29th International Conference
ENGINEERING MECHANICS 2023
Milovy, Czech Republic, May 9 – 11, 2023

CONDUCTIVE FILM SENSOR FOR HEALTH MONITORING OF A BEDRIDDEN PATIENT

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Abstract: *The work is aimed to analyse the possibility of using the Velostat® film technology to help medical staff in the care of bedridden patients. System were prototyped and tested. Velostat® film bedsheet is an anti-bedsore module that utilizes dedicated pressure sensitive mat for position detection to signalize a possibility of a bedsore effect. The modules have been tested and the results of their functioning have been presented. The results of the tests is verification of the pressure sensing mat made of Velostat® film. On the basis of the pre-designed device and conducted research, a system is created for monitoring a lying patient and can be used for further clinical trials, supporting many hospital medical staff.*

Keywords: Velostat®, Health monitoring, Bedridden patient, Biomechanical measurements.

1. Introduction

In 2019, in Poland, households consisting only of the elderly constitute approximately 20% of households. It is estimated that this factor will increase to 40% in 2050 (Statistics Poland, 2021). 8% of Polish citizens are people with disabilities, of which 29% are severely disabled (Central Statistical Office, 2021).

The analysis of the presented situation clearly shows the increase in demand for care services. Most of the burden of providing this care will be on public authorities, including municipalities. From an economic point of view, ways should be sought to reduce the cost of care while increasing the quality of services. The answer to both problems may be the partial replacement of caregivers with technological elements taking over some of the duties, robotization of care, and the provision of telecare and telesupervision services. Of course, there are the negative social phenomena resulting from the dehumanization of care, but they constitute a separate issue.

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ISSN: 1805-8256, doi: 10.21495/em2023-99

Next module which is investigated within the smartbed project is pressure sensing mat. The main aim is detecting long lasting position for antibedsore protection. The mat is constructed as pressure multisensor in matrix structure. The pressure sensing material used in the prototype is Velostat® - piezoresistive foil which reduces its resistivity according to pressure increases. The Velostat® is kind of modern polymer composite consisting of carbon-impregnated polyethylene (Dzedzickis, 2020). The material is light, flexible and relatively cheap. The main disadvantage of the Velostat® is highly nonlinear characteristic which exhibits hysteresis loop. But it gives the opportunity to develop a wide range of flexible tactile sensors which are used in medicine and technology. The medical applications described in literature are pressure sensitive bed systems for respiratory monitoring or posture detection (Hsia, 2009), (Carbonaro, 2021) or prothesis replacing amputated limbs (Hopkins, 2020). The module is divided into three parts for three parts of bed floor.

2. Methods

In the work, a version of pressure sensitive bed mat is proposed. The application doesn't require fast response but good resolution. There are two layers of copper conducting tape which are rows and columns of the structure. In the middle Velostat® layer which closes the circuit with variable resistance across its thickness. In Figure 1, the cross section of the sensing mat is presented. Additional assembly element not included in the figure is two sides adhesive tape which joins polyethylene base with Velostat® in the gaps between copper tapes.

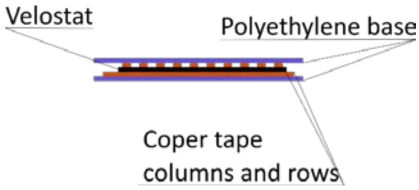

Fig. 1: Structure of multilayer composite pressure sensing mat.

The Controller measures resistance in each cross connection between row and column utilizing modified multiplexing algorithm where rows are signal sources and columns are sink. The rows are excited using shift register (SR) where only one signal is active and ADC reads voltage from each column using demultiplexer (Mx). When values from each column are collected shift register switches to the next row. In the Figure 2 the module is presented. The data is transferred to the main controller which processes data from all three modules and transfers data to the management system.

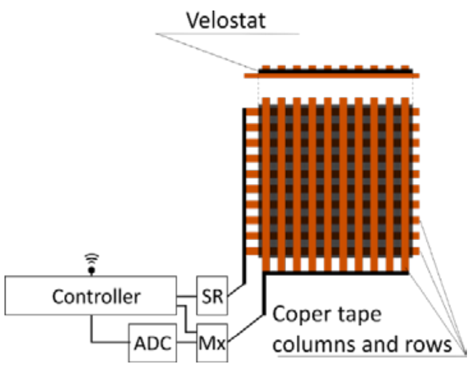

Fig. 2: Structure of mat with matrix controller.

To assess the possibility of manufacturing the mat based on Velostat® film, first the value of maximum pressure exerted on bed by an exemplary patient was estimated. Several pairs of height and body mass were picked arbitrarily, representing different types of physique. For those exemplary patients, body surface values were calculated using Mosteller model (Mosteller, 1987). Maximum pressure value was estimated to be 10 times bigger than the apparent average pressure, calculated if body weight was distributed uniformly when a patient lies flat on his/her back, to consider highly probable situations when body weight is distributed only over a portion of the body overall surface (e.g., when patient sits on a bed, lies on a side, etc.). The estimated maximum pressure values are approximately equal to 10 kPa.

After calculation of the operation range, a small demonstrator of a mat consisting of 4 columns and 6 rows was prepared. Such a demonstrator was loaded with a mass that was gradually increased up to a certain level, followed by its gradual decrease. Additionally, loading was performed in two ways: 1. mass was based on 4 cylinders with diameter of 9.75 mm, put directly over the crossing points of certain conducting columns and rows; 2. mass was based on a 96 mm x 60 mm plate resulting in an uniform distribution of the load on the whole demonstrator mat. Loading scheme is shown in a simplified Figure 3 that presents an overall laboratory stand. For every loading mass, cells B1, E1, B4 and E4 (denoted in Figure 3) were supplied with a constant voltage U_{cc} = 5 V and the value of the current flowing through the cells was measured. Results of the measurements are shown in the Figure 4.

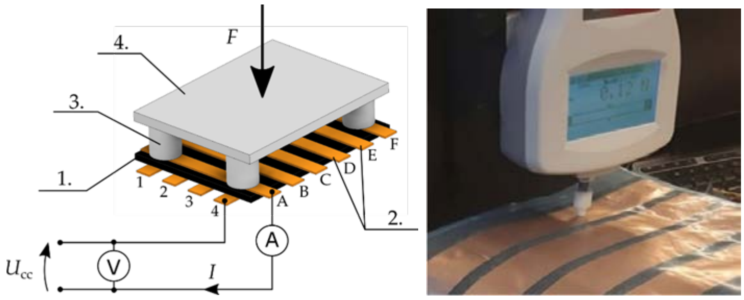

Fig. 3: A schematic view of a laboratory stand used to measure the characteristic of a demonstrator mat while loading and measuring the characteristic of (exemplary) A4 cell. 1. – Velostat® film, 2. – conducting paths, 3. – cylinders on which the loading mass is put, 4 plate.

The tests consisted in applying increasing pressure through a force gauge to a device made of Velostat® foil. Current values were read from the reference device with constant voltage input. The values for the pressure from 0 to 15 N were measured. Then, the measurements were made for the pressure from 15 N to 0 N.

3. Results

In accordance with the above methodology of conducting the experiment, the current response of the sensor as a function of pressure was determined. The results of measurements using a Velostat® foil mat were presented.

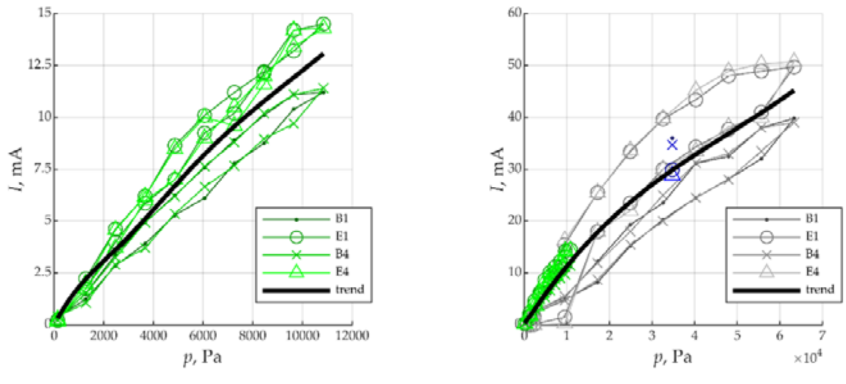

Fig. 4: Current flowing through certain cells of a demonstrator mat, supplied with the constant voltage U_{cc} = 5 V, as a function of a pressure on the cells: (a) in case of uniformly distributed loading mass, (b) in case of the load put on 4 columns. Legend denotes data obtained for various cells (as in Figure 3), and in the Figure (b) green marks denote data from Figure (a) for comparison, while blue marks denote results of an additional measurement done for a maximum available load distributed uniformly over whole mat.

For the load on the mat less than 10 kPa, the values of currents flowing through the cells do not exceed 15 mA. The overall characteristic of the mat can be considered linear but is strongly dependent on the cell – for example, for a maximum load resulting in the pressure value 10.8 kPa, the difference in the value of the measured current is equal to 3.1 mA (27%). For bigger values of the pressure (Figure 4b) a slight nonlinearity can be observed which might indicate an occurrence of a saturation phenomenon taking place in the process of the film conducting electrical current. Furthermore, a distinctive hysteresis loop can also be noticed.

4. Discussion

The original solution for measuring the pressure using the Velostat® foil presented in this publication was compared with a similar solution tested by Suprapto et al. (Suprapto, 2017). The authors checked the characteristics of the mat consisting of 32x32 sensors matrix. The test results confirm the near-linear characteristics in the measuring range up to 15 N. Suprapto et al. used the Velostat® film measurement system to measure ground reaction values while standing pose and compared the results to the PEDOSCAN reference device (DIERS International GmbH, Schlangenbad, Germany). The values of the maximum pressure exerted by the foot varied significantly depending on the measuring system. For the Velostat® platform it was 8.9 N/cm^2, for the reference device it was 29.7 N/cm^2.

Another publication in which the Velostat® film was used for biomechanical measurements is the work of Martinez-Casteros et al. (Martinez-Cesteros, 2021). In this paper, the Velostat® mat was used for Center-of-Preasure (CoP) displacements measurements. The results were compared with the commercial device Seating Mat (Sensing Tex SL, Barcelona, Spain) and PASPORT force plate PS-2131 (PASCO Scientific, California, USA). The results obtained with the Velostat® platform outperformed the results obtained with the Seating Mat by Sensing Tex system.

Both above mentioned projects clearly shows potential of foil-based measuring devices for biomechanical purposes. Unique features of Velostat® can be utilized in cases where measurement has to be minimal invasive and conducted during normal activity such as for example sleep monitoring.

5. Conclusions

Presented module is designed to detect a position of the bedridden patient to protect him against bedsore. As a mean of making such measurement, a sensor based on Velostat® foil was developed. Obtained results show that it can give an information about the presence of a force that applies pressure on certain cells of a (discretized) mat that can be put on the bed, but due to nonlinearities, hysteresis and the characteristic dependent on individual cell, it is not best suited for precise measurements of the values of this pressure. However, a key functionality of detecting the dynamics in the change of a patient position, for the pressure values estimated for an exemplary human, can be achieved using a proposed device. Proposed solution is under development and still requires work to achieve satisfactory results.

References

Carbonaro N., Laurino M., Arcarisi L., Menicucci D., Gemignani A., Tognetti A., Textile-based pressure sensing matrix for in-bed monitoring of subject sleeping posture and breathing activity, Appl. Sci., 2021, 11, DOI: 10.3390/app11062552

Central Statistical Office, Results Report: National Population and Housing Census 2011, Warszawa, 2012

Dzedzickis A., Sutinys E., Bucinskas V., Samukaite-Bubniene U., Jakstys B., Ramanavicius A., ET AL., Polyethylene-carbon composite (Velostat®) based tactile sensor, Polymers (Basel)., 2020, 12, 1–17, DOI: 10.3390/polym12122905.

Hopkins M., Vaidyanathan R., Mcgregor A.H., Examination of the Performance Characteristics of Velostat as an In-Socket Pressure Sensor, IEEE Sens. J., 2020, 20, 6992–7000, DOI: 10.1109/JSEN.2020.2978431.

Hsia C.C., Liou K.J., Aung A.P.W., Foo V., Huang W., Biswas J., Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system, In: Proceedings of the 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society: Engineering the Future of Biomedicine, EMBC 2009, IEEE Computer Society, 2009, 6131–6134, DOI: 10.1109/IEMBS.2009.5334694

Martinez-Cesteros J., Medrano-Sanchez C., Plaza-Garcia I., Igual-Catalan R., Albiol-Pérez S., A velostat-based pressure-sensitive mat for center-of-pressure measurements: A preliminary study, Int. J. Environ. Res. Public Health, 2021, 18, DOI: 10.3390/ijerph18115958

Mosteller R., Simplified Calculation of Body-Surface Area, N Engl J Med , 1987, 317, 1098–1098, DOI: 10.1056/NEJM198710223171717.

Statistics Poland, Information on the situation of older people in Poland for 2019, Białystok, 2021

Suprapto, Sena Sukmananda & Setiawan, A.W. & Zakaria, Hazem & Adiprawita, Widyawardana & Supartono, Basuki. (2017). Low-Cost Pressure Sensor Matrix Using Velostat. 137-140. 10.1109/ICICI-BME.2017.8537720.