Design and implementation of a foot pressure measurement

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ABSTRACT

Foot plantar pressure is the pressure field that acts between the foot and the support surface during everyday locomotor activities. Information derived from such pressure measures is important in gait and posture research for diagnosing lower limb problems, footwear design, sport biomechanics, injury prevention and other applications.

This work explain the way and the main component that used to design a system for measuring foot pressure. This system is characterized by simplicity and portability. So, it suitable for patient and economically viable in countries with people having low socio-economic status.

Keywords: Foot pressure , locomotor activities , measuring

1.1 Introduction

Recently, measurement systems for foot plantar pressure are gaining attention in biomedical and sports-related research fields, such as ergonomic footwear design, sports performance analysis and injury prevention, improvement in balance control, physical therapy, rehabilitation training systems, and disease diagnosis. Monitoring foot plantar pressure distribution during daily activities provides a lot of useful biometric information related to human health condition. Analysis of this information helps us to develop personal-optimized footwear, enhance sports performance, monitor the rehabilitation state of a patient, and even detect diabetic foot ulceration early [1,2].

To obtain the information effectively and accurately, a variety of plantar pressure measurement systems have been reported. In general, they can be classified into two types, platform systems and in-shoe systems, which have advantages of long-term usage and mobility, respectively [3].

However, in-shoe systems are receiving more attention than platform systems these days due to their extensive utility. The systems maintain their functionality under repeated and sometimes harsh deformations from daily activities, while not causing any discomfort from wearing them. To endeavor to develop a reliable and comfortable foot plantar pressure monitoring system, many studies have been conducted [4].

Previous measurement systems have many strengths in miniaturization, low-power consumption, and wireless setup, but neither durability nor sufficient sensitivity has been reported. Many high-sensitivity sensors have been studied, but they are not suitable to withstand the pressure from body weight and daily activities. Here, we present a foot plantar pressure sensing system that is robust, highly sensitive, and easy to make [5].

In our project we will shed light on a simple design of foot pressure measurement system. This system simply consist of Shoes, Force sensors FSR402, Resisters, Buffer amplifier, Nano Arduino, Jumper wires and LCD for displaying the final results.

1.2 literature survey

This section presents a set of most relevant information for the implementation and design of a foot manometry

Kharboutly et al. [6] presented the design of a multiple-axis robotic platform for postural stability analysis. Standing on the platform, the subject is evaluated for various dynamic posture stability control features, including (i) sagittal tilt angle, (ii) frontal tilt angle, (iii) vertical rotation angle, and (iv) translation. The designed robotic platform of Kharboutly et al. is a very complicated structure and hence its construction is expensive. Ma et al. [7] designed an omni-directional platform for balance analysis. Measuring the COP, the system is equipped with force and inertial sensors intended for the evaluation of human posture for static and dynamic equilibrium analysis of a human subject standing on it. The system is also capable of applying balance disturbance to measure the subject's balance efficiency. The advantage of Ma et al.'s platform is its compactness and structure, which offer a better sense of comfort and safety when used in small spaces such as therapists' offices or hospitals.

Park et al. [8] designed a soft robotic ankle foot orthosis for post-stroke patients that is capable of real-time gait analysis for rehabilitation. The device also contains a wearable gait-sensing module for measuring the leg trajectory and the foot pressures in real time for feedback control. One of the drawbacks of the soft wearable gait-sensing module of Park et al. is that the wearing of the module could affect the natural movement the body.

Refai et al. [9] developed a remote real-time monitoring system for dynamic gait and balance performance using force and moment sensors and inertial measurement units (IMU) installed in the shoe. Three-dimensional force and moment are estimated using a linear regression model. Refai et al.'s research work is customized for specific subjects and hence requires a calibration phase that involves observing the subject walking for a brief period. A generic model that can be applied to any subject is envisaged for future work. A Kinect sensor, which includes a camera and a depth sensor,

2.2 Needs for Plantar Pressure Measurement

Feet provide the primary surface of interaction with the environment during locomotion. Thus, it is important to diagnose foot problems at an early stage for injury prevention, risk management and general wellbeing. One approach to measuring foot health, widely used in various applications, is examining foot plantar pressure characteristics. It is, therefore, important that accurate and reliable foot plantar pressure measurement systems are developed.

One of the earliest applications of plantar pressure was the evaluation of footwear. Lavery et al., in 1997 determined the effectiveness of therapeutic and athletic shoes with and without viscoelastic insoles using the mean peak plantar pressure as the evaluation parameter. Since then there have been many other studies of foot pressure measurement; for example, Mueller applied plantar pressure to the design of footwear for people without impairments (i.e., the general public). Furthermore, Praet and Louwerens and Queen et al. found that the most effective method for reducing the pressure beneath a neuropathic forefoot is using rocker bottom shoes and claimed the rocker would decrease pressure under the first and fifth ray (metatarsal head). The metatarsal heads are often the site of ulceration in patients with cavovarus deformity [13,14].

Queen et al. indicated that future shoe design for the prevention of metatarsal stress fractures should be gender specific due to differences in plantar loading between men and women.

With regard to applications involving disease diagnosis, many researchers have focused on foot ulceration problems due to diabetes that can result in excessive foot plantar pressures in specific areas under the foot. It is estimated that diabetes mellitus accounts for over $1 billion per year in medical expenses in the United States alone . Diabetes is now considered an epidemic and, according to some reports, the number of affected patients is expected to increase from 171 million in 2000 to 366 million in 2030 [14].

Improvement in balance is considered important both in sports and biomedical applications. Notable applications in sport are soccer balance training and forefoot loading during running. With respect to healthcare, pressure distributions can be related to gait instability in the elderly and other balance impaired individuals and foot plantar pressure information can be used for improving balance in the elderly. Based on the above discussion, it is crucial to devise techniques capable of accurately and efficiently measuring foot pressure.

2.3 Foot Plantar Pressure Measurement Environments

There are a variety of plantar pressure measurement systems but in general they can be classified into one of two types: platform systems and in-shoe systems.

2.3.1. Platform Systems

Platform systems are constructed from a flat, rigid array of pressure sensing elements arranged in a matrix configuration and embedded in the floor to allow normal gait. Platform systems can be used for both static and dynamic studies but are generally restricted to research laboratories. One advantage is that a platform is easy to use because it is stationary and flat but has the disadvantage that the patient requires familiarization to ensure natural gait.

Furthermore, it is important for the foot to contact the center of the sensing area for an accurate reading. Limitations include: space, indoor measurement, and patient’s ability to make contact with the platform, Figures (2.1) and (2.2) show a platform-based sensor [15].

Figure (2.1): A platform-based foot plantar pressure sensor.

Figure (2.2): Anther design of a platform based foot plantar pressure sensor.

2.3.2. In-Shoe Systems

In-shoe sensors are flexible and embedded in the shoe such that measurements reflect the interface between the foot and the shoe. The system is flexible making it portable which allows a wider variety of studies with different gait tasks, footwear designs, and terrains [16].

Figure (2.3): An in-shoe based foot plantar pressure sensor

Figure (2:4): An in-shoe based foot plantar pressure sensor

They are, therefore, highly recommended [11] for studying orthotics and footwear design but there is the possibility of the sensor slipping. Sensors should be suitably secured to prevent slippage and ensure reliable results. A further limitation is that the spatial resolution of the data is low compared to platform systems due to fewer sensors . Figures 3 and 4 illustrate in-shoe based systems.

2.4. Requirement of Foot Plantar Sensors

In taking any biomechanical measurements, devices must be optimized for the specific application to ensure that readings are accurate. Detailed analysis must be thoroughly undertaken prior to any measurements and for foot plantar system two main considerations must be met; the target implementation requirements and the sensor requirements.

2.4.1. Target Implementation Requirements

Real-time measurement of natural gait parameters requires that sensors should be mobile, untethered, can be placed in the shoe sole, and can sample effectively in the target environment. The main requirements of such sensors are as follows [17]:

1. Very Mobile: To make a sensor mobile, it must be light and of small overall size, the suggested shoe mounted device should be 300 g or less.
2. Limited Cabling: A foot plantar system should have limited wiring, wireless is ideal. This is to ensure comfortable, safe and natural gait.
3. Shoe and Sensor Placement: To be located in the shoe sole the sensor must be thin, flexible and light. It is reported that a shoe attachment of mass 300 g or less does not affect gait significantly. Shu et al.,mentioned that the sole of foot can be divided into 15 areas: heel (area 1–3), midfoot (area 4–5), metatarsal (area 6–10), and toe (area 11–15), as illustrated in Figure (2.5). These areas support most of the body weight and are adjusted by the body’s balance; therefore, ideally the 15 sensors are necessary to cover most of the body weight changes.
4. Low Cost: The sensor must be affordable for general application to benefit from inexpensive, mass-produced electronics components combined with novel sensor solutions.
5. Low Power Consumption: It should exhibit low power consumption such that energy from a small battery is sufficient for collecting and recording the required data.

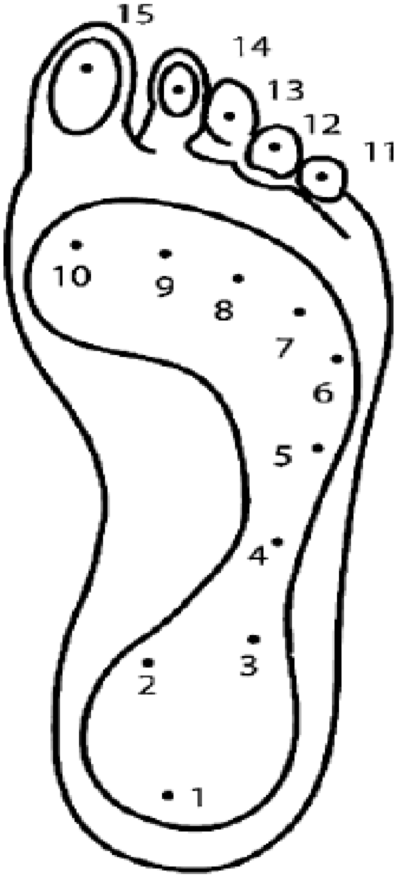

Figure (2.5): Foot anatomical areas.

2.4.2. Plantar Pressure Sensor Requirements

The key specifications for sensor performance include: linearity, hysteresis, sensing size, pressure range and temperature sensitivity [18]. Brief discussion of these is important as a basis for the selection of a sensor for specific applications.

1. Hysteresis: Hysteresis can be determined by observing the output signal when the sensor is loaded and unloaded. When the applied pressure is increased by loading or decreased by unloading, two different responses are observed.

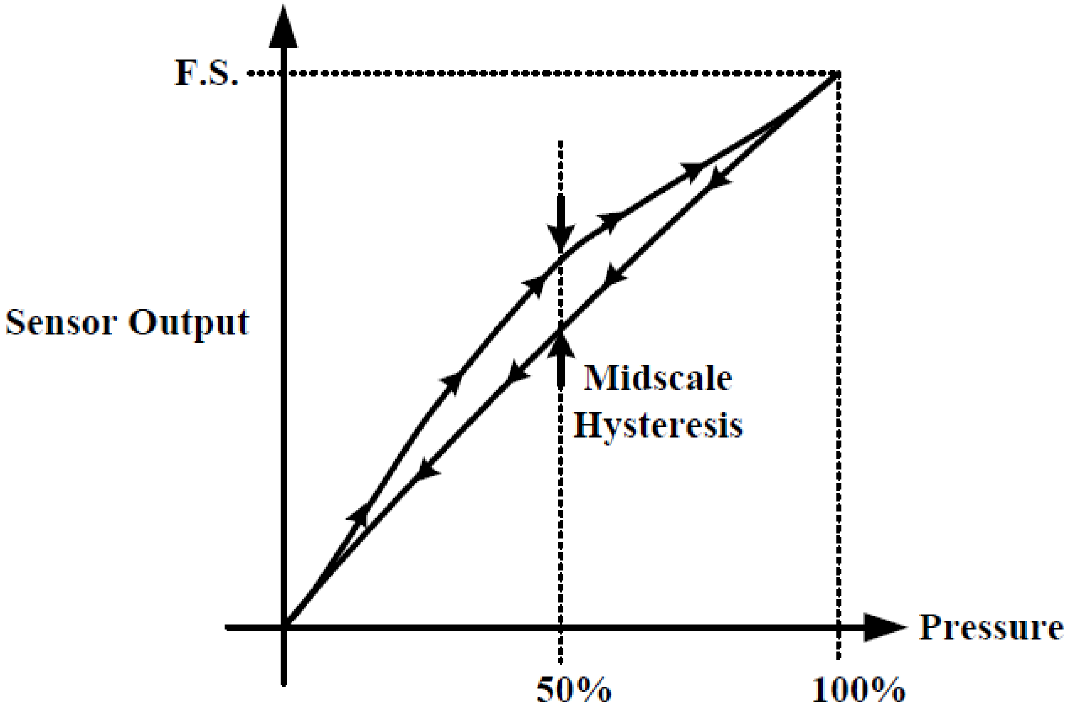

Figure (2.6): Hysteresis caused by loading and unloading a pressure sensor usually measured at the 50% pressure range.

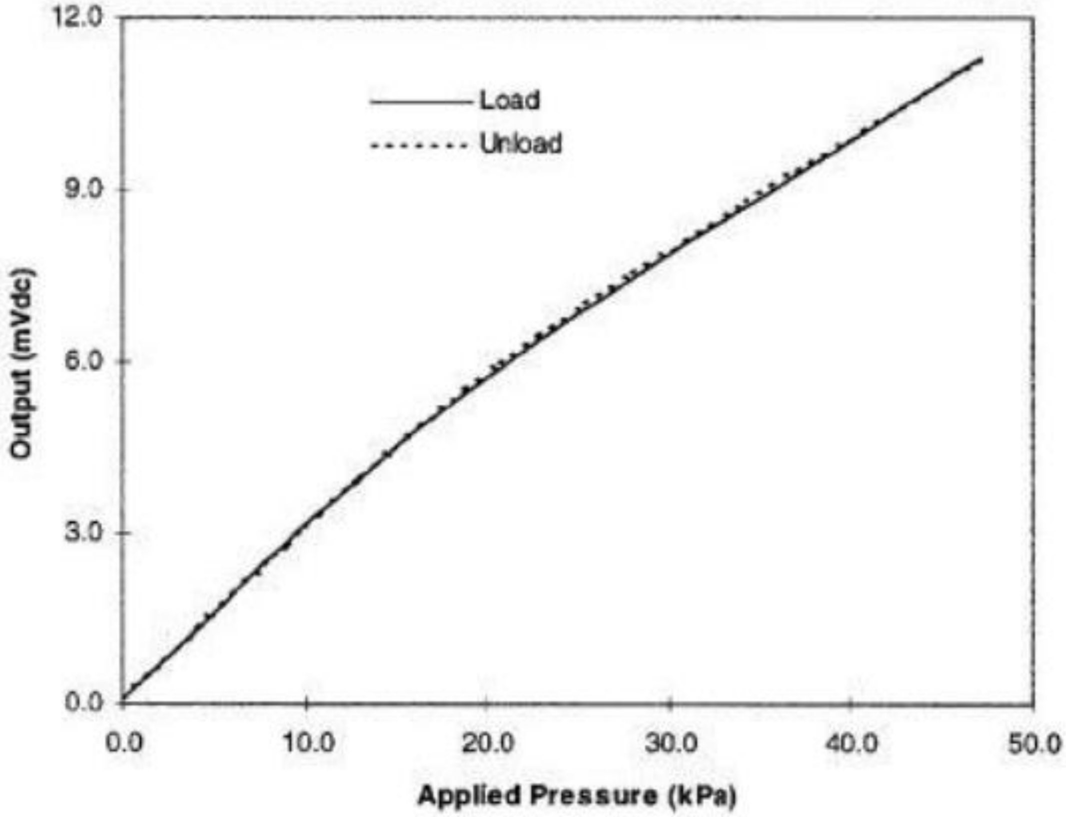

Figure (2.7): Negligible hysteresis of MEMS-based pressure sensor.

2. Linearity: The response of the sensor to the applied pressure, when plotted, will show the linearity figure of merit, i.e., how straight the plotted line is. Linearity indicates how simple or complicated the signal processing circuitry will be, a highly linear response requires very simple signal processing circuitry and vice versa, a linear pressure sensor is, therefore, preferred.
3. Temperature Sensitivity: Sensors may produce different pressure readings as the ambient temperature changes. This may be due to the materials that are part of the sensor body as they respond differently to temperature change. A sensor with low temperature sensitivity in the 20 °C to 37 °C range is preferred.
4. Pressure Range: The pressure range is the key specification for a pressure sensor. As different applications require different operating pressures application-specific sensor development is normally adopted in the design. Maximum pressure is the upper limit that the pressure sensor can measure and vice versa. It is also important to note that burst pressure is the maximum pressure that the sensor can withstand before breakage as opposed to maximum pressure. Foot plantar pressure values of up to 1,900 kPa are typically reported in the literature but an extreme pressure of up to 3 MPa . One of the foot plantar pressure sensor designs considers 3 MPa as burst pressure value, for comparison when a healthy person of 75 kg body mass is standing on only one forefoot, if pressure is evenly distributed, the interfacial pressure for every 31.2 mm2 foot plantar area approximates 2.3 MPa.
5. Sensing Area of the Sensor: Size and placement of the sensor are also critical, as shown in Figure 8. As a large sensor may underestimate the peak pressure and it is suggested that a minimum sensor of 5 mm × 5 mm should be used, whereas sensors smaller than this must be designed as array sensors.
6. Operating Frequency: It is recommended that to measure foot plantar pressure precisely for running activities the sensors must be capable of sampling at 200 Hz. This frequency is generally considered sufficient for sampling most everyday gait activities.
7. Creep and Repeatability: Creep is the deformation of material under elevated temperature and static stress. It directly relates to the time dependent permanent deformation of materials when subjected to a constant load or stress, as in Figure (2.9) Low creep sensors are one of the key requirements in foot pressure measurement. Repeatability refers to the ability to produce reliable result even after long period of time. High cyclic loads may cause deformation or fatigue. Repeatability problems can be eliminated if the sensor exhibits no creep or deformation over repetitive or high cyclic loads.

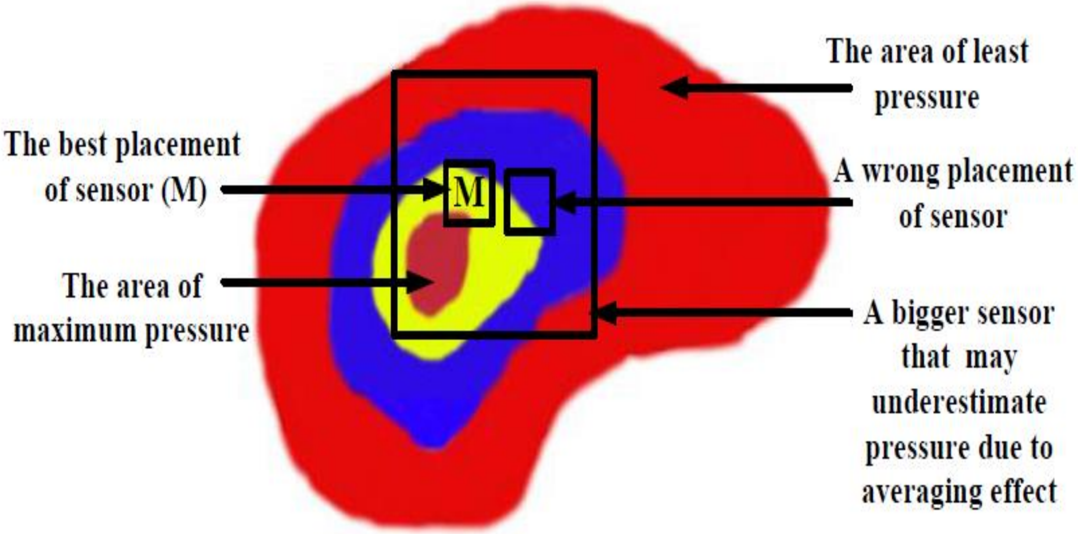

Figure (2.8): Effect of sensor sizing and placement.

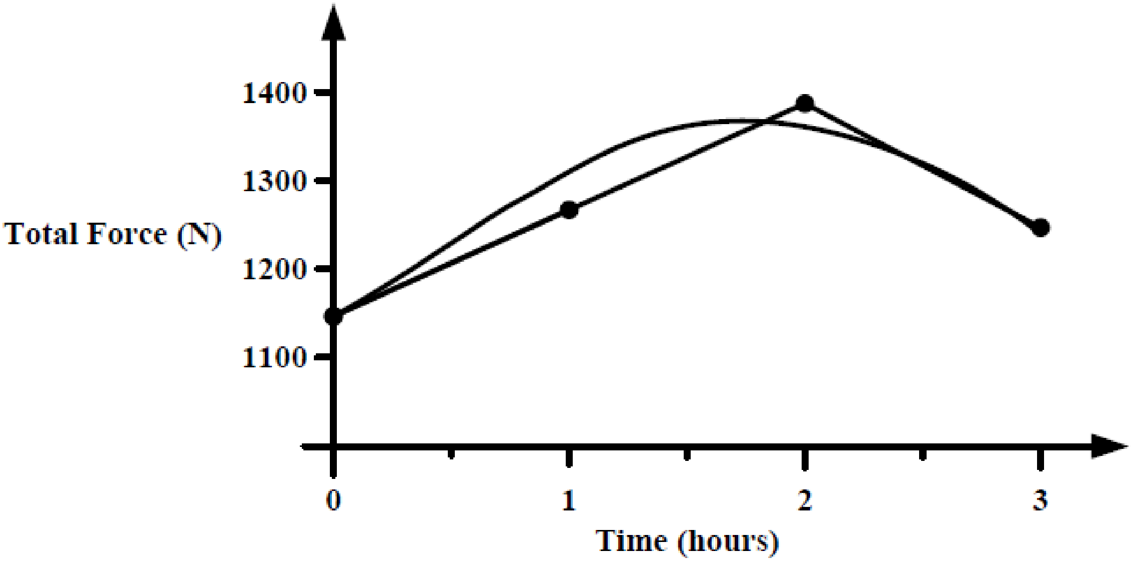

Figure (2.9): Example of erroneous readings. The curve is the error reading by the sensor and plotted line is the correct pressure values.

2.5 Recent Trends in Foot Plantar Pressure Measurement

Trends in biomedical monitoring are toward using real-time and in-situ measurement of normal daily life parameters to keep pace with a fast-changing and demanding scientific environment. Gait analysis researchers are focusing on designing systems for uninterrupted measurement of real life parameters which is important in understanding the effect of daily activities on health. The ideal system to achieve this would be mobile, un-tethered, placed in the shoe sole and able to measure effectively in the targeted environment.

As early as the 1990s, Zhu et al. developed a system for measuring the pressure distribution beneath the foot using seven force-sensitive resistors (FSR) and they used it to differentiate pressure between walking and shuffling. In 1995, Hausdorff et al. built a footswitch system capable of detecting temporal gait parameters using two FSR sensors. Later, in 1997, Cleveland Medical Devices Inc. created an in-shoe wireless system which could measure time of foot contact, the weight on each foot and the centre of pressure (COP) of each foot. The system used a set of thick-film force sensors and since then there has been further development of in-shoe pressure sensor systems [19].

2.6 Wired Systems Application

Over the past two years there has been increasing interest in developing in-shoe foot plantar pressure systems and recently there have been applications to plantar pressure using both wired and wireless systems. In 2011, a paper employed dynamic plantar pressure for human identification in-sole pressure sensor. They compared the pressure at different positions of key points then identified and classified them using a support vector machine (SVM) running on a PC. The system uses wire to transfer data from the sensor to a data acquisition card on a PC (Figure (2.10)) and it is reported that the system has 96% identification accuracy.

Figure (2.10): Identification based on dynamic plantar pressure in-shoe system.

Yamakawa et al. also proposed their own biometric identification in-shoe system based on both feet pressure change and reported that the system could recognize over 90% of the test subjects.

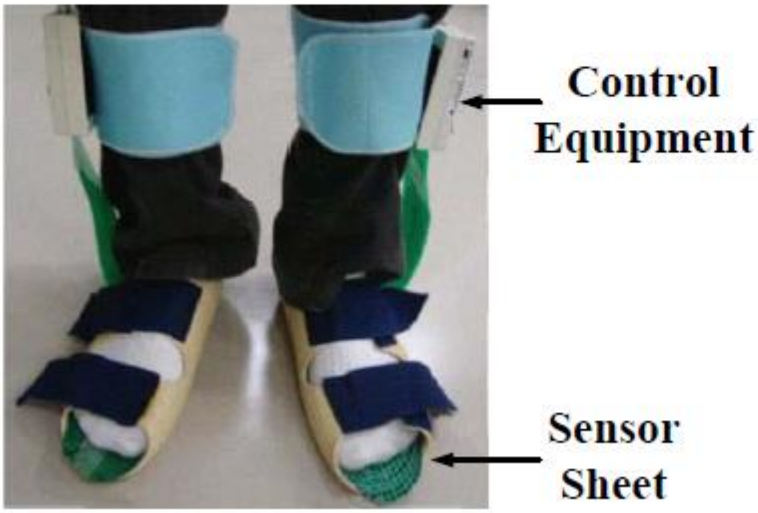

Figure (2.11): Biometric identification based on foot pressure pattern changes.

Another innovative application is an in-shoe system to measure triaxial stress in high-heeled shoes. The paper investigated the distribution of contact pressure and sheer stress simultaneously in high-heeled shoes utilizing five in-shoe triaxial force transducers commercialized by Anhui June Sport, China.

The system is named “WalkinSense” and consists of a data acquisition and processing unit and eight individual sensors. It appears that only the sensor part is their own development. The location of the sensors is illustrated in Figure (2.12), whilst the WalkinSense System is shown in Figure (2.13).

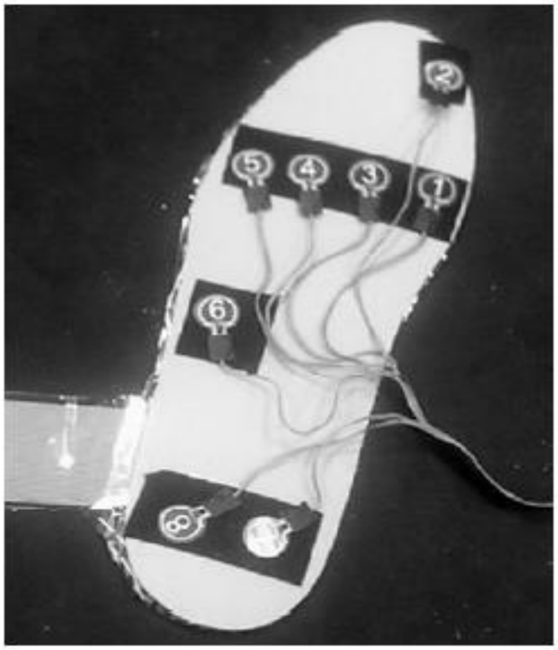

Figure (2.12): WalkinSense sensor placement.

Figure (2.13): WalkinSense system.

All of the works described above have a common feature that is wired to the processing unit or PC. All of them have certain benefits but for a wired system the major limitation is application in everyday monitoring. The wired system may encumber the test subject causing trip hazards or even a fall, and it can also affect the normal gait patterns. Therefore, it is recommended to make the system mobile for everyday usage, and the system must adapt to a wireless system [20].

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