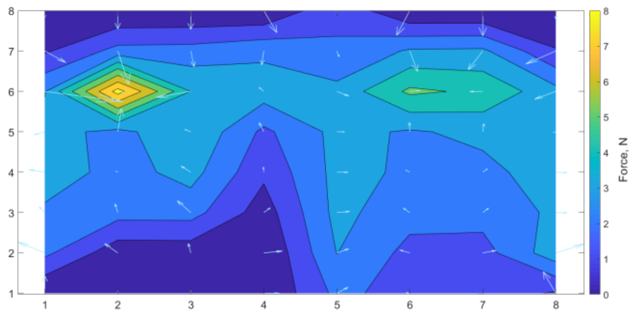
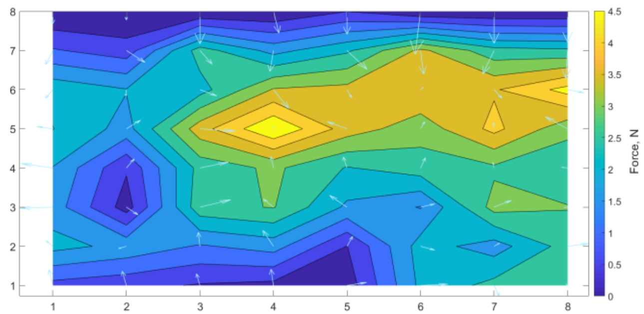
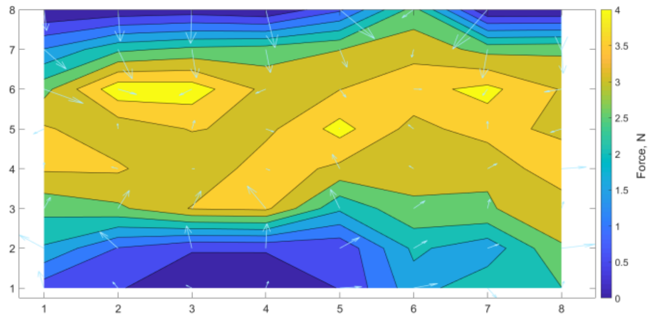


Graph 3. 8 Max force gradient



Graph 3. 9 Force dispersion index (DI)

Table 3. 5 Sitting posture comparison between Different BMI

<table>
<tr><th>Min-BMI</th><th>AVG-BMI</th><th>Max-BMI</th></tr>
<tr><th colspan="3">Sitting on the edge</th></tr>
<tr>
<td>
F (max) = 5,943 N
Max Force gradient = 13,491
Force dispersion index (DI) = 3,884</td>
<td>
F (max) = 9,973 N
Max Force gradient = 26,992
Force dispersion index (DI) = 5,521</td>
<td>
F (max) = 7,147 N
Max Force gradient = 15,584
Force dispersion index (DI) = 2,609</td>
</tr>
<tr><th colspan="3">Legs crossed</th></tr>
<tr>
<td>
F (max) = 8,408 N
Max Force gradient = 28,114
Force dispersion index (DI) = 2,848</td>
<td>
F (max) = 4,981 N
Max Force gradient = 18,121
Force dispersion index (DI) = 1,386</td>
<td>
F (max) = 4,347 N
Max Force gradient = 15,703
Force dispersion index (DI) = 1,269</td>
</tr>
</table>

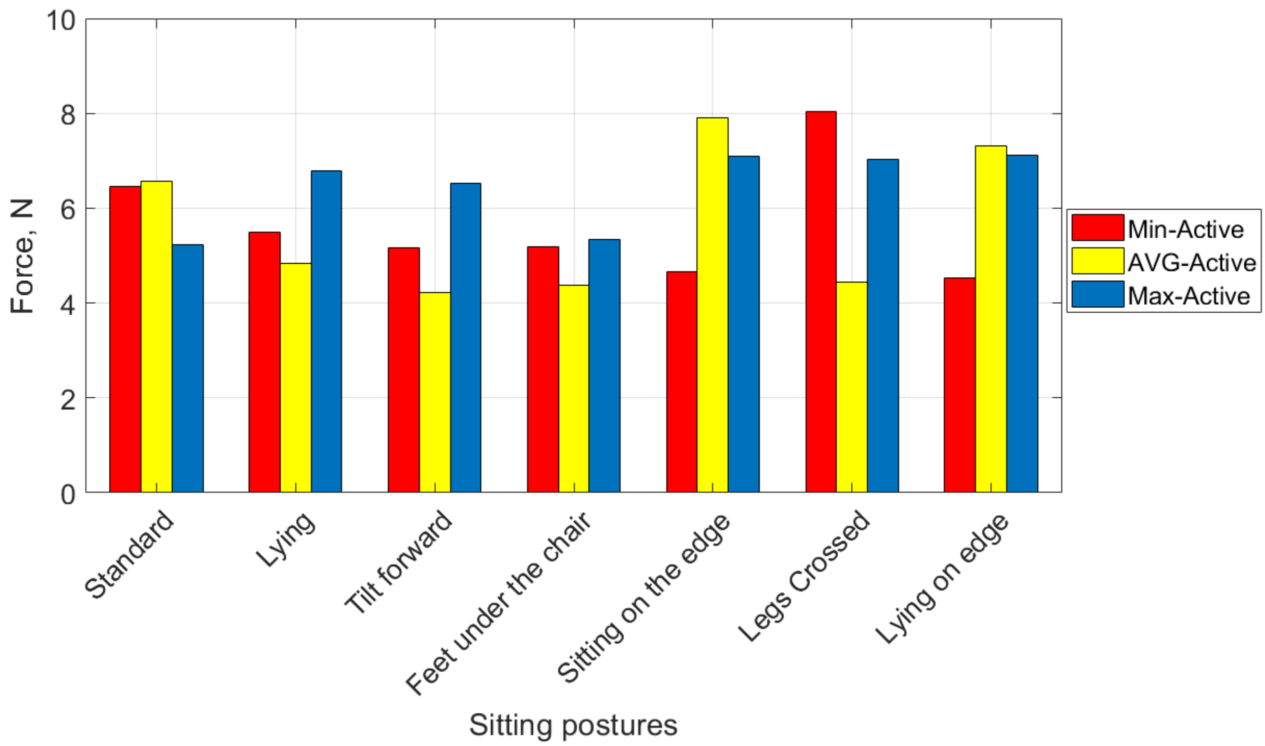
3.6 Sitting posture tendency differences according to human lifestyle activity.

This section analyze how human activity can help with mass distribution during different sitting postures in office environment. In this case the comparison of sitting postures completed for participants with different lifestyle activity. 9 participants were grouped in three, by dividing range of participant lowest to highest number of steps per month:

- **Min-Active** – person's average steps per month is between 184320-247435.
- **Avg-active** – person's average steps per month is between 247435-310551.
- **Max-Active** – person's average steps per month is between 310551-373666.

Min-Active people are the ones with relatively low BMI index (low weight) or overweight. BMI is coherent with lifestyle activities. People with higher number of steps most likely practice some field of sport: running, playing team games etc. Active people will have more muscle on buttock area than fat.

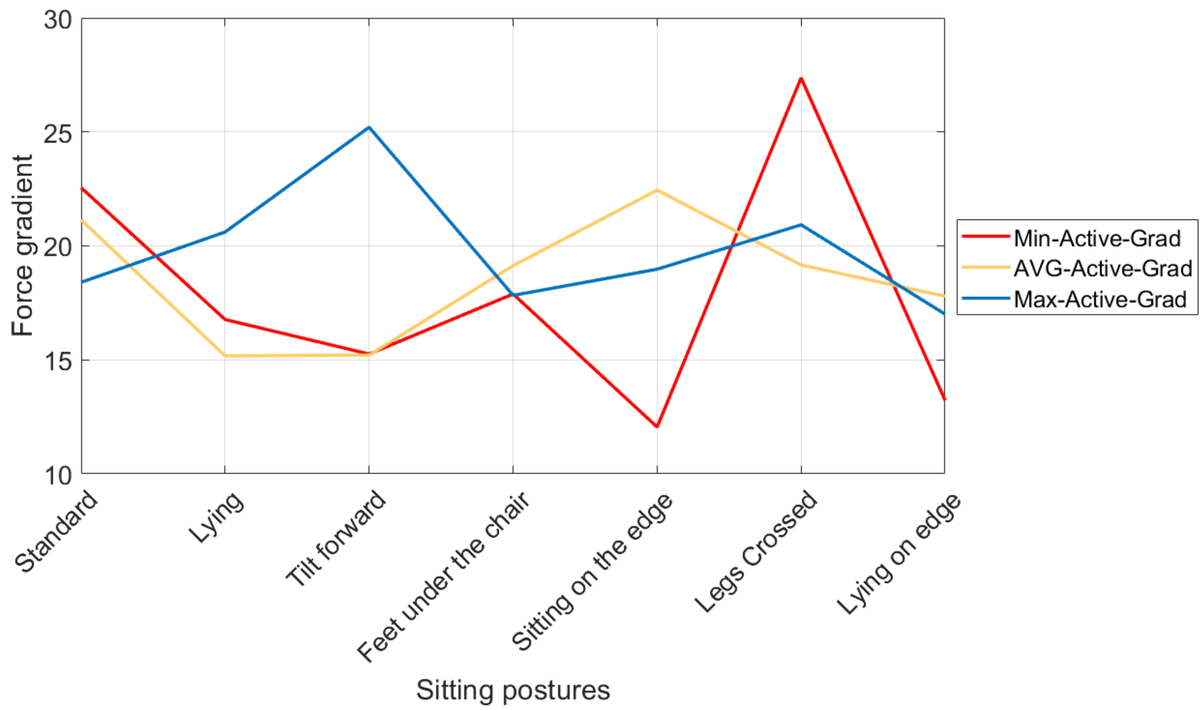
At first, looking at average matrix force the values are close to each other (small deviation between different sitting postures), for that reason they are not analysed in detail. Max matrix graph created for sitting posture for comparison between grouped participants (graph. 3.10).



Graph 3. 10 Max Matrix Force graph

Min-Active and Avg-Active people manages to spread mass better (average max force both ≈5.6N) than max-Active objects (6.45N). That could be explained that Max-Active subjects had a smaller amount of fat. It is assumed that min & average active people have enough muscle and fat ratio in buttock area for affective force distribution.

The fastest pace of change in force is explained with matrix max force gradient (graph 3.11) – it shows that minimum active participants hold low force gradient vectors, which can be collated with fat layer. Similar patterns can be found and in BMI Max force gradient (Fig 3.8). While average active subjects reached the peak during sitting on the edge, the same as participants with average BMI, max-Active participants reached the peak at tilt forward.



Graph 3. 11 Max force gradient

Maximum active participant's mass distribution map is taken to understand the vector's location, direction and cause why the peak created in this sitting pattern (fig. 3.10). In matrix the force mostly distributed in wide range of buttock area near the bone. The max gradient direction is where should be the coccyx contact area. But in contrast with nominal participant data, max-Active participant mass is more focused on hip bones and less distributed to over legs. Assumption would be, that human mass is not distributed evenly due too little fat layer, the muscle layer is not able to distribute body weight more evenly around the buttock and leg area.

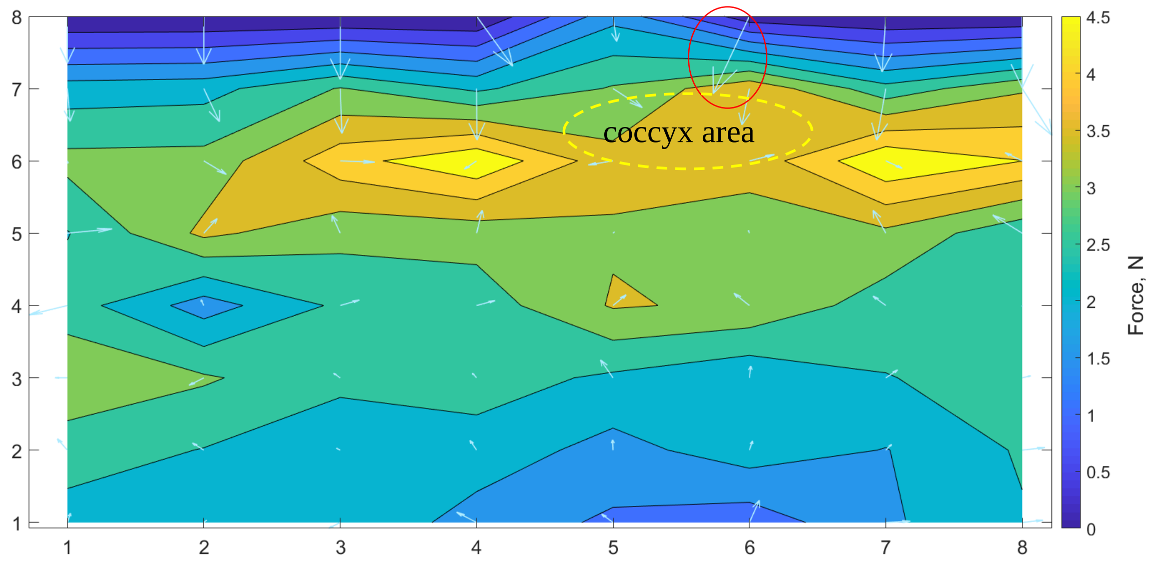
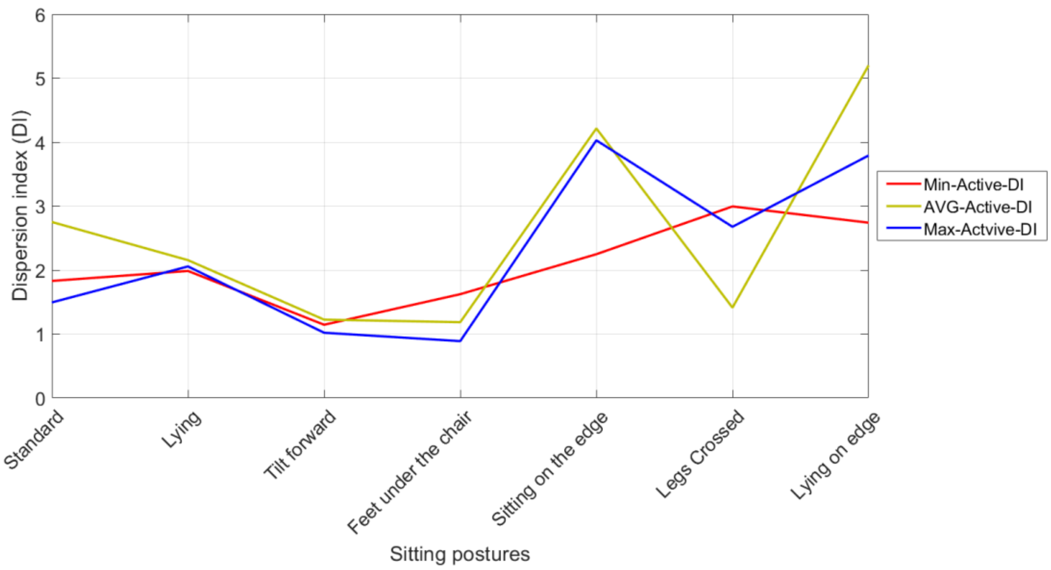


Fig. 3. 10 Max-Active person matrix of sitting posture – tilt forward

Another analysed parameter is Force Dispersion Index (DI) (graph 3.12). It would give more information about how force values are dispersed in the matrix. At a first glance, the average and maximum active participant curves have similar trajectories. In contrast with Avg-Active, Max-Active subjects' curve has a smaller deviation. Avg-Active, Max-Active have reached the peaks while sitting on the edge, which is relatable to sitting pattern – matrix is covered by half of its width. Min-Active generated smaller index due better force distribution by sufficient fat layer and due relatively small participant weight. During lying and tilt forward sitting postures all three group results are similar. The deviation is reduced probably due back seat on lying position, where the participant could lay back and because of the office table, where subject could use his hands and transfer mass through shoulders to the desk. Feet under the chair have smaller deviation values as the participants were using more legs to support mass distribution over the chair.



Graph 3. 12 Force dispersion index (DI)

3.7 Partial experimental conclusions

Average force result comparison between men and women matrixes highlights men dominance at min & average. Women generated higher average and max avg. force results in contrast with men. It happened hence women lack of mass, fat and muscle layer on buttock area. The assumption is approved by max force & distribution index results (graph 3.4). from 7 postures in 5 of them women generated higher max force than men, small DI can be related with focused force in several points.

During person with spinal trauma sitting posture analysis, noticed that in standard sitting posture are noticeable differences between healthy versus unhealthy total & mean contact area results. Looking at max force gradient graph 3.6 legs crossed sitting posture produces the highest gradient coefficient. Having closer look at these matrixes can be noticed, that unhealthy person's mass in both sitting postures is more focused on left side.

Participants, with different BMI index, data can explain how the composition of the human body can differ during the change of sitting postures. Looking at graph 3.7 subjects with relatively small BMI index produced high max force results. Avg-BMI and Max-BMI results are similar, while visible differences can be noticed in sitting on the edge and legs crossed sitting postures. Max force gradient graph 3.8 confirms the fact, that during standard and legs crossed sitting postures the highest change in force is created by Min-BMI participants. Force dispersion index (DI) in graph 3.9 explain, that Avg-BMI participant's results during sitting and laying on the edge sitting postures DI are the highest, hence they have insufficient layer of fat and most of their mass must be distributed in small area. Avg-BMI subjects produced low DI index in these sitting postures, where they could use leg muscles as additional support.

While comparing results between active lifestyle living participants, noticed that min & average active people maintained similar and low max force results (5,6N) in contrast with Max-Active participants (6,45N). The difference occurs because of muscle and fat ratio. Max-Active subjects lack of fat layer and with insufficient layer of muscle they cannot spread mass in wider area. Max force gradient results explain that Min-Active people creates lower force gradient vectors in comparison with Avg-Active and Max-Active participants (except legs crossed sitting position where the mass is focused more in one area). Avg-Active DI peak is at sitting on the edge while for Max-Active is at tilt forward. While analyzing Max-Active participant tilt forward position, in the matrix can be seen max gradient vector's direction pointed to coccyx area (fig. 3.10). Moreover, the figure shows, that participant's mass is focused in hip bone area. The force is distributed more in hip bone area due larger amount of muscle layer compared with Min-Active participants. But this muscle layer is not sufficient for affective mass distribution due wrong muscle and fat ratio. Nominal man tilt forward position takes much more matrix area to spread mass more evenly. Looking at force dispersion index (graph 3.12) Avg-Active and Max-Active participants have similar curves – probably due more similar muscle and fat layer ratio. Min-Active participants maintained relatively low DI coefficient probably due small mass, that theory confirms lowest coefficient during sitting on the edge and the highest result at legs crossed in contrast with Min-Active and Max-Active subjects, where the force is focused in one area.

Experimental conclusions – The hip bones are the biggest force raisers, reaction force goes through hips to over spine. Human, using fat and muscles can distribute the force more evenly over the hips. The fat density is smaller (0,909 g/cm^3) than muscle (1.060 g/cm^3) – fat can stretch more in sides and distribute force more evenly. When the force is applied in a smaller area, the fat stretches too much as result making hip bone closer to the chair surface and transferring more force over spine. The muscle has bigger density and smaller plasticity which help to outperform fat. While the mass is distributed over the muscles, they stretch less leaving more thickness for bone amortization. As consequence helping to spread the mass more during postures where the force is focused in one area. During result comparison between active participants, noticed that for affective force distribution need proper fat and muscle layer ratio, hence while in smaller area fat layer helps spread mass force, it cannot to do so while the force is focused in one point as muscles and versus versa.

CONCLUSIONS

Pressure matrix purpose to diagnose human trauma severity, evaluate posture or behaviour related to person's psychology. The matrix as system is made of non-conductive material (outer layer), conductive plane, sensors, hardware and software. When the force is present on a matrix, conductive layer reduces his resistance. The change of output is registered and collected be microcontroller, the data then transferred to computer via USB connection. Scientific articles promote 3 fields for matrix use: human posture classification, sitting posture optimisation, human behaviour analysis. The matrix resolution can be from 8x8 piezorezistor sensors to 15x16 textile sensors.

8x8 matrix in this research was built using conductive material – Velostat® and copper wires laid one side horizontally and other side vertically. When the force is applied on the matrix, voltage from horizontal stripes goes through velostat to vertical line – current as output flows to microcontroller. The output voltage decreases due Velostat, material has a property to change resistance due deformation. For sensor control, data transfer to Arduino were build multiplexer scheme.

Calibration continued using 1N – 20N weights. Calibration done for one point at the time. The weight was increased, registered data as curves presented using MATLAB. Using curve generated Force vs velostat resistance differential equation, it will be used for raw data calculation into final results. For human posture analysis in office environment decided to review 7 sitting positions: standard, lying-1, tilt forward, normal position, feet under chair, sitting on the edge, legs crossed, lying-2. Data collected and grouped according to gender, health, BMI index and according to person's activity. Parameters calculated as average and max matrix pressure, mean & total surface area, max force gradient and pressure dispersion index (DI).

Using calibration graph, registered raw data have been digested and as result created human mass force matrixes. One participant chosen as nominal – all 7 sitting posture results presented in fig 3.2 – fig 3.8. The first participant comparison was according to gender. After data comparison it was noted that women generate bigger average and max force values than men (graph 3.3) despite the fact, that men are heavier. Only during sitting on the edge posture men generate bigger values. Explanation would be that women hip bone interaction with the chair generates higher forces than men. But when a smaller chair area is used to distribute body mass, men results are higher. When the data was compared between a healthy person and with subject, who has spinal trauma, noted that unhealthy person takes more chair surface area than the healthy participant, while in legs crossed sitting posture have the highest change of force. When analysing these two sitting postures in detail (table 3.4), can be noticed that unhealthy person's body mass is focused more on the left side. For data comparison between different BMI participants were grouped together in three: Min-BMI, Avg-

BMI, Max-BMI. Looking at max force results (graph 3.7) are noticible Min-BMI generated higher max force values in contrast with other groups. According to max force and max force gradient graphs (graphs 3.8 & 3.9) can be seen clear differences in peaks between Avg-BMI and Min-BMI, Max-BMI group during sitting on the edge and legs crossed sittng posture. Force dispersion index for BMI comparison explain, that while Avg-BMI participants are not able to maintain even force dispersion during sitting on the edge, Max-BMI have the same issues during legs crossed sitting posture. The peaks of dispersion index (DI) for Avg-BMI and Max-BMI, created at lying on the edge posture is related with high body mass index. Avg-BMI subjects are able to distribute mass most evently in comaprison with Avg-BMI and Max-BMI. When posture related to sitting on all chair area, where can be used additional support, the leg muscles are forced to stretch more. The last comparison were between active lifestyle living participants. Max force graph 3.10 showed very similiar results among Min-Active and Avg-Active participants (total max force ≈5,6N), while Max-Active generated higher results (6,45N). The explanation could be, that the difference is created due unappropiate muscle mass ratio. Max-Active subjects have thin muscle layer, lack of fat layer as result increasing max force. Max force gradient (graph 3.11), created for lifestyle comparison, curve of Min-Active people is the lowest in contrast with others probably due small weight or thin layer of fat in bottock area. Looking at force dispersion index (graph 3.12) can be noticed curve peaks of Avg-Active at lying on the edge, while for Max-Active is at sitting on the edge posture. For Min-Active is at legs crossed. Assumption would be that Avg-Active and Max-Active subjects have similiar anatomy. Min-Active results are relatively low because of small body mass index coeficient. For better understanding of Max-Active people sitting posture patterns, detailed tilt forward sitting posture mass distribution map were taken in place (fig 3.10). The image show, that for Max-Active participants the mass is focused near hip bone, the force gradient vector‘s direction is at coccyx area. In mass distribution map the high mass forces are still focused near hip bone, hence participant do not have enough muscle and fat layer for affective weight distribution.

In conlusion, for affective mass distribution require proper muscle & fat layer ratio. According to all catagorization results the highest risks for spinal muscle disorders have minimally active people with relatively small weight. For these type of people recommendation would be to use additional cushion for better mass distribution. Subjects with high body mass index, which living not active lifestyle, can distribute body mass more evenly, but the biggest conserns raises durring legs crossed sitting posture – the body is not able to distributed the mass all over chair surface. Recommendation would try to avoid this sitting posture or increase muscle layer in bottock area. High active people have mass distribution problems due small fat and muscle layer ratio. Suggestion would be to strenghten the muscle layer or grow more of fat layer. The active people with high BMI have the highest chances to distribute the mass most evenly in office environment.

REFERENCES

Aissaoui, R., Lacoste, M., & Dansereau, J. (2001). Analysis of sliding and pressure distribution during a repositioning of persons in a simulator chair. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *9*(2), 215-224.

Anderson, S., Goede, B., Kramer, D., Leupp, M., Nemunaitis, G., Hefzy, M. S., & Pourazady, M. (2013). Correlating air cushion pressure to maximum interface pressure on the buttocks. In Resna Annual Conference.

Bao, J., Li, W., Li, J., Ge, Y., & Bao, C. (2013). Sitting Posture Recognition based on data fusion on pressure cushion. *TELKOMNIKA Indonesian Journal of Electrical Engineering*, *11*(4), 1769-1775.

Barba, R.; Madrid, Á.P.; Boticario, J.G. 2015. Development of an inexpensive sensor network for recognition of sitting posture. *International Journal of Distributed Sensor Networks*. Vol. 969237.

Casey V., Grace, P., & Clarke-Moloney, M. (2010). Pressure measurement at biomedical interfaces. *Appl. Biomed. Eng.*, 243-264

Dzedzickis, A., Sutinys, E., Bucinskas, V., Samukaite-Bubniene, U., Jakstys, B., Ramanavicius, A., & Morkvenaite-Vilkonciene, I. (2020). Polyethylene-Carbon Composite (Velostat®) Based Tactile Sensor. *Polymers*, *12*(12), 2905.

Fathi, A., & Curran, K. (2017). Detection of spine curvature using wireless sensors. *Journal of King Saud University-Science*, *29*(4), 553-560.

Heinrich, J., Blatter, B. M., & Bongers, P. M. (2004). A comparison of methods for the assessment of postural load and duration of computer use. *Occupational and Environmental Medicine*, *61*(12), 1027-1031.

Huang, M., Gibson, I., & Yang, R. (2016). Smart chair for monitoring of sitting behavior. *KnE Engineering*, 274-280.

Jun, Y. D., Cho, S., & Park, S. H. (2016). Body pressure distribution measurement for comfort evaluation of a coccyx seating Mat. Adv Sci Technol Lett, 140, 173-8.

Li, W., Mo, R., Yu, S., Chu, J., Hu, Y., & Wang, L. (2020). The effects of the seat cushion contour and the sitting posture on surface pressure distribution and comfort during seated work. *International Journal of Occupational Medicine and Environmental Health*, *33*(5), 675-689.

Liang, G., Cao, J., & Liu, X. (2017, March). Smart cushion: A practical system for fine-grained sitting posture recognition. In *2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops)* (pp. 419-424). IEEE.

Meyer, J., Arnrich, B., Schumm, J., & Troster, G. (2010). Design and modeling of a textile pressure sensor for sitting posture classification. *IEEE Sensors Journal*, *10*(8), 1391-1398.

Mota, S., & Picard, R. W. (2003, June). Automated posture analysis for detecting learner's interest level. In *2003 Conference on Computer Vision and Pattern Recognition Workshop* (Vol. 5, pp. 49-49). IEEE.

Postolache, O., Girão, P. S., Pinheiro, E., & Postolache, G. (2010). Unobtrusive and non-invasive sensing solutions for on-line physiological parameters monitoring. In *Wearable and Autonomous Biomedical Devices and Systems for Smart Environment* (pp. 277-314). Springer, Berlin, Heidelberg.

Roh, J., Park, H. J., Lee, K. J., Hyeong, J., Kim, S., & Lee, B. (2018). Sitting posture monitoring system based on a low-cost load cell using machine learning. *Sensors*, *18*(1), 208.

Skach, S., Healey, P. G., & Stewart, R. (2017, July). Talking Through Your Arse: Sensing Conversation with Seat Covers. In *CogSci*.

Sun, C., Li, W., & Chen, W. (2017). A Compressed Sensing Based Method for Reducing the Sampling Time of A compressed sensing based method for reducing the sampling time of a high resolution pressure sensor array system. Sensors, 17(8), 1848

Xu, W., Huang, M. C., Amini, N., He, L., & Sarrafzadeh, M. (2013). ecushion: A textile pressure sensor array design and calibration for sitting posture analysis. *IEEE Sensors Journal*, *13*(10), 3926-3934.

Yu, C. H., Chou, T. Y., Chen, C. H., Chen, P., & Wang, F. C. (2014). Development of a modularized seating system to actively manage interface pressure. *Sensors*, *14*(8), 14235-14252.

Zemp, R., Fliesser, M., Wippert, P. M., Taylor, W. R., & Lorenzetti, S. (2016). Occupational sitting behaviour and its relationship with back pain–A pilot study. *Applied ergonomics*, *56*, 84-91.

Zemp, R., Tanadini, M., Plüss, S., Schnüriger, K., Singh, N. B., Taylor, W. R., & Lorenzetti, S. (2016). Application of machine learning approaches for classifying sitting posture based on force and acceleration sensors. *BioMed research international*, *2016*.

Zhou, B., Cheng, J., Sundholm, M., & Lukowicz, P. (2014, February). From smart clothing to smart table cloth: Design and implementation of a large scale, textile pressure matrix sensor. In *International conference on architecture of computing systems* (pp. 159-170). Springer, Cham.

ANNEXES

Mechatronics
Mechatronika

ŽMOGAUS SĖDĖSENOS ANALIZĖ NAUDOJANT NEBRANGIĄ SLĖGĮ MATUOJANČIĄ MATRICĄ

HUMAN SITTING POSTURE ANALYSIS USING LOW COST PRESSURE SENSING MATRIX

Rokas DVARVYTIS[1,*], Inga MORKVENAITE-VILKONCIENE[1]

[1]*Department of Mechatronics, Robotics, and Digital Manufacturing, Vilnius Gediminas Technical University, J. Basanaviciaus Str. 28, LT-03224 Vilnius, Lithuania*
**Corresponding author: Rokas, Dvarvytis, rokas.dvarvytis@stud.vgtu.lt*

Received 23 April 2021; accepted date

Abstract. Booming IT, industrial fields attract many new employees to change their working place to an office environment. Prolonged sitting has increased complains about back pain, soreness, which can lead to spinal trauma – scoliosis. Therefore, the purpose of this research is to help identify main human body characteristics responsible for good body mass distribution and identify specific category, which an 8x8 pressure matrix was built. Its key material Velostat® is well known for its flexibility, pressure sensing and low price. For data gathering a multiplexer was used. After calibration 9 participants were evaluated in an office environment. After participant matrix map analyzation can be noticed, that subjects with small BMI index, low physical activity have the highest risks for blood supply distortion and spine, muscular disorders. For sufficient body mass distribution an appropriate muscle and fat ratio in the buttock area is required. This research will help to monitor office environment and increase worker's healthiness and productivity. For employees would give good information what lifestyle is the best for a health and what sitting postures should be avoided.

Keywords: sitting posture; spinal trauma; matrix; Velostat®; multiplexer, BMI index.

Introduction

Daily work in IT field, in an office, monotonous sitting posture can lead to upper extremities disorders – pain and functional impairment, deformation of soft tissues, disturbance of local blood supply and lymphatic circulation. Inappropriate sitting can lead to spine, muscular disorders, hospitalization, or inhalable trauma. To identify what type of people have the highest risks for these disease, the purpose of this research is to analyze a group of people and clarify these specific subjects.

In previous decade nurses and doctors evaluated human postures – used visual evaluation and questionnaires to determine spinal cord disease. It is easy to carry out and gives fast results. But this kind subjective analysis does not give any kind of numbers to prove diagnosis. As alternative for these tests had been developed various pressure sensing planes. For example, rigid force plates, which use accelerometer to analyse humans in standing or sitting position. That type of measure is inaccurate and does not give mass distribution map, so it used not that often. As solution other, more flexible systems were created. Today new pressure sensing systems are so advanced that they can be integrated to our clothing, cushions and chairs to analyse pressure distribution (Xu, W., et. al., 2013, Huang 2017), amplitudes and even respiration, sleeping posture (V. Casey, 2011, R. Zemp 2016, J. Meyer 2010). Moreover, systems can be installed with sitting supporting surface to correct wrong sitting position, alarm person and reduce risk to have ulcers on buttocks (Sun, C., 2017, Y. Yu, 2014). But these ,,intelligent" systems have several huge disadvantages: they are expensive due to regulations for medical equipment and presented data is complex, which is difficult to interpret (R. Barba, 2015). For that reason scientists are focused on cheaper alternatives, which could digest collected data and present it in a way that will not need doctor‘s interference.

Typical pressure sensing system is made of conductive planes (outer, inner), sensors, hardware and software. The main goal of every pressure sensor is to measure inner layer deformation in one small area. In whole plane are many sensing areas, which combined form a matrix and as result can be presented on a computer pressure distribution map. Deformation of inner layer can be measured by sensors. They can be of various types and measure different characteristics. The system's measured values are voltage drop or rise in one area. Voltage changes depend on sensor resistance. For these human posture analyses were used different types of sensors:

- **E-textile**: changes capacitance during pressure presence, is flexible and can be integrated into clothing.
- **Photoresistor**: to use this sensor small silicone cylinders are required. Light stream density changes when the silicone cylinder deformed. Sensors change resistance.

- **EMFi sensor:** it is similar capacitance type of sensor. But these sensors use multilayer polypropylene and void interferences, which gives advantages as static (mass) and dynamic (heart rate, breathing) human body evaluation and simultaneous observation.
- **Hall's sensor:** for these sensors silicone cylinders with a small magnet on top of them are required. When the cylinder is deformed, the magnet comes closer to sensor as result changing magnetic field. Sensor registers it as change of voltage in a system. These sensors are good when a settling time of milliseconds is required.
- **Velostat®:** material, used in this research as resistive sensor. Velostat is made of polymeric foil, impregnated with carbon black to make it electrically conductive, can change resistance while flexed or pressed. The main advantages of this material are flexible range of dimensions, mechanical and chemical stability and relatively low price (A. Dzedzickis. 2020).

For signal digital representation software is required, which can read that type of data. In many previous researches (V. Casey, 2011) proprietary software was developed, but despite them in some research MATLAB was used (D. Jun 2016, J. Bao, 2013, R. Zemp, et al. 2016). This program is widely used, has many functions and commands to process data and represent to audience. When the system is turned on, the MATLAB must read all sensors values, then in function window describe all values as zeros, determine sampling frequency. After program collects all sensors data – that is one sampling time. When sampling period is finished system waits, then the second sampling period has to occur. The results are written as matrix. The matrix size depends on how many sensors are displayed on sensing systems plane. Results are shown in numbers and figures. The bigger the matrix, the higher resolution and number of pixels represented.

The system can be applied to number of different fields: from medicine (J. Heinrich 2004, Xu, W., et al. 2013, D. Jun, 2016) to psychology (S. Anderson 2013, J. Bao 2013, Huang 2017). The system can be adjusted for these features:

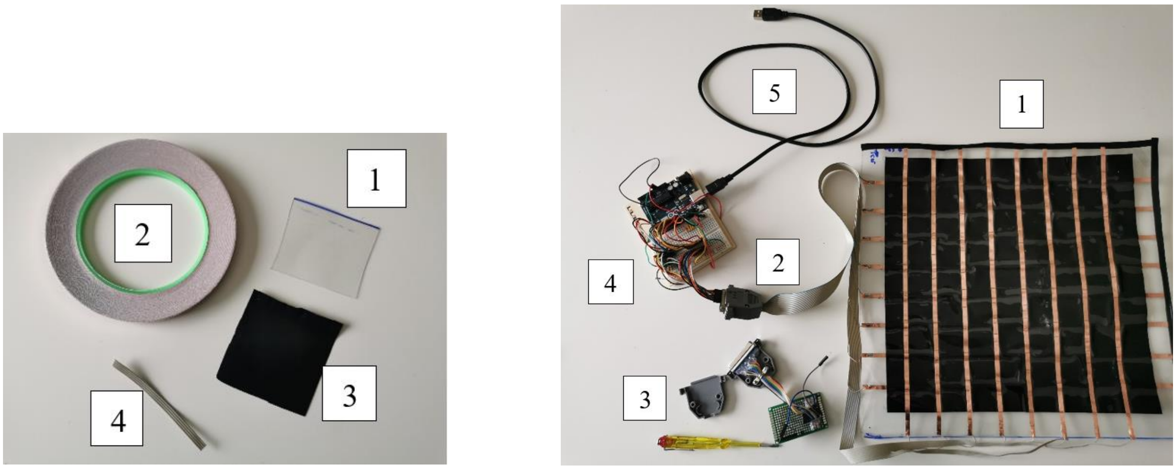
- **Trauma diagnosis:** the system can not only measure pressure sensing map, calculate amplitudes and etc. but classify it and objectively label sitting positions. This classification principle can be adjusted for trauma diagnosis in medicine field. This system save doctors time and give objective proves about encountered trauma.
- **Posture surveillance and control:** the pressure measurements can be useful in rehabilitation field. In hospitals people, who must stay in bed or in wheelchair have a higher chance for ulcer emergence due bad posture. For that reason, pressure sensing systems can not only identify bad sitting position, but also correct it with supporting planes. In this system an audio or LED signals can be implemented to inform person or hospital personnel due inappropriate human position.
- **Human psychology's analysis:** pressure sensing in real time can be applied analysing human behaviour while sitting and participating in conversation. As result, people that more often change their sitting posture participate in conversation more. Moreover, from pressure distribution map you can determine when a person is bored or exited (Huang 2017). This kind of system is useful for danger prevention – it can recognise stressful people in public, like terrorists and alarm the police for incoming danger (B. Zhou, et al. 2014).

1. Methodology

1.1. Matrix manufacture

Based on literature an 8x8 pressure matrix was built, which consists of: 35x35cm 0,5mm thick sticky tape (1), 0,5cm copper tape (2), 30x30cm velostat pad (Adafruit Industries) (3). The matrix is connected to multiplexer CD74HC4051E and Arduino Uno microcontroller using wires (4) (fig.1 a)). The pressure plate consists of three layers. At the top of the plate the copper tapes are wired horizontally, at the bottom the copper strips are in vertical position. There is a distance of 3mm between the stripes. The junctions where horizontal and vertical stripes meet can be called sensor points, where the pressure is measured. In the middle section of the a velostat pad is added. The Velostast® is a key material in this project as it can change his resistance when the pressure is applied.

Matrix system (fig.1 b)) consists of matrix plate (1), 25-pin port (2), multiplexer PCB board (3), layout board with Arduino Uno (4), USB cable to connect microcontroller with computer for data extraction. Data read and pressure sensor control is done using multiplexer. This microcontroller benefit is availability to read many sensor points using several microcontroller pins. Multiplexer was integrated into layout board (4) and after successful matrix plate read was soldered smaller version PCB board (3) according to scheme (fig.2).



a) b)

Figure 1. Parts of pressure sensing matrix. a) Piece of materials used to build a matrix, b) main parts of matrix system.

1.2. Matrix working principle

Working principle: one row is open (HIGH) and others are closed (LOW). Multiplexer is responsible for column control. The multiplexer has one pin HIGH, others are LOW. When the 5V voltage starts to flow from the open row it goes to the output which has least resistance – where the column is HIGH. When the output reaches multiplexer, it closes first channel and opens the second. 5V voltage then flows through channel 2. The process repeats until channel 8, then counting starts again from channel 1. All eight column values are transmitted through multiplexer's analog pin to Arduino pin A0. At the same time, when channel 8 is closed (LOW), the first-row pin (HIGH) is closed (LOW) and second is opened from LOW to HIGH. As result 5V flows from row 2, the multiplexer starts the counting and gathers the data by changing all 8 channels LOW-HIGH-LOW. The process repeats when all 8 rows are read. When the eight rows from HIGH becomes LOW, the Arduino program is completed – the program runs again where it started.

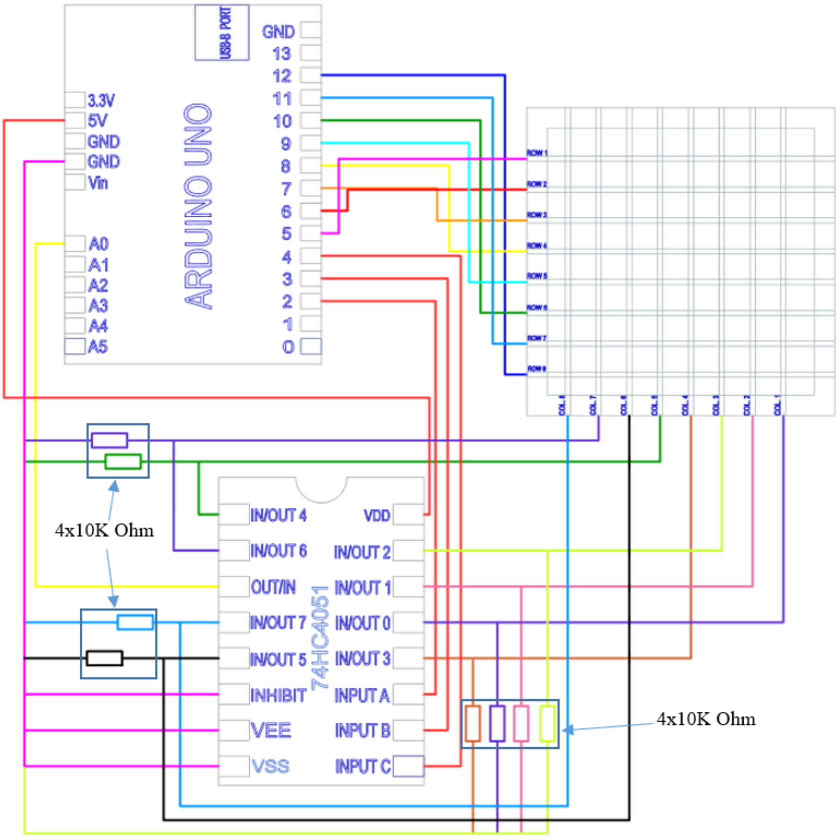


Figure. 2 Matrix system schematics

1.3. Calibration

Sensor calibration is done by measuring force to output voltage response. To evaluate how the system will respond to applied force 5x5cm width weights for each sensor point were used. Different output voltage values were achieved using different weights: 1-20N. During calibration pressure sensing plate is on flat surface. Output value has been measured 2 minutes after load application to make sure voltage measurement in steady state. The sensor calibration curve has been measured by converting 10bit ADC value to resistance by the following equation:

$$R_{(velostat)} = R_{(ref)} \frac{\left(1024 - V_{(ADC)}\right)}{V_{(ADC)}} \quad (1)$$

where $V_{(ADC)}$= 10 bit ADC value, $R_{(ref)}$= resistor reference on voltage divider (10K Ohm), $R_{(velostat)}$= sensor matrix resistance.

The results presented in figure 3 were used for raw data converter to final results. Figure 3 shows the wide deviation of the sensor results. this wide deviation value is possible because of hand-made manufacturing. Although deviation of 32 samples on sensor matrix is wide, its percentage tends to reduce as the force increases. Manufactured matrix more reliable to sense high forces.

$$R(\mathrm{x}) = (-0.04982) \cdot x^7 + (4.335) \cdot x^6 + (-156.5) \cdot x^5 + (3028) \cdot x^4 + (-3.379\mathrm{e}+04) \cdot x^3 + (2.168\mathrm{e}+05) \cdot x^2 + (-7.41\mathrm{e}+05) \cdot x + (1.054\mathrm{e}+06) \quad (2)$$

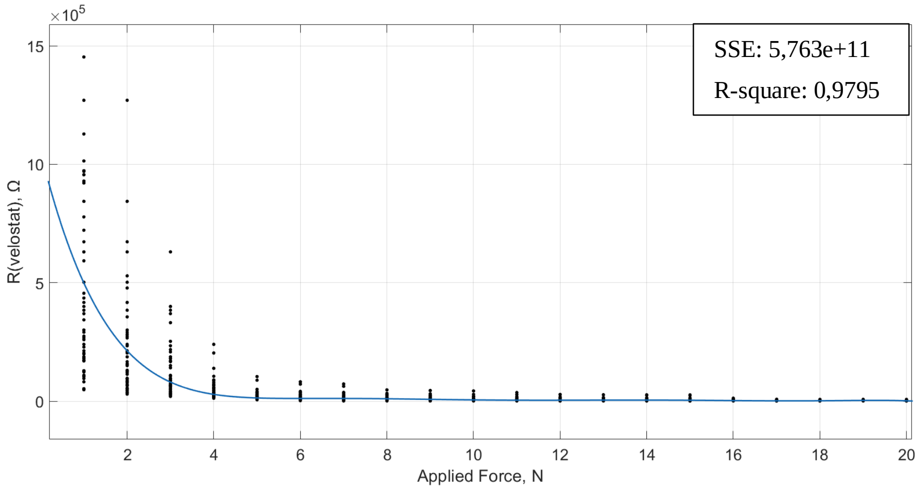


Figure 3. Velostat resistance versus applied force results (calibration curve). SEE – data's accuracy, or the scatter of point about the line for a given value; R-square – statistical measure of fit that indicates how much variation of a dependent variable is explained by the independent variable(s) in a regression model.

2. Research method
2.1. Defining sitting postures

The research purpose was to analyze human posture – mass distribution in office environment. 9 participants: 6 male and 3 females between age of 24-42 years were asked to sit in 7 most common posture positions to reflect different human behaviors next to their desk. 7 different sitting postures were:

1.Standard: back support, sitting back with the feet completely flat. This posture is characterized by the body exerting pressure on the back and seat.

2.Lying-1**:** a posture denoting boredom, where subjects sit up on the air, sitting on the edge of the chair. The body exerts strong pressure on the upper part of the back and the front of the seat.

3.Tilt forward: It denotes attention. Subjects sit back, leaning forward, feet under the chair. The body exerts a strong pressure on the front of the seat, without pressure on the back.

4.Normal position, feet under the chair: This posture de notes attention, where subjects sit with their back supported, sitting back with their feet completely flat. In this position, the body exerts very little pressure on support and strong pressure on the front of the seat.

5.Sitting on the edge: stance denoting attention, where the subject sits on the edge of the chair, back and flat feet completely on the air. No pressure is observed on the back, showing a homogeneous distribution on the seat.

6.Legs Crossed: posture denoting peace, subjects sitting normally with legs crossed. Depending on the crossed

leg, the weight is concentrated on the right or left of the seat and slightly on an edge of the back.
7.Lying-2: posture denotes fatigue. Subjects sit in are clinging position. In this position a lot of pressure is exerted on both the seat and the backrest.

Figure 4. Seven sitting postures: 1) Standard; 2) Lying-1; 3) Tilt forward; 4) Normal position feet under the chair; 5) Sitting on the edge; 6) Legs Crossed; 7) Lying-2.

2.2. Sitting posture classification

With every posture the data was registered by Arduino, raw data digested & reflected with colored matrix map using program MATLAB. The participants were categorized by:

- Sex.
- Health (person with no spinal traumas compared with participant who have scoliosis).
- Body mass index (BMI).
- Lifestyle activity.

2.3. Calculating matrix parameters

Using calibration data values will be generated posture pressure distribution matrix. Using all information from every participant were calculated these parameters (W. Li., 2020):

- **Average force:** matrix mean average.
- **Max force:** matrix map maximum identified value.
- **Total surface area:** the area of matrix points which reacted to applied force.
- **Mean contact area:** the area of matrix points which reacted to average pressure in a range of deviation of 1 sigma.
- **Max force gradient:** max pressure vector in matrix representing biggest change of pressure between points.
- **Pressure dispersion index (DI) (Fano factor):** statistical coefficient explaining scale of mass dispersion.

Max force gradient was calculated using MATLAB software. Force gradient is a vector which identifies the direction where value increases – the summary of vectors on one point. The vectors are calculated for each point. Pressure distribution calculated with equation:

$$DI = \frac{Variance}{F_{Avg}} \qquad (3)$$

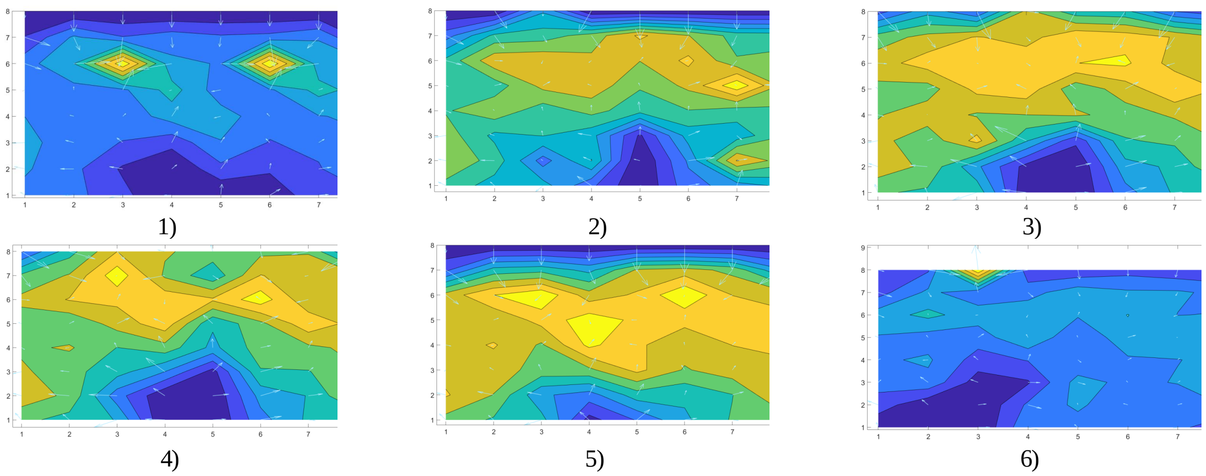
where Variance – variance based on the entire matrix, F_AVG – average matrix force.

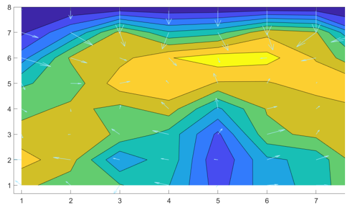
3. Research results

3.1. Participant data as nominal for matrix comparison

In this research participated 9 people with the age of 25 – 33, 1,58 – 1,93 m height, 56 – 93,5 kg weight. For this research one participant, man, 25 years old without any spinal trauma will be chosen as nominal. Other participant matrixes, conclusions partially will be referenced to his results.

Using these parameters, nominal man and other participant matrix results were generated. The data for each subject were grouped according to specified criteria and compared accordingly. The chosen person as nominal results presented in figure 5, calculated statistical results for each posture in table 1.





7)

Figure 5. Nominal man results – 7 sitting postures: 1) standard; 2) lying; 3) tilt forward; 4) normal position – feet under chair; 5) sitting on the edge; 6) legs crossed; 7) lying-2.

Table 1. Participant defined as nominal sitting posture results.

Positions	Average Force	Max Force	Total surface area, Max (64)	Mean contact area	Max force gradient	Pressure dispersion index (DI)
1	2,292	8,947	53	48	21,97	3,744
2	2,417	4,876	55	47	20,47	1,019
3	2,620	4,100	62	46	12,95	0,491
4	2,554	4,326	62	49	13,03	0,400
5	2,591	4,452	56	45	16,03	1,039
6	2,483	8,879	61	50	32,73	1,340
7	2,385	4,309	56	44	16,72	1,035
Average	2,478	5,698	58	47	19,13	1,296
Min	2,292	4,100	53	44	12,95	0,400
Max	2,620	8,947	62	50	32,73	3,744
StDev	0,119	2,209	3,716	2,160	6,898	1,129

3.2. Participant categorization

First categorization – gender comparison. 9 participants were grouped according to gender. From gathered data a matrix average force, max force & data dispersion index graph was created. Looking at the average matrix force results it can be noted that the max and average force of women is bigger than men. The results may look illogical as women weight less and Women-Avg Min value in figure 6 proves that. The Women force results are related with Max force matrix results (figure 7 & table 2). When men sit on the chair, they manage to distribute force more evenly, from matrix maps it is more difficult to tell where the Anal triangle is. When the siting posture is based on the chair edge, where the mass must be concentrated in one area, the men then surpass women with max force results – force distribution index (DI) values are the highest. But despite that, women manage to create the highest force on the matrix with the value of 7.14N (men 6.95 N).

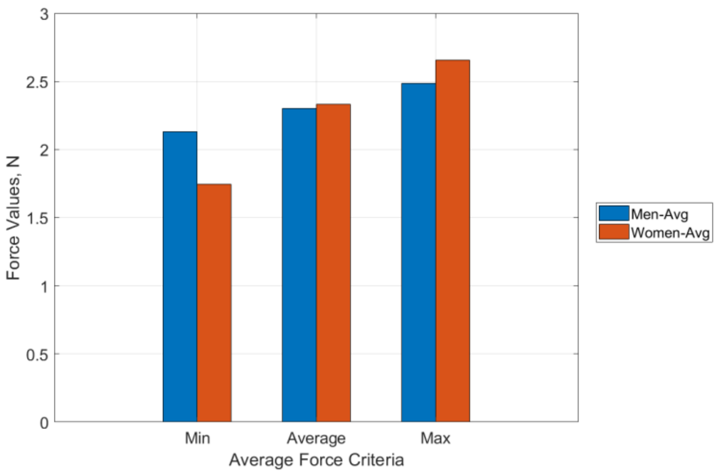


Figure 6. Men & Women average force results

Looking at this figure 7 defined two assumptions: during specific sitting postures (sitting on the edge, legs crossed, lying on the edge) the human weight is focused more in one area where hip bones are generating higher force values.

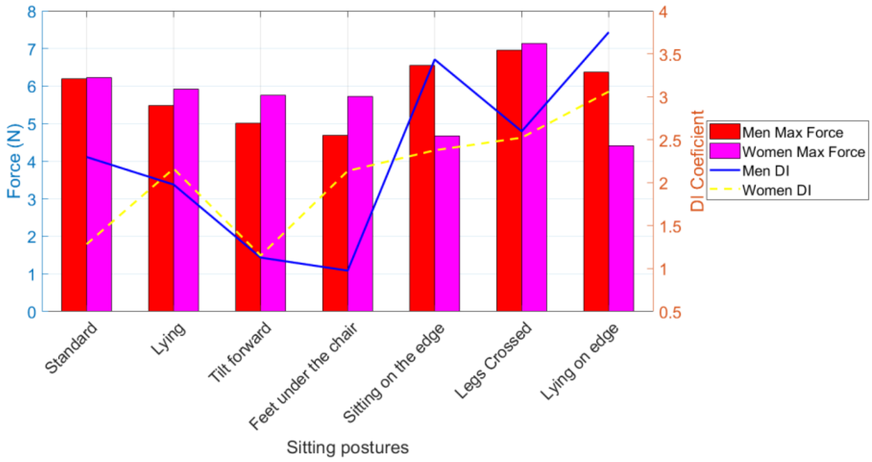
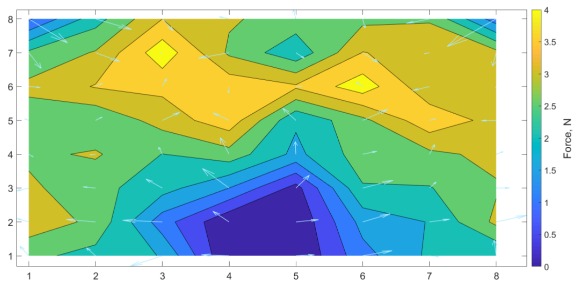
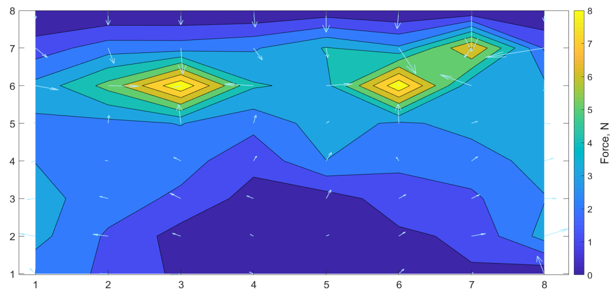


Figure 7. Men & Women Max force & distribution index results

For comparison, the results of women sitting with their feet under the chair are presented and compared with nominal man in more detail (figure 8). The woman matrix and results were compared with nominal man. Results show, that while nominal man can distribute his mass quite well with low DI index value 0,400, the woman mass is focused much closer to hip bone area. While average matrix force is similar, the woman generates the max force twice higher than nominal man. The assumption is that women lack muscle and fat layers for efficient body mass distribution in a wide area.



Nominal man posture, sitting feet under chair



Women posture, sitting feet under chair

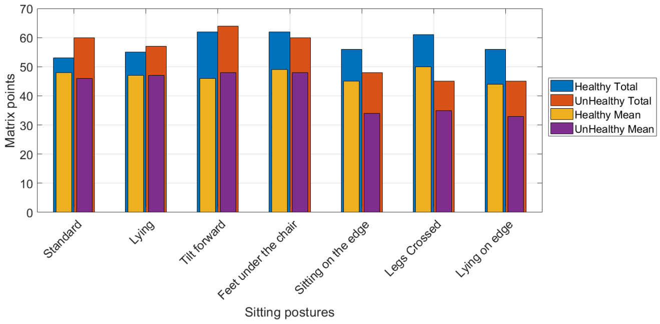
Figure 8. Sitting feet under chair posture comparison between healthy & unhealthy subject

Table 2. Sitting feet under chair force results

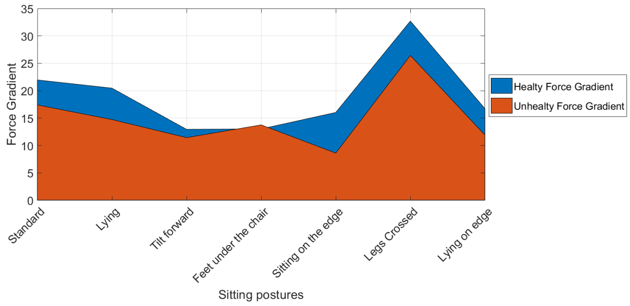
Gander	Average, N	Max, N
Man (nominal)	2,554	4,326
Women	2,253	8,859

Second data comparison between healthy & unhealthy person. One tested participant had scoliosis – spinal trauma, his data were compared with nominal man for analyzation, if sitting patterns are different. Looking at figure 9 a), matrix occupancy graph, that unhealthy person's chair occupancy has higher deviation: stdev=7.13, while healthy participant's stdev=3.7. During standard sitting posture while unhealthy subject occupies more chair area than healthy, but the mean occupancy of the person with scoliosis, is smaller than the healthy one. As a result, it was decided to look at the standard sitting posture in more detail.

Another analyzed sitting posture aspect was the Max force gradient figure 9 b). In plot, the peak force gradient was at the 6th sitting posture. It is possible that in other sitting postures man's results are always higher (expect fourth sitting posture) than women's due to BMI difference. For a detailed matrix review of nominal man and women with scoliosis standard and legs crossed sitting postures were chosen (table 3).



a) Matrix point occupancy

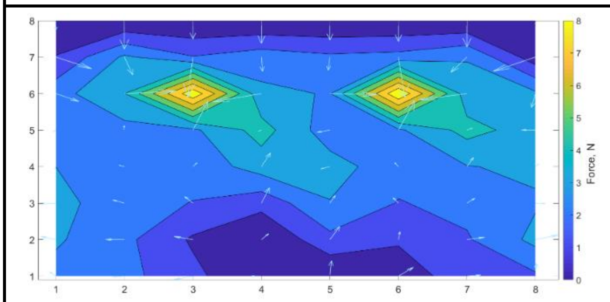
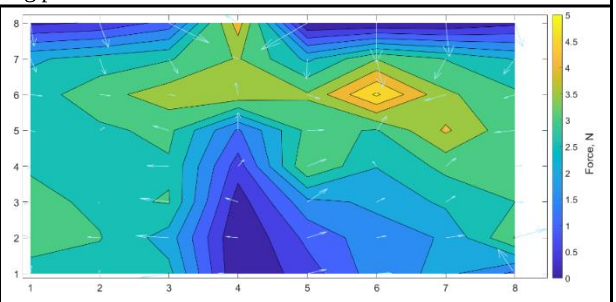
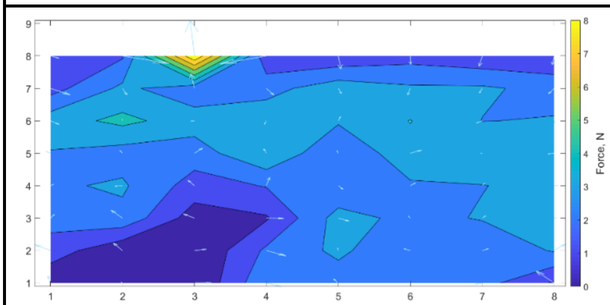
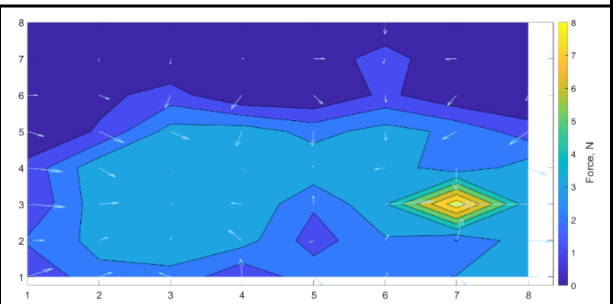


b) Max force gradient

Figure 9. Data comparison between healthy & unhealthy person: a) Matrix point occupancy; b) Max force gradient

At table 3 is presented healthy & person with scoliosis sitting postures: standard, legs crossed. Matrix results show that person with scoliosis body weight max forces is distributed more on left side than nominal man. Nominal person's mass in standard sitting posture is spread more evenly than women's with scoliosis. During legs crossed (right leg on the left) man force density increased on right hip area while women mass stayed focused on left hip side. In legs crossed sitting posture person's with scoliosis matrix is not fully covered. Explanation as follows – during sitting posture the participants were asked to cross right leg on the left. While women stayed in the same position the man changed his posture to standard and then crossed legs. He changed his posture to that he could use a seat back for additional back support. The matrix contact area results can be seen in table 3.

Table 3. Sitting posture comparison between healthy and scoliosis trauma having person

Healthy Person (Nominal)	Person with scoliosis
Standard sitting posture	
	
Legs Crossed sitting posture	
	

Third comparison according to BMI index. Sitting postures were compared between participants with different BMI index. 9 participants were grouped by three: Min-BMI, Avg-BMI, Max-BMI. After categorization, a max matrix force graph (fig. 10) was created. To begin with, Standard sitting posture presents strong explanation how body mass distributes with different BMI coefficients. Participants with small BMI should produce smallest force results, but it is not the case. During standard and legs crossed sitting posture the values are higher than other BMIs. It can be explained by small muscle and fat layer in buttock area – the force produced by hip bones. On the contrary, participants with high BMI coefficient managed to maintain relatively low max forces due to larger density of muscles and fat. The best performed participants with average BMI – while keeping max force in standard and lying on the edge postures close to total average max force of AVG-BMI, four sitting postures produced lowest force compared to others. Exception is sitting on the edge posture – probably due to a small area where the force can be distributed it generated the highest force and due to insufficient layer of fat. Min-BMI results were lowest because the participants weight the least, Max-BMI participant have a high fat ratio which helps to use a wider area on the chair to distribute hip mass more.

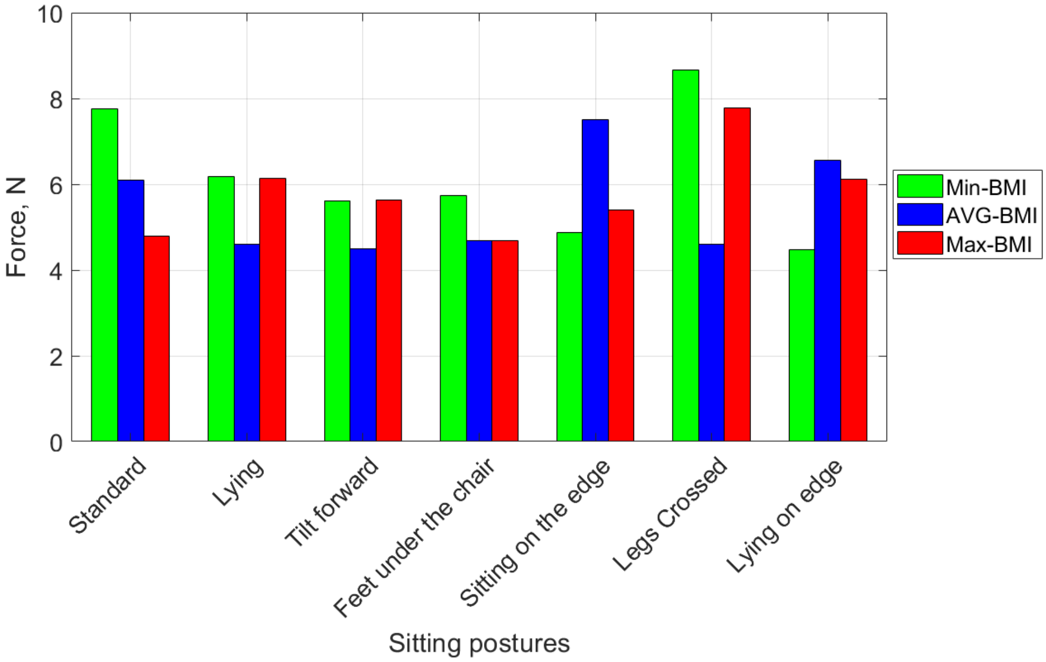
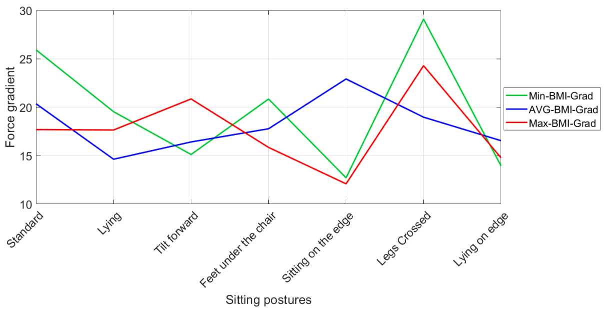


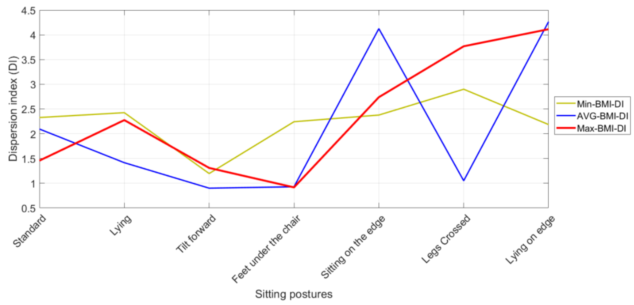
Figure 10. Max Matrix Force graph according to BMI

An explanation rises that for Min-BMI can distribute the body mass in small areas well, when the weight is focused more on one side, the forces increase drastically. As for Avg-BMI & Max-BMI – during sitting on the edge posture the values increased more, than Min-BMI as they don't have enough chair surface for mass distribution. During legs crossed sitting posture forces should be increased way more than Min-BMI because them pass is heavier. But during this sitting posture, participants from Avg-BMI & Max-BMI have more dense muscle and fat layer, which stretches and distributes mass more evenly.

Max force gradient (figure 11. a)) and force dispersion index (DI) (figure 11. b)) improve the understanding how hip bones interact with muscles and fat. Minimum BMI participants in standard and legs crossed sitting postures produced the highest gradient due lack of layer of fat and muscle. Sitting on the edge the value is smallest due to small weight. Average BMI showed the smallest deviation between sitting postures. Sitting on the edge produced the biggest results (figure 11) as participants lacked fat layer, muscle layer is not enough for proper mass distribution. During tilt forward, feet under chair and legs crossed DI is lowest – assuming muscles stretched more, used additional leg support to spread the force more sufficient. Max BMI subjects produced lowest gradient in fifth pose (sitting on the edge) due to a likely large fat layer. During legs crossed max gradient peak is reached. DI graph shows that putting feet under chair the force deviation was the lowest, as the participants were able to use legs (legs have their own muscle and fat layer). From sitting on the edge to lying the DI index increases due to high force values in a small area.



a) Max force gradient

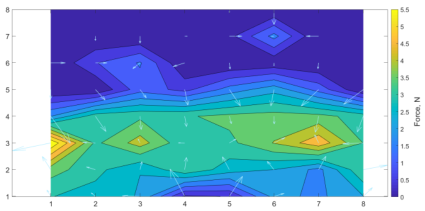
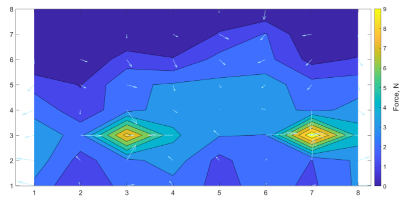
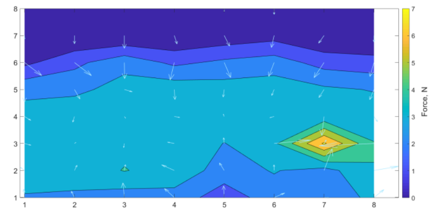
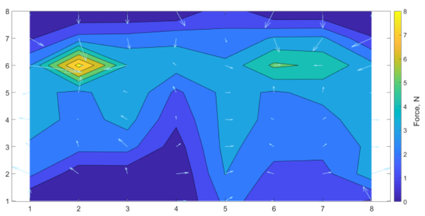
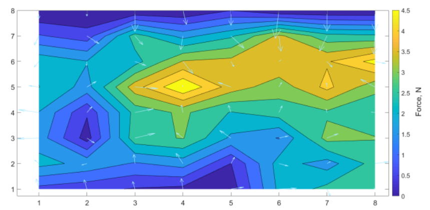
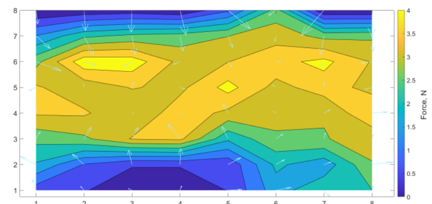


b) Force dispersion index (DI)

Figure 11. BMI catagorization resuls: a) Max force gradient; b) Force dispersion index (DI)

In table 4 pressure distribution maps for each group are presented. Participants from Min-BMI group produce low maximum force results F(max)=5,943N in contrast with others: 9,973N & 7,714N. Contrary, Min-BMI subjects in legs crossed sitting posture, where the mass is focused more on one side, create noticeable high max force results F(max)=8,408N, while Avg-BMI 4,981N and Max-BMI 4,347N.

Table 4. Sitting posture comparison between Different BMI.

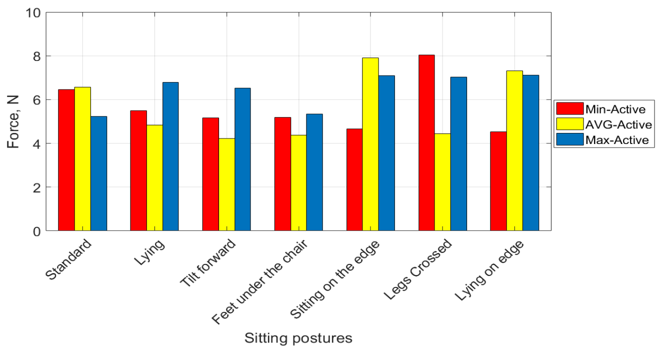
Min-BMI	Avg-BMI	Max-BMI
Sitting on the edge posture		
 F(max) = 5,943 N Max Force gradient = 13,491 Force dispersion index (DI) = 3,884	 F (max) = 9,973 N Max Force gradient = 26,992 Force dispersion index (DI) = 5,521	 F (max) = 7,147 N Max Force gradient = 15,584 Force dispersion index (DI) = 2,609
Legs crossed sitting posture		
 F (max) = 8,408 N Max Force gradient = 28,114 Force dispersion index (DI) = 2,848	 F (max) = 4,981 N Max Force gradient = 18,121 Force dispersion index (DI) = 1,386	 F (max) = 4,347 N Max Force gradient = 15,703 Force dispersion index (DI) = 1,269

Fourth categorization – lifestyle activity comparison. During last data classification the subjects were grouped according how much steps they do in a month. For this, three groups were created: Min-Active, Avg-Active, Max-Active. The group data were summed together and generated max force and max force gradient graphs.

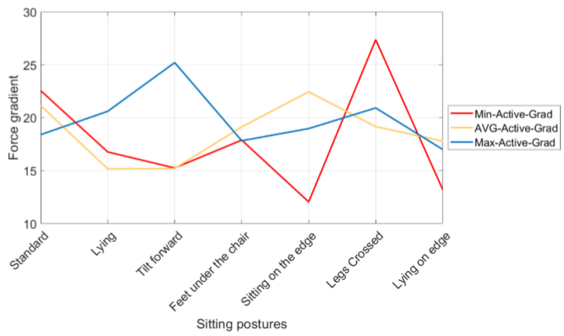
Min-Active people are the ones with relatively low BMI index (low weight) or overweight. BMI is coherent with lifestyle activities. People with higher number of steps most likely practice some field of sport: running, playing team games etc. Active people will have more muscle on buttock area than fat.

At first, looking at average matrix force the values are close to each other (small deviation between different sitting postures), for that reason they are not analysed in detail. Max matrix graph created for sitting posture for comparison between grouped participants (fig 12 a)). Min-Active and AVG-Active people manages to spread mass better (average max force both ≈5.6N) than max-Active objects (6.45N). That could be explained that Max-Active subjects had a small amount of fat. It is assumed that min & average active people have enough muscle and fat ratio in buttock area for affective force distribution.

The fastest pace of change in force is explained with matrix max force gradient graph 3.11 – it shows that minimum active participants hold low force gradient vectors, which can be collated with fat layer. Similar patterns can be found and in BMI Max force gradient in Figure 12 b). While average active subjects reached the peak when sitting on the edge, the same as participants with average BMI, maximum active participants reached the peak at tilt forward.



a) Max Matrix Force graph



Graph 3. 11 Max force gradient

b) Max force gradient

Figure 12. Categorization according to lifestyle results. a) Max force gradient; b) Force dispersion index (DI)

Maximum active participant mass distribution map is taken to understand the vector location, direction and cause why the peak created in this sitting pattern (fig. 13). In matrix the force mostly distributed in wide range of buttock area near the bone. The max gradient direction is where should be the coccyx contact area. But in contrast with nominal participant data, max-Active participant mass is more focused on hip bones and less distributed to over legs. Assumption would be, that human mass is not distributed evenly due too little fat layer muscle layer is not able more evenly distribute force in hip bone area.

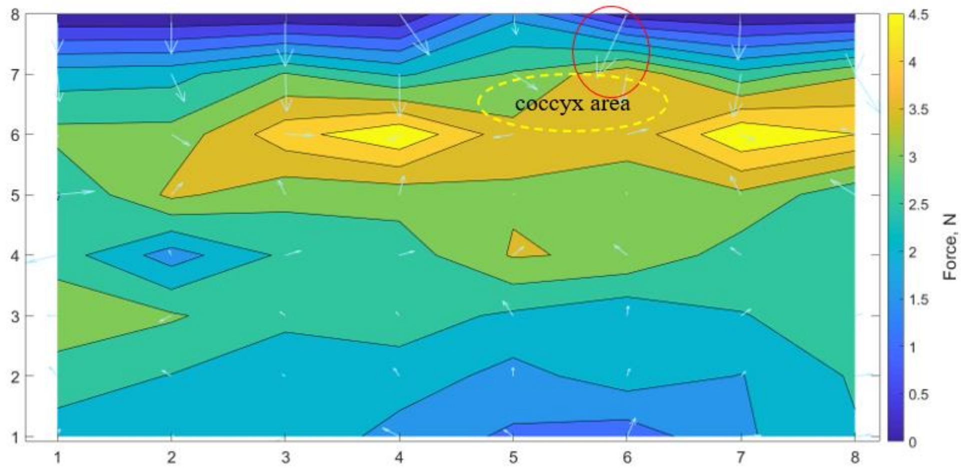


Figure 13. Max-Active person matrix of sitting posture – tilt forward.

Another analyzed parameter is Force Dispersion Index (DI) (fig 14). It would give more information about how force values are dispersed in the matrix. At a first glance, the average and maximum active participant curves have similar trajectories. In contrast with AVG-Active, Max-Active subjects' curve has a smaller deviation. AVG-Active, Max-Active have reached the peaks while sitting on the edge, which is relatable to sitting pattern – matrix is covered by half of its width. Min-Active generated smaller index due better force distribution by sufficient fat layer and due relatively small participant weight. During lying and tilt forward sitting postures all three group results are similar. The deviation is reduced probably due back seat on lying position, where the participant could lay back and because of the office table, where subject could use his hands and transfer mass through shoulders to the desk. Feet under the chair have smaller deviation values as the participants were using more legs to support mass distribution over the chair.

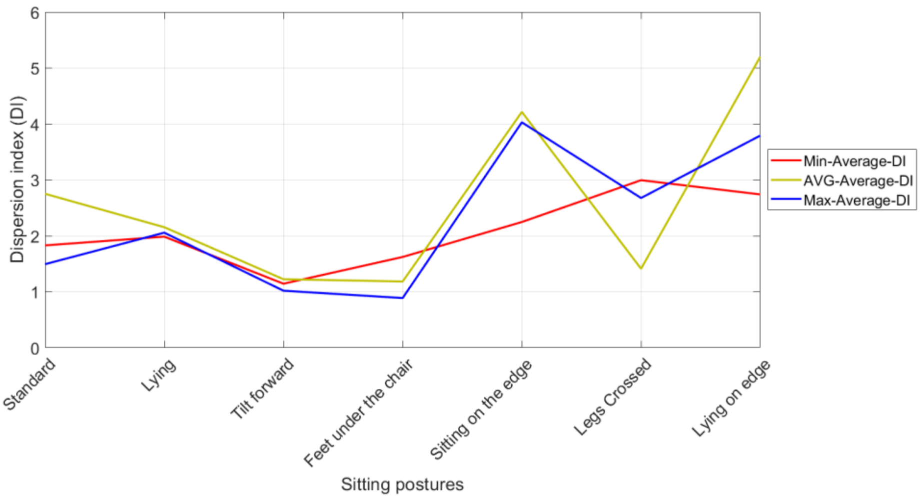


Figure 14. Force dispersion index (DI) according to lifestyle activity

Conclusions

The purpose of a pressure matrix is to diagnose human trauma severity, by evaluating the sitting posture. The matrix as system is made of non-conductive material (outer layer), conductive plane, sensors, hardware, software. When the force is present on a matrix, conductive layer reduces its resistance. 8x8 matrix in this research was built using conductive material – Velostat® and copper wires laid one side horizontally and other side vertically. When the force is applied on the matrix, voltage from horizontal stripes goes through velostat to a vertical line – current as output flows to microcontroller. The output voltage decreases due to Velostat®, material has a property to change resistance due to deformation. For sensor control, data transfer to Arduino, a multiplexer was used.

Using calibration curve graph, registered raw data was processed and as result human mass force matrixes were created. One participant was chosen as the nominal. The first participant comparison was according to gender. After data comparison it was noted that women generate bigger average and max force values than men despite the fact, that men are heavier. Only during sitting on the edge posture men generate bigger values. Explanation would be that women hip bones interaction with the chair generates higher forces than men. But when a smaller chair area is used to distribute body mass, men results are higher. When the data was compared between a healthy person and with subject, who has spinal trauma, noted in standard sitting posture, which is the most correct for the human body, the unhealthy person takes more chair surface area than the healthy participant, while in legs crossed sitting posture have the highest change of force. When analysing these two sitting postures in detail, can be noted that unhealthy person's body mass is focused more on the left side. For data comparison between different BMI participants were grouped together in three: Min-BMI, Avg-BMI, Max-BMI. Participants with different BMI index data explain how the composition of the human body can influence sitting posture patterns. Looking at figure10, subjects with relatively small BMI index produced high max force results. Avg-BMI and Max-BMI results are similar, while visible differences can be noticed in sitting on the edge and legs crossed sitting postures. Max force gradient figure 11 a) confirms the fact, that during standard and legs crossed sitting postures the highest change in force is created by Min-BMI participants. Force dispersion index (DI) figure 11 b) explains, that Avg-BMI participants during sitting and laying on the edge sitting postures DI is the highest as they have insufficient layer of fat and in a small area, they have to distribute most of their mass. Avg-BMI subjects produced low DI index in these sitting postures, where they could use leg muscles as additional support.

While comparing results between active lifestyle living participants, it was noted that min & average active people maintained similar and low max force results (5,6N) in contrast with Max-Active participants (6,45N). The difference occurs because of muscle and fat ratio. Max-Active subjects lack a fat layer and with insufficient layer of muscle they cannot spread mass in wider area. Max force gradient results explain that Min-Active people create lower force gradient vectors in comparison with Avg-Active and Max-Active participants (expect legs crossed sitting position where the mass is focused more in one area). Avg-Active DI peak is at sitting on the edge while for Max-Active is at tilt forward. While analyzing Max-Active participant tilt forward position, in a matrix can be seen max gradient vector's direction pointed to coccyx area (fig. 13). Moreover, the figure shows, that participant's mass is focused in hip bone area. The force is distributed more in hip bone area due larger amount of muscle layer compared with Min-Active participants. But this muscle layer is not sufficient for effective mass distribution due to wrong muscle and fat ratio. Nominal man tilt forward position takes much more matrix area to spread mass more evenly (figure 5). Looking at force dispersion index figure 14 Avg-Active and Max-Active participants have similar curves – probably due more similar muscle and fat layer ratio. Min-Active participants maintained relatively low DI coefficient probably due to small mass, that theory confirms lowest coefficient during sitting on the edge and the highest result at legs crossed in contrast with Min-Active and Max-Active subjects, where the force is focused in one area.

Experimental conclusions – The hip bones are the biggest force raisers; reaction force goes through hips to over spine. Humans can distribute the force more evenly over the hips by using fat and muscles. The fat density is smaller (0,909 g/cm3) than muscle (1.060 g/cm3) – fat can stretch more in sides and distribute force more evenly. When the force is applied in a smaller area, the fat stretches too much as result making hip bone closer to the chair surface and transferring more force over the spine. Muscles have bigger density and smaller plasticity which help to outperform fat. While the mass is distributed over muscles, they stretch less, leaving more thickness for bone amortization, therefore helping to spread the mass more during postures where the force is focused in one area. During result comparison between active participants, it was noted that for affective force distribution, a proper fat and muscle layer ratio is needed, while in smaller area fat layer helps spread mass force, it cannot do so while the force is focused in one point as muscles and vice-versa.

References

Barba, R., de Madrid, Á. P., & Boticario, J. G. (2015). Development of an inexpensive sensor network for recognition of sitting posture. *International Journal of Distributed Sensor Networks*, *11*(8), 969237. https://doi.org/10.1155/2015/969237

Casey, V., Grace, P., & Clarke-Moloney, M. (2010). Pressure measurement at biomedical interfaces. *Appl. Biomed. Eng.*, 243-264.

Sun, C., Li, W., & Chen, W. (2017). A compressed sensing based method for reducing the sampling time of a high resolution pressure sensor array system. *Sensors*, *17*(8), 1848. https://doi.org/10.3390/s17081848

Yu, C. H., Chou, T. Y., Chen, C. H., Chen, P., & Wang, F. C. (2014). Development of a modularized seating system to actively manage interface pressure. *Sensors*, *14*(8), 14235-14252. https://doi.org/10.3390/s140814235

Anderson, S., Goede, B., Kramer, D., Leupp, M., Nemunaitis, G., Hefzy, M. S., & Pourazady, M. (2013). Correlating air cushion pressure to maximum interface pressure on the buttocks. In *Resna Annual Conference*.

Heinrich, J., Blatter, B. M., & Bongers, P. M. (2004). A comparison of methods for the assessment of postural load and duration of computer use. *Occupational and Environmental Medicine*, *61*(12), 1027-1031. http://dx.doi.org/10.1136/oem.2004.013219

Xu, W., Huang, M. C., Amini, N., He, L., & Sarrafzadeh, M. (2013). ecushion: A textile pressure sensor array design and calibration for sitting posture analysis. *IEEE Sensors Journal*, *13*(10), 3926-3934. 10.1109/JSEN.2013.2259589

Jun, Y. D., Cho, S., & Park, S. H. (2016). Body pressure distribution measurement for comfort evaluation of a coccyx seating Mat. *Adv Sci Technol Lett*, *140*, 173-8.

Bao, J., Li, W., Li, J., Ge, Y., & Bao, C. (2013). Sitting Posture Recognition based on data fusion on pressure cushion. *TELKOMNIKA Indonesian Journal of Electrical Engineering*, *11*(4), 1769-1775. 10.11591/telkomnika.v11i4.2329

Huang, M., Gibson, I., & Yang, R. (2016). Smart chair for monitoring of sitting behavior. *KnE Engineering*, 274-280. https://doi.org/10.18502/keg.v2i2.626

Zhou, B., Cheng, J., Sundholm, M., & Lukowicz, P. (2014, February). From smart clothing to smart table cloth: Design and implementation of a large scale, textile pressure matrix sensor. In *International conference on architecture of computing systems* (pp. 159-170). Springer, Cham. https://doi.org/10.1007/978-3-319-04891-8_14

Zemp, R., Tanadini, M., Plüss, S., Schnüriger, K., Singh, N. B., Taylor, W. R., & Lorenzetti, S. (2016). Application of machine learning approaches for classifying sitting posture based on force and acceleration sensors. *BioMed research international*, *2016*. https://doi.org/10.1155/2016/5978489

Zemp, R., Fliesser, M., Wippert, P. M., Taylor, W. R., & Lorenzetti, S. (2016). Occupational sitting behaviour and its relationship with back pain–A pilot study. *Applied ergonomics*, *56*, 84-91. https://doi.org/10.1016/j.apergo.2016.03.007

Meyer, J., Arnrich, B., Schumm, J., & Troster, G. (2010). Design and modeling of a textile pressure sensor for sitting posture classification. *IEEE Sensors Journal*, *10*(8), 1391-1398. 10.1109/JSEN.2009.2037330

Dzedzickis, A., Sutinys, E., Bucinskas, V., Samukaite-Bubniene, U., Jakstys, B., Ramanavicius, A., & Morkvenaite-Vilkonciene, I. (2020). Polyethylene-Carbon Composite (Velostat®) Based Tactile Sensor. *Polymers*, *12*(12), 2905. https://doi.org/10.3390/polym12122905

Santrauka

Nuolat besiplečianti IT ir kitos sritys pritraukia daugumą kvalifikuotų specialisų dirbtį įmonėse, kuriose vyrauja biuro tipo sąlygos. Pastovus sėdėjimas žymiai padidina darbuotojų nusiskundimus nugaros skausmais, maudimu, kurie yra pirminiai ženklai vedantys link stuburo traumos – skoliozės. Atsižvelgiant į tai šio tyrimo tikslas – padėti identifikuoti pagrindines žmogaus anatomijos charakteristikas, atsakingus už tinkamą kūno masės paskirstymą ir išskirti žmonių grupę, kuri turi didžiausią riziką patirti stuburo traumą. Šiam tyrimui buvo sukonstruota 8x8 matrica. Velostat® yra šios matricos pagrindas, kuri pasižymi lankstumu, reagavimu į apkraunamo slėgio pokyčius ir žema kaina. Išvesties rezultatams surinkti naudojamas multiplekseris. Po kalibravimo biuro aplinkoje buvo ištirti 9 dalyviai. Įvertinant dalyvių kūno masės paskirtstymo matricas galima pastebėti, kad dalyviai su mažu BMI koeficientu, pasižymintys mažu aktyvumu turi didžiausius šansus sukelti kraujo tekėjimo ir stuburo srities problemas. Afektyviam kūno masės paskirstymui yra reikalingas tinkamas raumeninio ir riebalinio sluoksnio santykis. Šis tyrimas padės labiau stebėti ir įvertinti biuro aplinką, kad būtų galima išlaikyti gerą darbuotojų sveikatą ir padidinti produktyvumą. Darbuotojams suteiks daugiau informacijos koks gyvenimo būdas yra jiems labiau tinkamas ir kokias sėdėjimo pozicijas rekomenduojama labiau vengti.