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PRESSURE MAPPING SYSTEM FOR PHYSIOLOGICAL MEASUREMENTS

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Abstract: Pressure mapping provides knowledge about interface pressure between a person and the surface person is laying or sitting on. In medical applications the surface is commonly a bed or a wheelchair. The distribution of pressure applied to the skin by a supporting surface can be measured with a pressure mapping system. Depending on the magnitude and duration of the pressure, it can cause pain and tissue injuries, such as pressure ulcers to the person. By means of pressure mapping technology, it is possible to detect the areas where the pressure is concentrated and thus prevent the development of pressure ulcer. However, the properties of the commercial pressure mapping systems are usually inadequate for physiological measurements. In this study, properties of a commercial Xsensor pressure mapping system were studied. Measurements with test persons as well as measurements with a constant measurement load were carried out. Repeatability, sensitivity, temperature sensitivity and hysteresis of the pressure sensor were determined. Only the hysteresis was noticed to be poor while the other properties were satisfactory.

Keywords: pressure mapping, test measurements, pressure ulcer.

1. INTRODUCTION

Pressure mapping provides information on the interaction between a person and the surface person is laying or sitting on. In medical applications, the surface is commonly a bed or a wheelchair. The pressure applied to the skin by a supporting surface can cause pain and tissue injuries such as pressure ulcers to the person. Hence the pressure distribution is measured to find out the regions in the body where the pressure has high values.

The pressure ulcers, also known as pressure sores, bedsores or decubitus ulcers, are a dominant health problem for people who use wheelchair or spend long periods of time in bed [1]. Pressure ulcers usually occur over bony prominences such as hips or heels. Many causes have been identified as contributing the development of pressure ulcers, while pressure related to time is believed to be the most significant [1, 2]. Pressure ulcers are painful for patient and increase recovery time. Furthermore, pressure ulcers are also very costly for the caregivers [3].

Pressure ulcer occurs when tissue is compressed under pressure. The interface pressure exceeds the pressure of the capillary veins, leading to the weakening of the local blood circulation and finally, to ischemic necrosis [2], in other words, to the death of cells in the body in a localized area.

The pressure tolerance varies for each person. However, the threshold value of 32 mmHg has been used in several researches [2, 3]. Any load greater than 32 mmHg is harmful because it exceeds capillary pressure in blood vessels. Although the SI-unit of pressure is pascal (Pa), millimeter of mercury (mmHg) is generally used especially in medical applications (1 mmHg = 0.133322 kPa).

The pressure mapping technology is based on basic laws of physics. A person with mass m lying in a bed causes a force $F = mg$ to the bed and the bed causes an equal counterforce to the person, respectively. Here g is the acceleration due to gravity. The force interacting with the person can be represented as a pressure value - pressure is defined as a force per an area $p = F/A$. The pressure values measured are characteristically shown as a pressure map, as a color-coded figure [4]. The main advantage of pressure mapping technology is therefore to have an illustrative figure with one simple measurement.

Fig. 1 represents an example of pressure map of a person measured with 160 x 64 sensor array. The pressure map shown in the figure is measured in supine posture with no mattress. Hence the pressure values are greater than in a normal pressure map measured in a bed. The unit of pressure in the figure is mmHg.

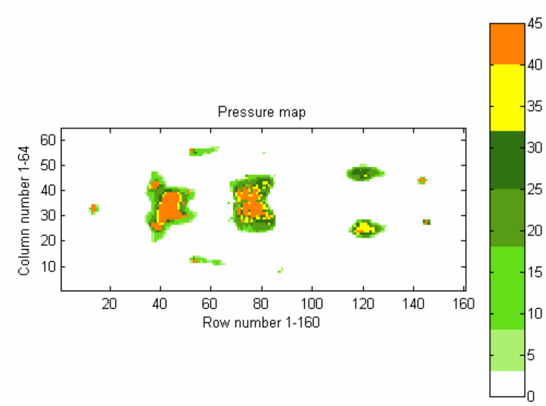

Fig. 1. Example of pressure map of a person laying on a sensor array with no mattres. The unit of pressure is mmHg.

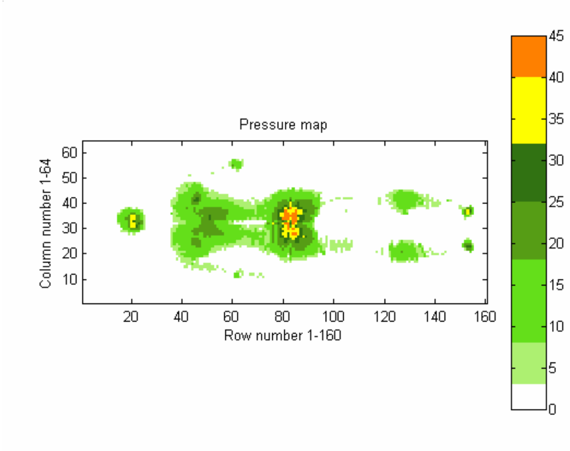

Fig. 2. Example of pressure map of a person laying on a sensor array with a thin mattress. The unit of pressure is mmHg.

In Fig. 2 the pressure map is measured in supine posture on a thin mattress. In Fig. 1 and Fig. 2, same test person has been used. Any load greater than 32 mmHg is marked in the pressure maps with obtrusive colors [2], yellow and orange. The satisfactory pressure values are drawn with different shades of green. Pressures less than 3 mmHg were neglected due to the noise. As it can be seen from Fig. 2, the mattress is not suitable for a long-term use since some of the pressure values are still too high.

The areas where the pressure is too high can be detected with pressure mapping system and the pressure can be relieved. The pressure level is reduced by moving the pressure away from critical areas to more tolerant areas, that is, the single peak pressures are eliminated [1]. The pressure can also be reduced by distributing the pressure over a larger contact area [1]. This can be done with appropriate mattress structures that distribute the pressure uniformly over the surface. Pressure mapping systems are therefore designed mainly for commercial applications, such as mattress designing and manufacturing. However, such a system is not necessarily suitable for physiological measurements.

A lot of opinions have been stated which is the best descriptor of interface pressure [2]. In particular, maximum pressure or average pressure values of a certain area are reported in articles. The maximum pressure is the highest individual sensor signal value, whereas the average pressure is the mean of all the individual sensor signal values. In this study, the average pressure values were determined. The average pressure value is a more stable measure and gives a better overall picture of interface pressure [2].

With pressure mapping technology it is possible to objectively measure interface pressure and provide computer generated data that is not based on opinion [5]. Pressure mapping technology has become commercially available over the past decade due to the improvements in data processing and sensor technology [6]. By means of pressure mapping technology, it is possible to reduce interface pressure by selecting an appropriate pressure-relieving surface or use adjustable and active mattress, and thus improve the quality of life.

In Section 2, the purpose of the study is described. The pressure mapping system used in the measurements as well the properties measured are presented in Section 3. Section 4 introduces the results obtained. Sections 5 and 6 represent the discussion and conclusions.

2. PURPOSE

The purpose of this study was to research properties of pressure mapping systems suitable for physiological measurements. Pressure mapping systems on the market are mainly designed for commercial applications, such as mattress manufacturing. Thus the properties of the systems are not usually adequate for physiological measurements. Especially the software used to analyze the pressure data is often a limiting factor.

When concerning clinical decision making, properties need to be sufficient and reliable enough. In this study, some of the most important properties of a commercial pressure mapping system (Xsensor) were measured.

3. METHODS

Pressure mapping systems typically consist of a sensor mat, read-out electronics and computer and special software to analyze the pressure data. The structure of sensor mats can widely vary depending on the number of sensors in the array as well as the type of the sensors. Nowadays there are three generally used types of sensor technologies in pressure mapping: resistive, capacitive and piezoresistive [6].

Before choosing an appropriate system for physiological measurements, commercial pressure mapping systems were compared. In the comparison, three pressure mapping system manufacturers were selected for a more precise evaluation. These systems were Tekscan Body Pressure Measurement System, Vista Medical Force Sensing Array and Xsensor Full Body Sensing. In Table 1, the properties of each system are introduced.

Table 1. Some properties of the three commercial pressure mapping systems compared. [7, 8, 9]

Property	Tekscan	Vista Medical	Xsensor
Sensor type	resistive	piezoresistive	capacitive
Sensor array size [cm x cm]	196 x 85	192 x 67	203 x 81
Number of sensors	16 128	1024	10 240
Pressure range [mmHg]	0-250	0-200	0-220
Temperature range [°C]	-9 … +60	+15 … +32	0 … +40

The Xsensor Full Body Sensing was chosen due to its versatile properties. Tekscan Body Pressure Measurement System would also have been a decent alternative, but the Xsensor system had the best price-quality ratio of those systems compared in this study.

The Xsensor sensor mat used in the study consists of an array of 164 x 64 capacitive sensors. Simplified, the capacitive sensor consists on two electrodes separated by an air gap. When the distance between the electrodes is changed due to a force applied to the sensor, also the capacitance is changed. The electrodes are made from conductive silver traces and separated by a compliant elastomeric layer. [10]

For the test measurements, the sensor mat was laid out on the floor, without a mattress. The Xsensor system used in the measurements is shown in Fig. 3. Data was collected from the sensor mat in raw data format, excluding measurements with test persons. The data was analyzed with Matlab® self made software instead of Xsensor commercial software. With Xsensor software, it would also have been possible to collect the data in three different pressure formats (5-50 mmHg, 5-100 mmHg and 10-200 mmHg). However, in the pressure formats the data was preprocessed; the raw data format was chosen since the unprocessed data was preferred. Only the measurements with test persons were done with pressure format 5-100 mmHg.

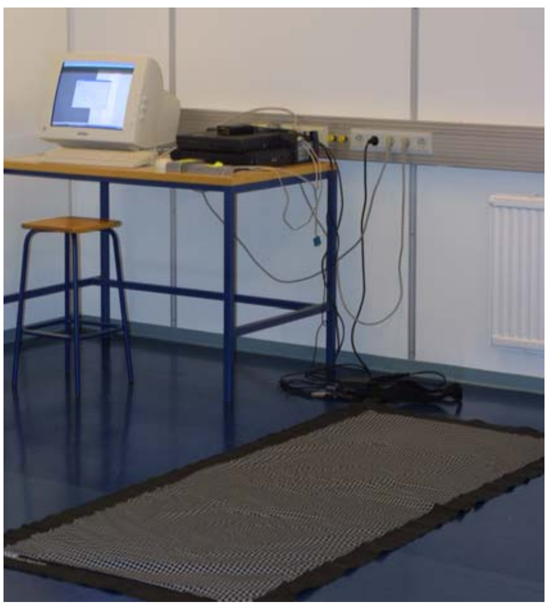

Fig. 3. The Xsensor system: sensor mat, laptop computer with Xsensor software and read-out electronics.

Measurements with test persons as well as measurements with a constant measurement load were carried out. A stack of five metal plates was used as a constant measurement load. Each metal plate weights half kilogram, in total the mass was m = 2.6 kg. The area of the metal plate was A = 16.0 x 7.0 cm. By combining these two results the theoretical pressure of the stack of five metal plates was p = 17.1 mmHg.

The measurements with test persons were carried out by measuring pressure maps with five test person in supine posture. The tests with persons were carried out to determine how well the high pressure areas can be distinguished from pressure maps. An example of pressure map with a person lying on a sensor array with no mattress is shown in Fig. 1. The figure is drawn with Matlab® software developed for the study. In the figure, the dangerous high pressure areas are marked with yellow and orange colors. The average pressure values are shown in the unit of millimeter of mercury. Fig. 2 represents the same situation with a thin mattress.

The following subsections introduce the main properties related to the testing of the Xsensor pressure mapping system. Repeatability, sensitivity, temperature sensitivity and hysteresis of the pressure sensor were determined with a constant measurement load.

3.1. Repeatability

Repeatability is the system's ability to report a consistent measurement value every time it is used under the same conditions [3]. In this study, repeatability was defined by measuring the pressure map in five consecutive days. The measurement load was located in the middle and in the right side upper edge of the sensor mat. These two locations were chosen since the middle of the sensor mat is exposed to a greater load when measuring pressure maps with patients.

3.2. Sensitivity

The sensitivity was measured to find out how much the average pressure values vary in different places of the sensor mat. The pressure was measured from seven positions, from each corner and from three places middle of the sensor mat. Also in this measurement the places in the middle of the sensor mat were chosen due to the greater load.

3.3. Temperature sensitivity

Temperature sensitivity was determined by exposing a constant pressure over time to the sensor mat and increasing the temperature simultaneously. Pressure maps were measured in four temperatures: 10°C, 20°C, 30°C and 37°C. Temperature 37°C was taken into account since it corresponds to normal body temperature. Average pressure values differ from the other pressure values since the measurements were carried out in a special test room – the floor of the room was covered with a fitted carpet, and thus the average pressure values are smaller.

3.4. Hysteresis

Hysteresis is defined as output's dependence to vary whether the measurement is made in increasing or decreasing way [11]. Hysteresis was found out by increasing the mass of measurement target by adding two more plates in the stack at a time and measuring the pressure map after each increase. The measurement was replicated until there were 11 plates in the stack. After this metal plates were removed from the stack, two at a time, until there were five plates, respectively.

4. RESULTS

The following subsections represent the results obtained in the test measurements. From the data, average pressure values were calculated.

4.1. Repeatability

The average pressure values obtained in the repeatability measurements are shown in Fig. 4. In vertical axis the average pressure values are shown in the units of millimeter of mercury (mmHg). The horizontal axis introduces the number of test days. The middle of the sensor mat is shown in the figure with red graph and circles and the upper edge of the sensor mat with blue graph and squares. The maximum difference between test days was 2.4 mmHg. Also, there was an equal difference in pressure values depending on whether the measurement was carried out in the middle or in the upper edge of the sensor mat.

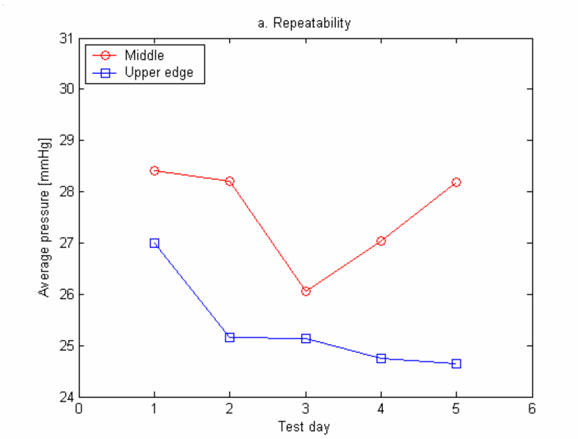

Fig. 4. Repeatability. The average pressure is shown as a function of test days.

4.2. Sensitivity

The average pressure values received from the sensitivity measurements are shown in the Fig. 5. The vertical axis represents the average pressure values and the horizontal axis the number of test places.

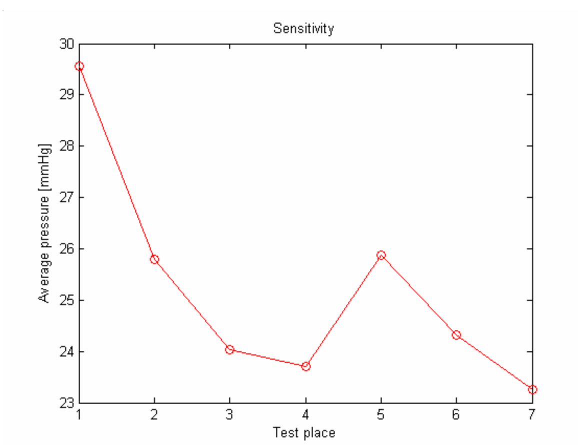

Fig. 5. Sensitivity. The average pressure is shown as a function of test places.

Numbers from 1 to 4 correspond to the each corner of the sensor mat. Numbers from 5 to 7 were places in the middle of the sensor mat. According the figure, the difference between the values of different test places was 6.3 mmHg at the maximum.

4.3. Temperature sensitivity

The average pressure values obtained from the temperature sensitivity measurements are shown in Fig. 6. In the figure, the average pressure values are shown as a function of the temperature values. The average pressure increased approximately 2 mmHg as a function of temperature.

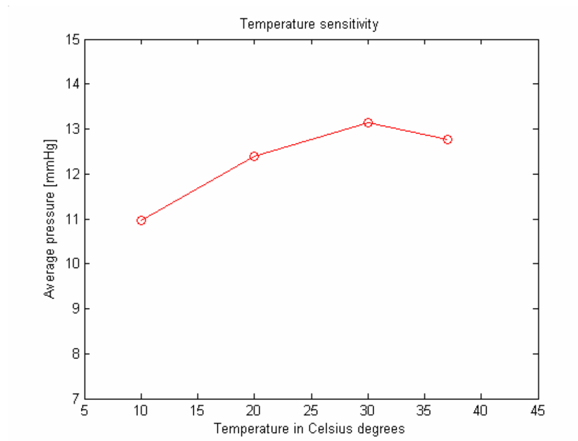

Fig. 6. Temperature sensitivity. The average pressure is shown as a function of temperature.

4.4. Hysteresis

In Fig. 7, the average pressure values are represented as a function of applied pressure. The increasing way is shown with red graph and circles and decreasing way with blue graph and squares. In hysteresis measurement, the difference between increasing and decreasing way was 10.6 mmHg at the maximum. The difference between corresponding measurement points increases the less there are metal plates in the stack.

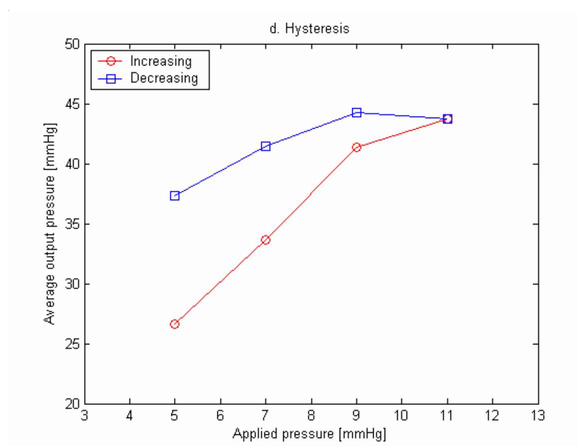

Fig. 7. Hysteresis. The average output pressure is shown as a function of applied pressure.

5. DISCUSSION

In repeatability measurements the differences between test days were not very remarkable. The maximum difference was 2.4 mmHg. An equal difference along the sensor array between the middle and right side upper corner average pressure values was also noticed. This may derive from the greater load the middle of the sensor mat is exposed in a normal use. On the other hand, also in the sensitivity measurements some differences in pressure values between test places were found out. The difference between the test places was 6.3 mmHg at the maximum. Compared to the other values, the test place 1 has greater pressure value than the others. This one value may be erroneous. Instead, no significant difference between the places was noticed whether the place is in the corner or in the middle of the sensor mat.

In temperature sensitivity measurements the average pressure values slightly increased as a function of temperature. However, the maximum difference between the values was only 2.2 mmHg. The average pressure values in temperature sensitivity measurements were different compared to the results of the other test measurements due to the fitted carpet covering the floor of the test room.

According to the measurement results, the hysteresis seems to be the system's poorest property. The maximum hysteresis error between increasing and decreasing way was 10.6 mmHg. The reason for to hysteresis results could be the structure of capacitive sensors: the elastomer between electrodes may not recover from the load fast enough.

From the measured properties, repeatability, sensitivity and temperature sensitivity measurements provide relatively good results. Instead, in hysteresis results some imperfections can be seen. To conclude, the hysteresis seems to be the system's poorest property while the other properties are satisfactory.

6. CONCLUSIONS

In this study, the properties of a commercial Xsensor pressure mapping system were studied. Repeatability, sensitivity, temperature sensitivity and hysteresis of the sensor were determined through test measurements carried out with a constant measurement load. The theoretical pressure produced by the constant measurement load, a stack of five metal plates, was 17.1 mmHg. The data was collected from the sensor mat in raw data format, that is, no data processing operations were done. Due to the data format, all the pressure values collected were throughout about 10 mmHg bigger than the theoretical. The difference between measured and theoretical values could also be affected by the sensor mat itself – the sensor mat was only few millimeters thick but it still may change the measurement values slightly.

The properties of the pressure mapping systems are widely varied depending on the number and type of the sensors used in the sensor mat. For instance, Ferguson-Pell & Cardi [11] compared three commercial pressure mapping systems and perceived that the differences between systems were remarkable. The system used in this study consists of an array of 164 x 64 capacitive sensors. The number of the sensors was adequate, but the sensor type induces some problems. The elastomer of the capacitive sensor did not recover fast enough from the load and since the hysteresis of the system was so poor. On the other hand, more test measurements would have been needed to analyze the properties of the system more reliably.

Pressure mapping is a promising method in physiological measurements. Although some of the properties of commercial pressure mapping systems are not yet satisfactory, it is already possible to measure suggestive interface pressure maps. In the future the measurement of pressure distribution may be a significant part of clinical decision making.

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