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XSENSOR Technology: A Pressure Imaging Overview

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Abstract

{article type} Viewpoint

{purpose} An innovative method for imaging the pressure distribution between two interface surfaces is presented. The physical principles behind the design of the pressure imaging system are explained, and some case studies involving the use of this technology in diverse applications are described.

{design} The XSENSOR pressure sensor is comprised of a matrix of capacitive sensing elements. Pressure applied to the surface of the sensing element causes a change in capacitance that is correlated to a change in pressure. Proprietary Windows based software compensates for sensor non-linearity, hysteresis, and creep over time, resulting in enhanced accuracy.

{findings} XSENSOR's capacitive based pressure imaging sensors can graphically display pressure distributions in real time between virtually any two surfaces in contact. The sensor element is accurate, thin, flexible, and robust. These physical characteristics minimize any artificial influences created by the presence of the sensor during data collection.

{practical implications} Pressure imaging technology can be used in industrial and engineering environments for product design and verification, process control, or quality assurance.

{What is original/value of paper} This paper will be useful to the engineer or business manager interested in applying sensor technology to solve engineering or design problems.

Keywords
Pressure imaging, capacitive sensor, medical, industrial, tactile sensing, pressure sensing

1. INTRODUCTION

Pressure imaging is a method of graphically displaying the pressure distribution between two interface surfaces in real time using a pressure sensing matrix with specialized electronics connected to a computer. XSENSOR has developed a leading pressure imaging technology by implementing a matrix of capacitive pressure sensors formed into a continuous film. This film is placed between two interface surfaces, and connected to an electronics module that translates the physical compression of each cell of the matrix into a capacitance value that is correlated to pressure. This data is then displayed on a computer screen to show a map of the interface pressures between the two surfaces. Even slight variations in the pressure distribution between the two surfaces can be detected. This information is valuable to engineers who need to validate the pressure fit between two parts or surfaces. Applications include assessing wheelchair bound patients for the risk of developing pressure ulcers, verifying the effectiveness of door seals, analyzing the grip profile and contact area of a tire tread under different loading and tire inflation levels, statistically validating consistency of automotive seats on a production line, and a sales tools in the mattress retail industry.

2. SYSTEM OPERATION

2.1 Sensor

The XSENSOR pressure sensor is comprised of two grids of parallel conductive strips that are set perpendicular in orientation. The grids are separated by a thin compressible elastomer (see figure 1). The intersection of any two perpendicular strips forms a capacitive node. The capacitance at each node is determined by the surface area of the intersection of the two conductive strips, and the distance of separation between the two strips as determined by the compressible elastomer. As pressure is applied to the node, the elastomer compresses, the strips are forced closer together, and the capacitance increases. The change in capacitance is correlated to pressure through a process of calibration. By using multiplexing circuitry the system sequences through each line on the input and output sides of the sensor matrix, thereby measuring the capacitance and therefore the pressure distribution over the entire sensor matrix.

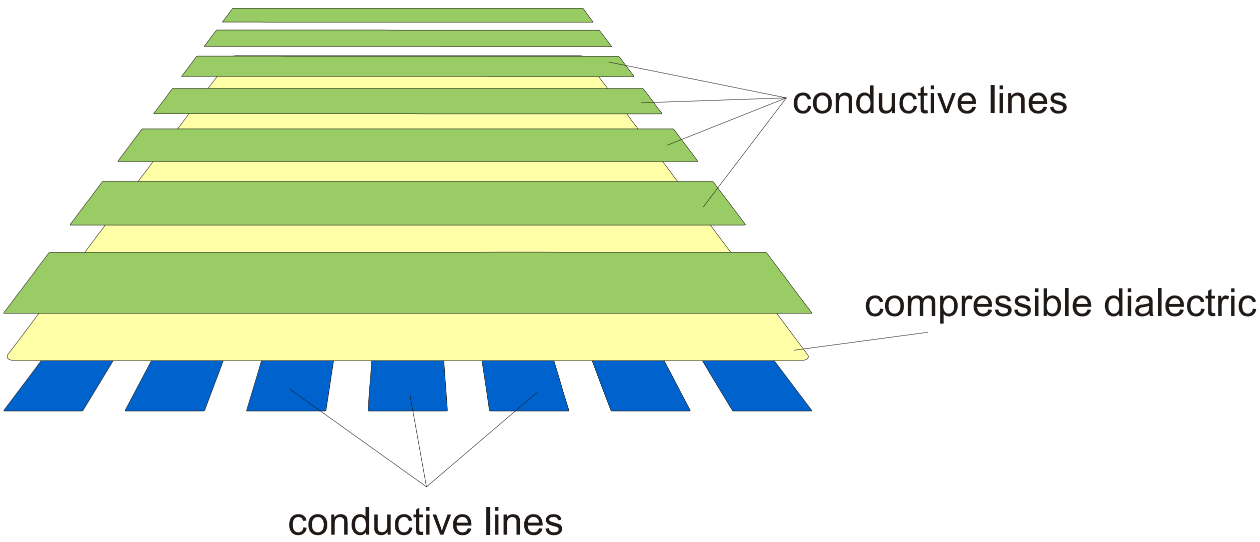

Figure 1 - A Schematic of Basic Sensor Construction

XSENSOR's proprietary manufacturing process can produce pressure imaging pads at various resolutions and for different pressure ranges. Spatial resolutions as high as 100 sensors per square centimeter are possible.

The sensors are constructed by enclosing the conductive lines and dielectric material in a thin, pliable and durable cover layer to protect the active layers. The cover layer is printed with a grid to indicate the active area of the system. Sensor specific information, such as calibration data, serial numbers, and configuration parameters are stored in permanent memory on the sensor matrix. The sensor pad itself is approximately 1 mm thick and is manufactured in standard sizes ranging from 3 inches by 5 inches (7.6 cm by 12.7 cm) to 32 inches by 80 inches (81.3 cm by 203.2 cm) within the sensing area. The sensors are also easily customizable for specific dimensions, pressure ranges and applications.

This sensor architecture and construction method has two distinct advantages. First, the materials used and the way they are assembled combine to create a very pliable and conformable sensor pad. This minimizes any distortion of the true interface pressure by the presence of the sensor pad. Second, the sensor pad is extremely robust. For example, it can be repeatedly crumpled into a ball and still function (see figure 2). Sensor lifetime depends on usage frequency and the environment in which it is used, but the sensor pads are intended for long term usage comprised of many sensing cycles.

Figure 2 - An Example of XSENSOR Flexibility and Durability

2.2 Electronics

The XSENSOR system is modular (see figure 3) which makes the system more flexible, scalable, facilitates diagnostics and provides more choices of capabilities to the customer when selecting a system for purchase.

The sensor pad is part of the electronics system. An excitation signal is applied to the intersection of a row and column (a capacitive node) on the sensor matrix. The detected signal is pre-processed though proprietary analogue circuitry, then sampled by a 16 bit analogue to digital converter. The digital values are then further processed by a digital signal processor (DSP). Algorithms in the DSP filter signal noise and calculate capacitance values. The system is user adjustable to increase the sensor accuracy by oversampling with the analogue to digital converter. This, however, will increase the time for data acquisition and reduce the overall frame rate of the system. Multiple capacitive nodes can be monitored simultaneously on the output side of the system to increase data acquisition rates. Each data acquisition channel is capable of measuring up to 25,000 sensing points per second. The sensor electronics currently come in two different versions: one with one channel of measurement capability and one with four channels of measurement capability.

From the sensor electronics, the digital signal is sent to a hub unit. The hub unit provides power to any attached electronics, optical power isolation for safety, control functionality, and external device synchronization capabilities as well as sending to signal to the display and recording software. The hub unit comes in three different models: the X3, which has one input port; the X3 Pro, which has four input ports and the X3 Display, which has one input port, but also provides graphical display and recording functionality, therefore eliminating the need for a computer.

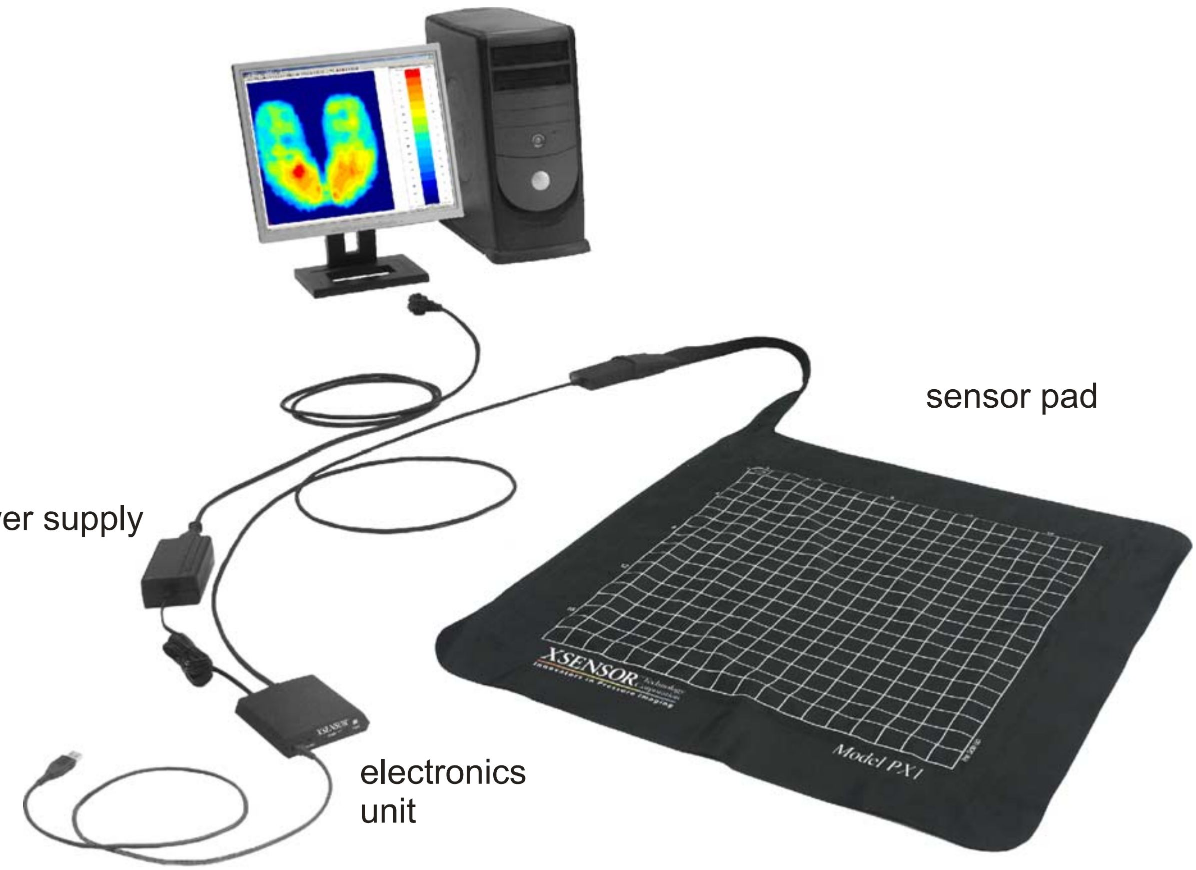

Figure 3 - A Complete Sensor System

Another component called a Node can be placed in-line between the hub unit and the electronics. The Node has three sensor ports and expands the connection capabilities of each port on a hub unit, allowing multiple sensors to be connected simultaneously. The Node can be used with any of the hub units.

The electronics architecture is flexible and allows a variety of sensors to be used simultaneously. For example, with an X3 Pro unit connected to 4 Node units, up to 12 sensor pads can be connected and recorded simultaneously at up to 325,000 sensing points per second. This kind of flexibility and expandability allows a user to add on to the system over time as his or her requirements change and grow.

2.3 Software

XSENSOR software running on either a computer or portable display unit is required to record and visualize the data from the sensor pad. The software can record and visualize either raw data from the sensor pad or use the calibration file to convert the raw value to actual pressure measurements depending on what mode the user selects in the software. Data is recorded in frames, one cycle of sensor reading for every capacitive node in the matrix. The frame rate of the sensor system depends on the sensor pad resolution and size as well as the model of electronics used with the sensor pad. For example, the standard seat sensor pads used with 4-channel electronics and an X3 Pro unit are capable of 45 frames per second.

The sensor electronics transfer data to the software via standard USB protocols. Use of the USB protocol has allowed the sensor systems to take advantage its “plug-and-play” functionality. This simplifies system setup and use significantly. One has to simply install the software, plug in the sensor and begin pressure imaging.

During recording the sensor data may be visualized a number of different ways. There is the standard 2D view, 3D, a histogram view showing the percentage of the sensor matrix is a given pressure range, and a pressure versus time graph (see figure 4). Sensor sub-groups can also be defined and visualized. Once a session is finished and recording is stopped the entire session can be replayed continuously or individual frames can be reviewed.

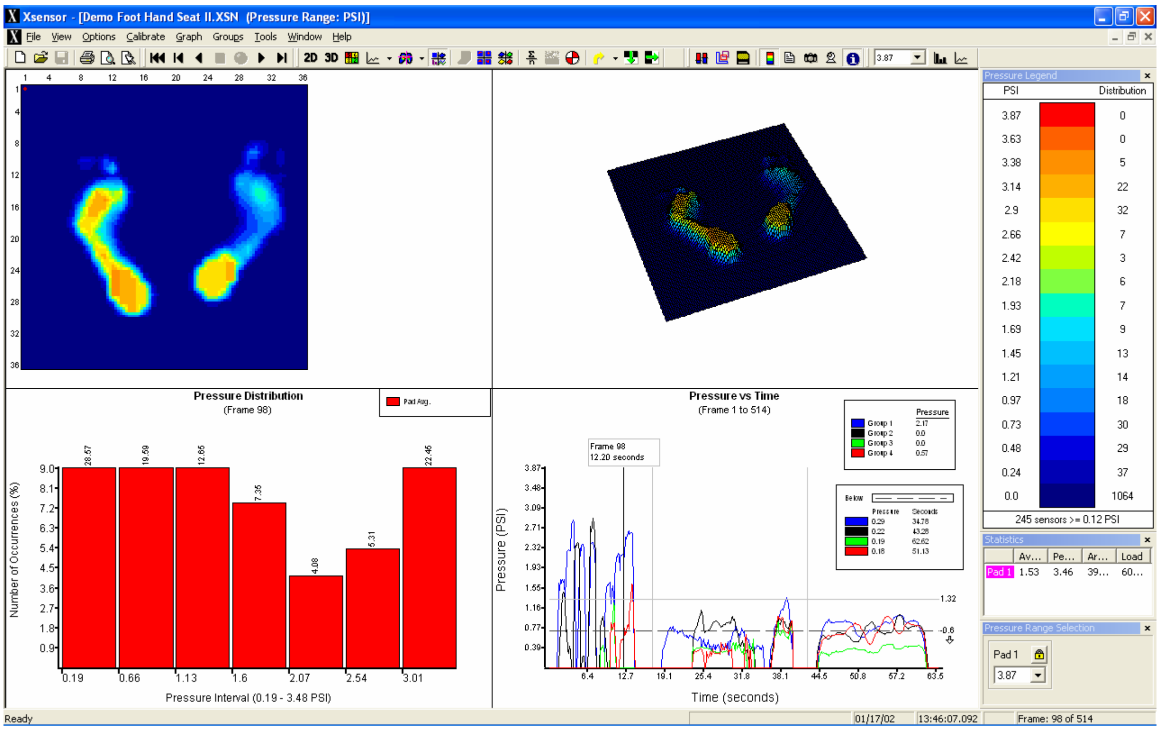

Figure 4 – Multi-display View

The software reads calibration information stored on connector unit on the sensor and applies the calibration data to the raw digital signal sent to it during recording sessions. For some dielectric materials additional compensation algorithms have been developed to handle hysteresis and creep effects. These compensation models improve system accuracy significantly.

There is also annotation and video synchronization functionality. Written or audio comments can be attached to individual frames during a session. Pictures may be attached and video files can be linked to clarify what interaction caused a specific pressure distribution behavior.

There are multiple versions of the software optimized for different applications for both the computer and the portable display unit. The Point of Sale software is customized for displaying mattress sensors and contains customer branding and logos. Recording comparison functionality is simplified to more easily show the difference between mattresses during the sales process.

The Medical software version is tailored around performing rehabilitation seating assessment. Settings and workflow are structured around this application including picture annotation and note taking functionality.

The Professional software version is the most fully featured software version. It provides robust display functionality as well as advanced playback and export capabilities. The export capabilities allow the frame average data to be analyzed by third party analysis tools.

3. SENSOR APPLICATIONS

There is a broad need in a variety of industries for interface pressure imaging. The versatility and robustness of the XSENSOR systems make them perfectly suited to meet those needs. Here is a subset of applications met by standard XSENSOR products.

3.1 Medical

The XSENSOR PX100:36.36.02 seat sensor is the most recent incarnation of the original XSENSOR sensor pad. This sensor pad is mainly used in rehabilitation seating assessment, where its dynamic range, sensitivity and conformability allow a rehab therapist to get a very accurate picture of the pressure distribution on a person's seat surface. This allows the therapist to modify the seating surface to reduce pressure "hot spots" and gradients to help their client avoid pressure ulcers. In seating applications the critical point to monitor are where the ischial tuberosities or "sit bones" rest on the seating surface. Attention must be given to the coccyx or "tailbone" as adjustments to minimize pressure on the ischial tuberosities can sometimes shift the pressure onto the coccyx with undesired consequences. The dynamic pressure imaging of the XSENSOR system allows a clinician to monitor the entire resting surface before and after adjustments to ensure the seating pressure is distributed most effectively.

Medical sensors (see figure 5) are constructed using the method and material described in section 3.1. The primary resolution used in these sensors is 0.5" both dimensions. Seat sensors are made in 18", 20", and 24" versions and another configuration combines both a seat and back sensor for imaging the pressure distribution in both planes simultaneously. These sensors can be calibrated to operate in the following pressure ranges: 5 to 50 mmHg, 5 to 100 mmHg, and 10 to 200 mmHg.

Figure 5 - Medical Sensor Systems

The PX100 product family has also been extended to bed size sensors to help rehab therapists modify the resting surface of a bed-bound client to help avoid pressure ulcers. Long term care patients confined to their beds most commonly develop pressure ulcers on their heels, buttocks, tailbone, elbows and shoulder blades. Real time monitoring of the entire bed to patient interface allows adjustments to minimize the risk of pressure ulcers.

Another configuration of this basic design is used in a much smaller size to monitor the pressure distribution applied by a pressure bandage. These systems can also be manufactured as small spot sensors in almost any aspect ratio and resolution.

3.2 Tire Tread Analysis

The IX500: 256.256.22 tire sensor system is another standard XSENSOR product offering; however, it utilizes very different materials and construction techniques. These sensors provide 1.15 mm resolution over a 29.4 cm by 29.4 cm area for a total of 65,536 sensing points in the matrix. These sensors are less flexible and conformable, but much more robust and able to operate under the high pressure conditions of the weight of a motor vehicle. Tire sensors are calibrated for use up to 200 psi.

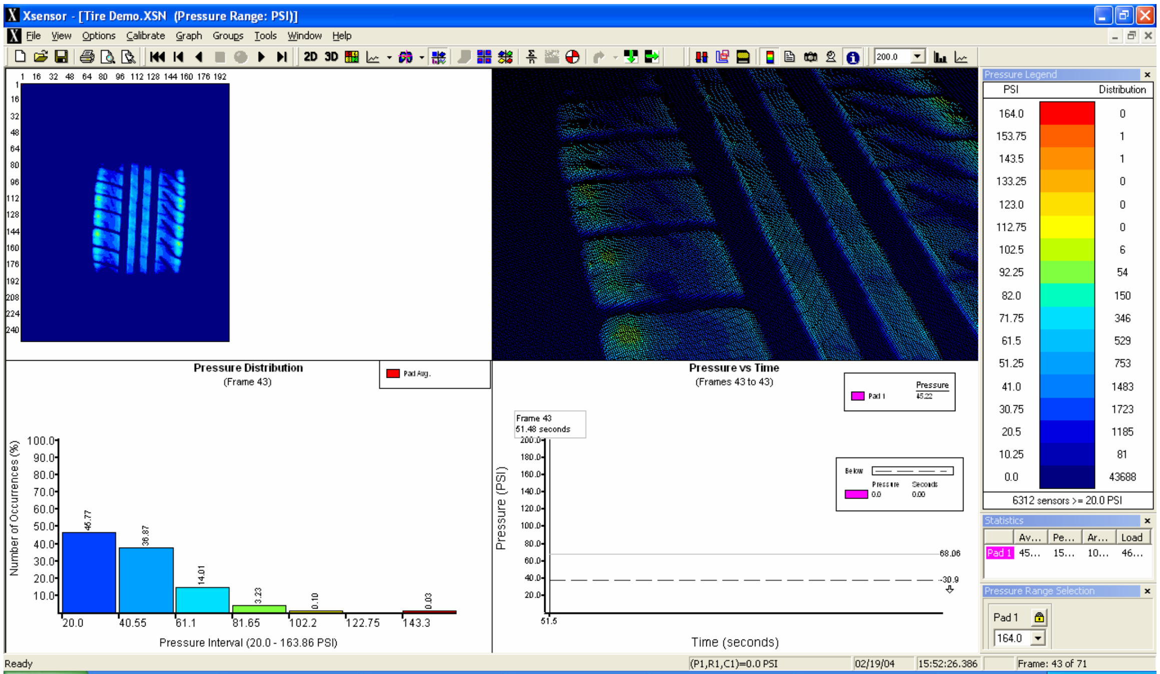

Figure 6 - Pressure Image of a Tire Tread

The primary use of this sensor has been to image the tread pattern pressure distribution of an inflated tire in a loaded condition (see figure 6). The pressure distribution information is used by tire companies to test and validate tire designs. Due to the higher number of sensing points, multiple connector units are needed to address the conductive lines on each side of the sensor. Multiple connectors are also required on larger sensors of the PX100 sensor family.

This type of sensor can also be scaled down to different aspect ratios and resolutions to create custom high pressure spot sensors. Non-rectangular form factors are possible (see figure 7). XSENSOR has produced a shoe insole sensor using construction materials and techniques similar to the tire sensor. These sensors are calibrated to operate in the following pressure ranges: 5 to 100 psi, 10 to 150 psi, or 10 to 200 psi.

Figure 7 - Industrial Sensor Systems

3.3 Other Industrial Sensors

The tire sensor is an excellent example of how XSENSOR systems are used during product design activities. These industrial sensors can be used in other business functions as well. For example, a major German automotive manufacturer uses XSENSOR industrial seat sensors in conjunction with some robotic testing machines to verify quality on every automotive seat before it leaves their factory.

XSENSOR systems are also used in some process control applications. In the packaging industry nip sensors are used to ensure the correct pressures are applied during different lamination processes. Additionally, spot sensors are used to verify efficacy in ultrasonic sealing processes.

3.4 Point of Sale

The Point of Sale application illustrates how the benefit of pressure imaging crosses over to a variety of different industries. The bed sensors XSENSOR developed for the medical industry were purchased by mattress manufacturers to test their products. Some manufacturers began using these systems in their retail outlets to show customers the difference in their pressure distribution when lying on a premium mattress versus when lying on an average mattress. The mattress retailers have also related the mattress pressure distribution to mattress comfort. This has proven to be an effective sales tool. The vibrant pressure image combined with simple software tools and user interface has provided significant sales improvements for mattress retailers. They can now show a visual predictor of comfort for a specific product or demonstrate the difference between mattress technologies such as viscoelastic foam, gel, air, and inner spring.

The Point of Sale sensors are standard or low-resolution bed sensors large enough to capture a full body pressure image when a person is lying down on a bed surface. The software developed for use with these sensors has additional functionality for pressure image comparison, as well as custom features tailored around a customer company's sales strategy.

3.5 Custom Sensors

A wide variety of custom sensors are possible using the general engineering principles and manufacturing techniques of the XSENSOR systems. Custom sensors have been developed for the following applications: harness straps assessment, a glove sensor, an orifice probe, a windshield wiper sensor, a milking machine sensor, a coffee harvester sensor, and a heart valve sensor. This illustrates how diverse the need for accurate pressure imaging is, as well as the flexibility of the capacitive pressure sensor architecture.

4. CONCLUSION

The XSENSOR pressure imaging systems are an extremely effective method of determining the interface pressure distribution created between almost any two surfaces. The system is thin and flexible to eliminate any interference by the sensor itself. Our proprietary construction method provides for a very durable sensor that can be used for many sensing cycles. The system architecture provides for leading accuracy levels as well as an unrivalled level of scalability and configurability.

These sensors have been adopted for use in a variety of applications and uses. Three of these are particularly noteworthy and are the medical seating industry, the tire design industry, and the mattress retail industry. A wide variety of other industrial and research applications exist, demonstrating the great utility of pressure imaging.