NEAR EAST UNIVERSITY
FACULTY OF ENGINEERING
BIOMEDICAL ENGINEERING DEPARTMENT

GRADUATION PROJECT II

Flat Feet Detector

BY

ERCAN KAYA
ESTER CHUKWUMA
AMER BASHIMAM

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS
FOR THE DEGREE OF BACHELOR OF SCIENCE
IN BIOMEDICAL ENGINEERING

NICOSIA 2016

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ACKNOWLEDGEMENT:

Our project represents the last chapter of our life as an undergraduate students, and prepares us to the long way of real and practical life, this project will also be the first step for serving humanity and pushing the efforts of science.

We are grateful for every person who participated and made effort to complete this project, we can't forget the role of chairman of biomedical engineering department *Assoc. Prof. Dr. Terin Adali* who was our mentor and enlarged our minds and thinking. Then our supervisors *Mr. Alper Yusuf* who had patience on us and spent time to help us finish this project. Finally we would thank all family members and friends who stood beside us during this time.

ABSTRACT:

Foot is a part of human body, which plays an important role in biomechanical contribution to postural control. Besides being easily exposed to a variety of potential infections and injuries, there are several genetic conditions that can affect shape and function of foot, including a metatarsus adductovarus, skew foot, club foot, high arch foot, low arch or flat foot, and congenital vertical talus. People with these abnormal feet may develop gait problem or have high risk of injury.

The aim of the arches is to give us spring and distribute our body weight across our feet and legs. The structures of the arches of our feet determine how we walk - they are rigid levels which allow us to move smoothly. However, the arches need to be sturdy as well as flexible to adapt to various surfaces and stresses.

Customized foot orthotics is fabricated by taking a negative cast of the 3-D plantar surface of the foot with a plaster or impression foam. Orthotic material is then molded to a positive impression generated from the negative cast.

The aim of this project is to design a reliable low cost foot pressure mapping system that will provide required data for the identification of flat feet and other feet disorders and assist the manufacture process of customized shoe insoles.

Keywords: flat feet, pressure mapping, feet disorders, force resistance sensor, podiatry.

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1 CHAPTER 1: ANATOMY

1.1 Introduction:

Feet come in all shapes and sizes. Some have well balanced arches with minimal callusing and a healthy appearance, while others deal with chronic foot pain due flat feet, high arches, and bunions – just to name a few. While most of us fall somewhere in the middle, it's been reported that 80% of all adults will suffer some foot disorder during the course of their lives. Heredity can be a significant predictor of your overall foot health, but so can factors such as — the types of shoes you wear, the amount of time you spend on your feet, and whether or not you're overweight. Add to this your mental and physical health and well-being, and we start to get a clearer of picture of what your feet are saying about you.

Flatfoot is usually thought of as "significant" flattening of the arch, potentially accompanied by a variety of other possible structural deviations. It was noted as early as 1896 that flatfoot was not necessarily debilitating, but sometimes it was extremely so, and that the presence of symptoms did not necessarily correspond to the appearance of the foot. (Kerr, Stebbins, & Theologis, 2015)

Several kinematic studies have compared participants with flat or pronated feet to those with normal foot posture. However, the results of these studies have been inconsistent due to variations in foot posture classification and biomechanical modelling methods used. Previous foot posture classification methods used include visual observation, arch ratio measurement and the combination of static and dynamic two-dimensional measurements of the medial longitudinal arch. Although these studies have provided insight into the potential influence of foot posture on kinematics, less than optimal reliability for a range of clinical foot measurements limits the methodological strength of these studies. Subsequently, there remains a need to assess the influence of flat-arched feet on kinematics using more reliable and objective foot posture classification methods. (Levinger, Men, & McSweeney, 2010) .

1.2 Medial Arch:

When we talk about our arches, we're most often referring to the medial longitudinal arch. Spanning the heel to ball of foot, its main function is to distribute body weight and absorb shock.

High, low or collapsed medial arches disrupt the distribution of body weight across the foot, impairing shock absorption. Low or collapsed arches are often associated with overpronation, while high arches are often associated with excessive supination (underpronation). However, this is not a hard rule. You can still overpronate with high arches or underpronate with low arches.

Our feet are our body's first shock absorbers - they alternately flex and stiffen as the body moves to absorb impact, respond to uneven surfaces and act as a lever to propel the body forward. Feet can be classified into three broad categories based on how they perform in this role.

Neutral: Neutral refers to good alignment in the feet and ankles in which the feet and ankles form a straight line. The feet form a stable platform with pressure distributed evenly across the heel and forefoot.

Overpronation: Pronation is the natural way that our feet absorb shock: when our feet strike the ground the arches flex down and in to disperse the impact.

Excessive supination: Supination is a natural part of all walking and running. It is the way the feet propel the body forward: the foot turns or rotates outward as the heel lifts, weighting the forefoot and toes to push-off the ground.

This illustration shows the many areas of the body affected by overpronation. By simply supporting the feet properly overall body alignment can be improved, alleviating pain and helping the body heal itself. (Rauhansalo & Hakkala, 2013).

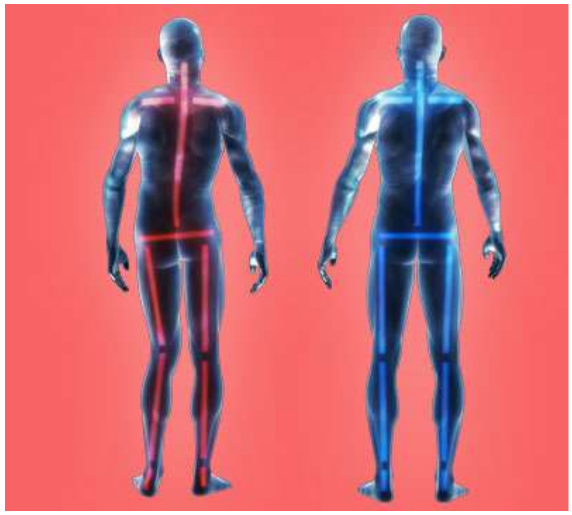

Figure 1 Flat feet effect to posture (Rauhansalo & Hakkala, 2013)

1.3 Definition

You have flatfeet when the arches on the inside of your feet are flattened, allowing the entire soles of your feet to touch the floor when you stand up.

A common and usually painless condition, flatfeet can occur when the arches don't develop during childhood. In other cases, flatfeet develop after an injury or from the simple wear-and-tear stresses of age.

Flatfeet can sometimes contribute to problems in your ankles and knees because the condition can alter the alignment of your legs. If you aren't having pain, no treatment is usually necessary for flatfeet.

Foot posture is an established factor in determining the function of the lower limb and may therefore have a role in a predisposition to repetitive injury. Flat foot deformity is frequently encountered in paediatric orthopaedic and rehabilitation practices. Flat foot (pes planus) is a biomechanical problem consisting of a constellation of physical features that includes excessive eversion of the subtalar complex during weight-bearing, with plantar flexion of the talus, plantar flexion of the calcaneus in relation to the tibia, dorsiflexion and abduction of the navicular, supination of the forefoot, and valgus posture of the heel.

Flexible flat foot tends to disappear when the lower limb is not weight-bearing and rarely causes disability or requires treatment, although overuse may cause pain.In contrast, rigid flat foot is a pathological foot condition that may arise from acquired or congenital causes ranging from structural abnormalities, collagen disorders, musculoskeletal abnormalities, trauma, spastic conditions, or neuromuscular conditions. People with flat foot are at higher risk of foot pain, knee pain, foot injury, stress fracture, and poor exercise performance. The prevalence of flat foot varies across different studies. Some researchers have shown that prevalence of pes planus decreases with age. Others have a pointed sex preponderance.

There are 20 muscles in the foot that give the foot its shape by holding the bones in position and expand and contract to impart movement.

The posterior tibial, which supports the arch; Ligaments hold the tendons in place and stabilize the joints. The longest of these, the plantar fascia, forms the arch on the sole of the foot from the heel to the toes. By stretching and contracting, it allows the arch to curve or flatten, providing balance and giving the foot strength to initiate the act of walking. Medial ligaments on the inside and lateral ligaments on outside of the foot provide stability and enable the foot to move up and down.

Orthotics: Inserts worn in the shoes can improve many foot problems. Orthotics may be custom-made or standard-sized.

Orthotics is a specially designed shoe insert, which provides support for the foot by distributing pressure or realigning foot joints while standing, walking or running. Research reports show that orthotics is effective in relieving symptoms of lower extremity problem and facilitating rehabilitation.

1.4 Symptoms:

Symptoms may vary and generally depend on the severity of the condition. Some have an uneven distribution of bodyweight and find that the heel of their shoes wears out more rapidly and more on one side than the other. The most common signs or symptoms of flat feet are:

Pain in the:

- Ankle (inner side), there may also be swelling
- Foot in general
- The arch of the foot

- The calf
- The knee
- The hip
- The back
- The general lower leg area

People with flat feet may also experience stiffness in one or both feet. One or both feet may be flat on the ground (either no arch, or very slight arch). Shoes may wear unevenly.

1.5 Causes of flat feet

- Family history; experts say fallen arches can run in families.
- Weak arch; the arch of the foot may be there when no weight is placed on it, for example, when the person is sitting. But as soon as they stand up the foot flattens (falls) onto the ground.
- Injury
- Arthritis
- Tibialis posterior (ruptured tendon)
- Pregnancy
- Nervous system or muscle diseases - such as cerebral palsy, muscular dystrophy, or spina bifida.
- Tarsal Coalition - the bones of the foot fuse together in an unusual way, resulting in stiff and flat feet. Most commonly diagnosed during childhood.

The following risk factors are linked to a higher probability of having flat feet:

- Obesity
- Diabetes
- Getting older (aging)
- Pregnancy
- Rheumatoid arthritis
- Foot or ankle injury
- Posterior tibial tendon tear or dysfunction
- Diabetes

- Age and wear and tear; years of using your feet to walk, run, and jump eventually may take its toll. One of the eventual consequences could be fallen arches.

The posterior tibial tendon may become weakened after long-term wear a tear. The postario tibial tendon is the main support structure of the arch of our feet. The tendon can become inflamed (tendinitis) after overuse - sometimes it can even become torn. Once the tendon is damaged, the arch shape of the foot may flatten.

People with other foot problems may find that flat feet either contribute to them or make symptoms worse. Examples include:

- Achilles tendinitis
- Arthritis in the ankle(s)
- Arthritis in the foot (feet)
- Bunions
- Hammertoes
- Plantar fasciitis (pain and inflammation in the ligaments in the soles of feet)
- Posterior tibial tendinitis
- Shin splints.

1.6 Diagnosis:

People who have flat feet without signs or symptoms that bother them do not generally have to see a doctor or podiatrist about thems. However, if any of the following occur, you should see your GP or a podiatrist:

- The fallen arches (flat feet) have developed recently
- You experience pain in your feet, ankles or lower limbs
- Your unpleasant symptoms do not improve with supportive, well-fitted shoes
- Either or both feet are becoming flatter
- Your feet feel rigid (stiff)
- Your feet feel heavy and unwieldy

Most qualified health care professionals can diagnose flat feet just by watching the patient stand, walk and examining his/her feet. A doctor will also look at the patient's medical history. The feet will be observed from the front and back. The patient may be asked to stand on tip-toe while the doctor examines the shape and functioning of each foot.

In some cases the physician may order an X-ray, CT (computed tomography) scan, or MRI (magnetic resonance imaging) scan.

1.7 Reflexology and flat feet

The feet are the mirrors of the body. And since every part of the body is represented on the feet via its reflex, the appearance and sensitivity of those reflexes can hold a wealth of information about our health. Calluses and corns for example, tend to develop in areas of high friction – it's the body's way of protecting itself by adding more cushioning. But they could also be an indication of congestion or some other imbalance in that part of the body. Where it appears and to what extent can be of significant importance.

Bunions for example, form around the first metatarsal joint, just below the big toe. It's true that some people inherit them from their parents, but it's equally as true that tight, uncomfortable shoes can lead to bunion formation. When we consider the area where bunions form, we have the upper thoracic spine and neck reflexes. Could our choice in footwear be contributing to upper back and neck issues…? Whether the imbalance starts in the body or whether it starts on the feet, no one can truly say. What can be said is that there appears to be a strong connection between the two.

Flat feet and high arches are other fairly common foot conditions. The relative height of your medial arches can have a significant impact on how your weight is distributed on your feet. Most people with flat feet will have their weight shifted to the insides of their feet, while people with high arches bear their weight along the outer parts of their feet. This could have an impact on your posture and the proper functioning of the spine. People with low back pain should start with a pair of comfortable shoes with good arch support.

The tips of the toes represent the head and brain reflexes and the sides correlate to the sinuses. Issues such as hammertoe, claw toe, rigid toe, or any deformity of the toes, could create congestion in those areas but could also be representative of some imbalance that's already present. People with high arches and those that wear open toed shoes such as sandals, are more likely to develop hammertoe.

Skin conditions such as plantar's warts, athlete's foot, eczema, or even just dry skin, could be used as an indicator for that part of the body's overall health. Again, the placement and extent of the condition is key. Toenail problems such as ingrown toenails, thickened toenails, or fungal infections, could be an indicator of a poor diet or vitamin deficiency.

Pain anywhere on the foot is of significant importance and should be attended to with care. Whether it is pain resulting from arthritis, gout, bunions, heel spurs, neuromas, or plantar fasciitis, any painful areas on the feet should be considered in relation to the whole body. The feet are our first and primary contact with the earth and the ground beneath us. Establishing a firm and secure foundation should be a top priority in our lives.

The basis of reflexology is not known for sure. Feet have been molded by evolution to be highly sensitive to impulses, courtesy of the thousands of nerve endings that are present. Proponents of reflexology claim that the extensive innervation of the feet is key to the flow of what is referred to as "vital energy" thoughout the body. A ready flow of this energy is beneficial, while blockage in the flow due to injury or illness is not. Reflexology aims to restore the proper energy flow.

Not surprisingly, given the claimed full-body benefits of reflexology, practitioners use it for a variety of ailments including anxiety, headache, digestive disorders, incontinence, pain, and fatigue from illnesses such as cancer and diabetes.
How is the feet connected to different parts of the body (Appendix A).

2 CHAPTER 2: load distribution measurement Methods

2.1 Barefoot measurement

Static and dynamic studies of plantar forces can be achieved efficiently, using force and load distribution measurement platforms. Force platforms have been developed to a high level of performance. For example, the Kistler force plate provides independent measurement of total vertical and shear forces. Analysis and is not capable of measuring plantar load distribution. However, the high specification, good repeatability and long-term stability have resulted in the use of the Kisfler force plate as the 'Gold standard' against which other systems are evaluated.

Since the early 1980s, several improved methods of measuring plantar load distribution under the barefoot have been developed. The commercially available Musgrave Foot-print systerm1" uses force-sensing resistors, comprising two polymer sheets, one with deposited pectinate electrodes and the other coated with the semiconducting material (molybdenum disulphide). Contact area between the electrodes and the semiconducting material increases with applied force, resulting in a large change in resistance.

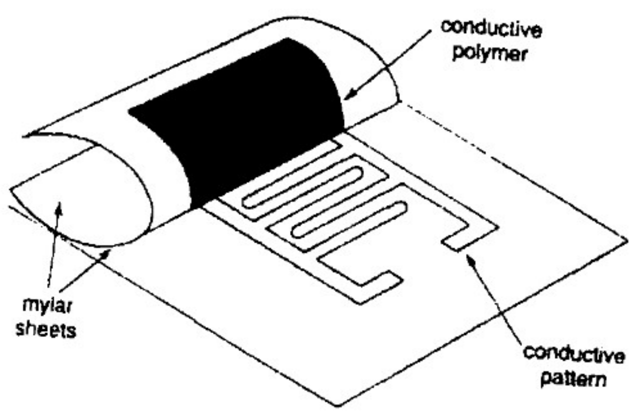

Figure 2 Structure of force-sensing resistor (MAALF.J & WEBSTE, 1998)

Several clinical studies have been undertaken using this system, Bennet and Dupleck undertook clinical trials on 86 asymptomatic subjects and obtained results comparable with other methods (BENNET & DUPLOCK, 1993). Roggero *et al* investigated the effectiveness of reconstructive surgery resulting from a wide range of foot pathologies (ROGGERO, BLANC, & at, 1993) . In all studies, a period of accustomisation was normally required.

Optical techniques have provided the highest levels of resolution for barefoot measurement. In the pedobarograph (BETRS, DUCKWORTH, & al, 1980) the upper surface of a glass plate is covered with a thin opaque material, typically a plastic sheet. Under load, variations in the level of contact at the glass/plastic interface result in a change in the refractive index and attenuation of light propagating in the glass plate. When viewed from below, areas of contact are seen as low-intensity regions. The structure of the pedobarograph and the behaviour at the plastic/glass interface are depicted in figure 3.

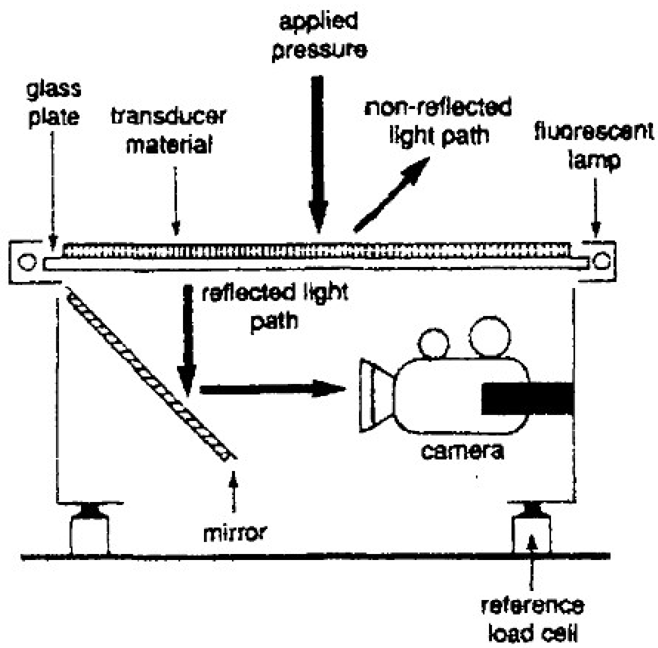

Figure 3: Structure of the pedobarograph (BETRS, DUCKWORTH, & al, 1980)

Criteria for the selection of the transducer material are described by Franks and Betts, who identify several problems occurring across a range ofnnaterials: nonlinearity; adhesion to the glass plate; saturation within the range of interest; material deformation and wear;, poor dynamic response time; image intensity and uniformity dependent on surface granularity (FRANKS & BETTS, 1988) .

Several clinical studies have been undertaken using the pedobarograph. Betts *et al.* investigated load distribution for two subjects with foot deformity resulting from spina bifida, and they undertook a post-operative assessment of four subjects with hallux rigidus (BETRS, DUCKWORTH, & al, 1980). Minns used the pedobarograph for static measurement in an evaluation of direct printing methods and noted that a stabilisation period of (30 sec) was required before obtaining art image, due to creep of the transducer material (MJNNS, 1982). Image-processing techniques to overcome the low-intensity, low-contrast image obtained from the pedobarograph have been developed by (PATIL, 1990)

Transducers employing piezoelectric materials are not well suited to static measurements due to the charge leakage arising from the non-ideal characteristics of charge amplifiers. The unacceptably high time constant required for accurate static measurements imposes a typical low-frequency limit of around 0.1 Hz on systems using piezoelectric materials (KYNAR, 1987).

2.2 Discrete sensors for in-shoe pressure measurement

Two significant disadvantages of barefoot measurement systems are the inability to assess behavior at the foot-shoe insole (CAVANAGH & HEWIIT, 1992) and the difficulty of synchronizing measurement to specific phases of the gait cycle (HENNIG & STAAT$, 1994). In-shoe discrete transducers for measurement at selected plantar sites overcome these problems, while introducing the problem of locating the transducers at the appropriate sites of interest (LORD & HOSEIN, 1992) Discrete in-shoe transducers can introduce errors by causing the load to become concentrated at the measurement site, leading to high readings or saturation (NEVlLL, 1991) .situation can be improved by reducing transducer thickness, ideally below 0-5 mm (FERGUSON-PELL, 1980). However, the mechanical properties of the transducer, the use of an insole and the insole of the shoe can also significantly affect the load distribution.

The Electrodynagram system provides seven discrete sensors with a thickness of only 0.3 mm. These sensors are suitable for both in-shoe and barefoot measurement. Each sensor is an integrated circuit containing a resistive bridge (SClENTIST, 1985). This system has been used in assessing variations in load distribution as a result of limb length discrepancy (C. & DINOWlTZ, 1985), diabetic foot ulceration (SMITH & PLErfWE, 1989) and assessment of the affect of varying shoe heel height on foot function (GASTWMTH & O'BRIEN, 1991)

The use of this transducer in a clinical environment is limited by the need to use specialized footwear and the difficulty of aligning the sensors. Care is also required to exclude any external light. The silicone rubber used was found to break-down at around 1000 loading cycles, and a stronger elastomer is required.

2.3 Foam Box Casting:

Impression foam casting has the obvious advantages of being both quicker and cleaner. It offers a good method of creating a negative of the patient's foot. Approximately 65 percent of all casts are taken with impression foam. The patient should be seated in a chair with both feet plantar-grade. It is important that the cast be taken slowly with the practitioner in control and guiding the descent of the foot. It is best not to take impressions on tiled floors as the box may slide halfway through the process. A good controlled cast will not crack or split the foam around the perimeter.

Impression foam is the method of choice when you are making accommodative foot molds. These orthotics are often designed to alleviate pain in a specific area of the foot. A semi-weight-bearing or even weight-bearing cast may often better capture the location of a bony prominence, callus, or fibrous tissue mass. Many practitioners use impression foam exclusively when dealing with restless patients, e.g. young children or people with certain disabilities.

Once the cast is complete, it is important to take a little time and care with the shipping. Plaster casts should be left out to cure and dry for 24 hours before being sent off. Otherwise they will tend to flatten and even dampen and potentially damage the shipping box. Although some impression foam is sold in boxes that are ready to ship, it is recommended that you send them inside another box for better protection. On occasion, if the carrier is having a rough day, all that may arrive at the lab is a forensic jigsaw puzzle.

2.4 Laser-based measurement systems:

Laser-based measurement systems suffer from several drawbacks. Firstly, it requires an interference-free image sensor, which is more expensive than commercially available image sensors. This is because, a coherent imaging implemented by using an ordinary image sensor produces an image, which is distorted by an interference pattern, making it impossible to reconstruct plantar surface precisely. This unwanted pattern occurs when the incident laser beam interferes with the ones reflected from a protective sheath covering the sensor surface. Secondly, it can only be used for bare foot measurement. Patients need to stand on a transparent platform during the data acquisition. This causes a similar problem that is the recorded information is distorted by the interference between the laser beam incident on the plantar surface and the beam reflected back from the platform surface.

These footprint analysis method suffers from some limitations as follows. Firstly, an ink-based footprint is easily contaminated or poorly reproduced. Secondly, in the case of using capacitance-based pressure platform, the resolution of its resultant imprint is lower than the ink printing approach, because capacitance sensors cannot detect accurately mid-foot Area where a foot arch exists. Thirdly, the conventional footprint method provides only two-dimensional (2-D) information of a plantar surface of the foot, from which a three-dimensional (3-D) foot arch height must be derived. Consequently, precise information of pathology is hardly obtained.

2.5 Planipes Mobile Foot Pressure Analysis:

For a long time, mobile health was essentially an oxymoron, as often health systems were bulky machines and therefore immobile. Only recently, with the popular success of mobile phones as an inexpensive computing platform, it became meaningful to consider mobile health systems as an alternative. This recent trend was particularly driven by developing countries, primarily to bring the cost of health systems down.

In this paper we study a mobile health system that is not motivated by cost, but rather by mobility itself, as we want to measure motion sequences in everyday life. To some degree, in 2011 one may even be surprised that somebody considered immobile health systems for curing such a strictly mobile issue!

It would be better to have a truly mobile system that does not hinder the patient in her natural movement, and can possibly record foot pressure throughout the day. In other words, instead of having the sensors on the floor, they should rather be directly on the foot. The analysis of the data can be done in real-time or off-line. Important however is that the system does not affect the patient’s natural gait. Currently used systems are either immobile, or simply impractical.

The proposed system consists of a pair of sensor soles, each connected to a small sensor board, and a smartphone application. The sensor data is transmitted from the sensor boards to the smartphone using Bluetooth. The small form factor and the wireless communication of the components allow to conduct dynamic measurements with minimal effect on a person's feet.

The aim of the Planipes system is to offer a versatile platform for a broad spectrum of different applications in pedography. Thereby, the focus of our system is to provide a cheap solution for precise measurements without impairing the mobility of the patient.

The Planipes system consists of two parts: two sensor devices and a smartphone application. The pressure distribution at each foot is measured by a pressure-sensitive insole, which is connected to a small sensor board. This board controls the sampling procedure of the pressure sensors and communicates with the smartphone over a Bluetooth connection. A dedicated smartphone application is responsible to collect, process and display the measurement data.

The sensor insole has been designed to measure the pressure affecting different regions of the foot. Each insole with 16 force sensing resistors (FSR) as depicted in Figure 2.

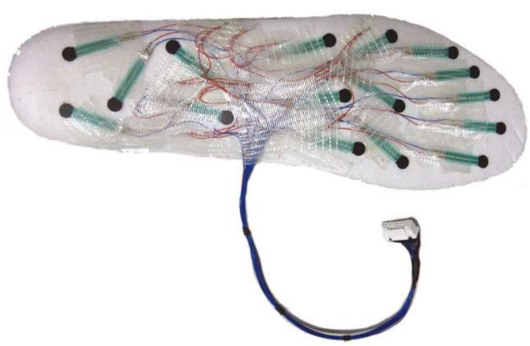

Figure 4 Planipes sensor placement (Pfaffen, Sommer, Stocker, Wattenhofer, & Welten, 2011)

Each sensor is built from two membranes separated by a small adhesive layer. When a force is applied, a carbon film on the top layer is pressed onto the active area of the bottom layer, resulting in a change of resistance which depends on the force being applied. With an appropriate electronic circuit, this change in resistance can be measured and the corresponding pressure can be calculated. In this system, the FSR is connected in series with a resistor between ground and the supply voltage to form a voltage divider.

The sensors placed underneath the insole are connected to a printed circuit board with a size of 2.5 x 5 cm. The core of the board is an Atmel ATmega328 microcontroller, which has 32 Kbytes of ROM and 2 Kbytes of RAM. A Lithium-Polymer rechargeable battery is used to power the sensor board. The battery can be charged with the integrated USB charger. The voltage at all 16 sensors has to be converted into digital values.

The board features a Roving Networks RN-42 low-power Bluetooth module, which provides a serial communication interface between the microcontroller and the phone through the Bluetooth serial port profile (SPP). Furthermore, four LEDs can be used to provide visual feedback to the user about the current operation mode of the system, e.g., to indicate that a Bluetooth connection to the phone has been established.

The application is responsible to handle the communication with the sensor boards over Bluetooth. Incoming sensor measurements are processed and stored on the phone's SD card for offline analysis. Furthermore, the data is visualized on the screen to provide an immediate feedback to the user.

The force sensing resistors used in the insoles of Planipes exhibit a non-linear dependency between the pressure applied and the resistance measured at the sensor. Therefore, the sensor data has to be post-processed at the smartphone to get the corresponding pressure value. The resistance of the sensor is converted into a 10-bit ADC value according to the voltage divider relation and the corresponding value of the applied force can be approximation using the parameters listed in the datasheet of the sensors. (Pfaffen, Sommer, Stocker, Wattenhofer, & Welten, 2011) .

2.6 LOW-COST FOOT PRESSURE:

Plantar loading has been studied in static and dynamic situations. To determine the load or pressure distribution exerted on the plantar surface, a number of investigations have divided the plantar surface into eight anatomical regions as shown in Figure, It has been reported that during normal stance, each foot carries about half of the body weight at the heel, forefoot and big toe whereas lowest plantar load is located under the midfoot.

It has been reported that during normal stance, each foot carries about half of the body weight at the heel, forefoot and big toe whereas lowest plantar load is located under the midfoot. However, a planter pressure PP distribution map alters noticeably during foot movement. Previous literature has shown that an increase in the speed of foot movement leads to an increase in peak PP in the foot regions such as heel, medial and central metatarsals and hallux.

Eight anatomical regions of the foot were defined to be used for plantar pressure distribution analysis, namely: M01 at the heel, M02 at the medial midfoot, M03 at the lateral midfoot, M04 at medial forefoot, M05 at the central forefoot, M06 at the lateral forefoot, M07 at the hallux, and M08 at the toes.

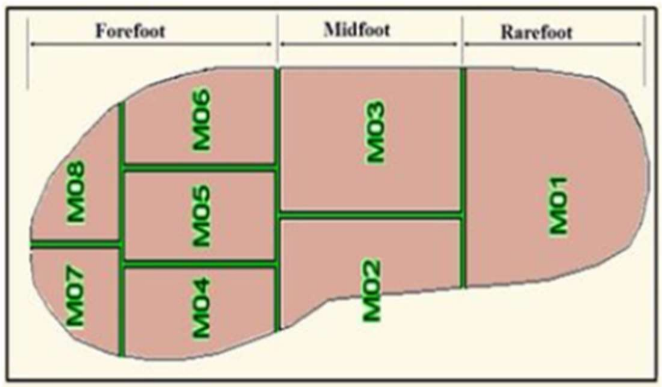

Figure 5 anatomical regions of the foot (AL-Baghdadi, K, & D., 2015)

Published literature has shown that the applied pressure underneath the plantar surface of flat-feet increases during foot movement, especially on the rearfoot, midial midfoot and lateral midfoot as compared with the normal foot. Contact area and PP in midfoot noticeably decreases in individuals who have a high foot arch (cavus foot).

Thin-sheet sensor pads manufactured by ShuntMode MatrixArray® were purchased for the fabrication of a l50cm by 400cm gait mat. Each sheet consists of 70 an array of 70 force sensing cells, 7 rows and 10 columns, allows the user to simultaneously measure force of every cell at once. The active area was approximately 5cm by 7.5 cm. Therefore, each sensor has a resolution of 7 mm by 7 mm square area. 16 sheets were assembled into a large gait mat. Software was written to record the conductance and output these data as pressure values. Before the final assembly of the gait mat, the sensor of individual sheets were calibrated as shown Figure 4. Each sheet in the assembly was identified so that the output can be converted to correct pressure value. (AL-Baghdadi, K, & D., 2015)

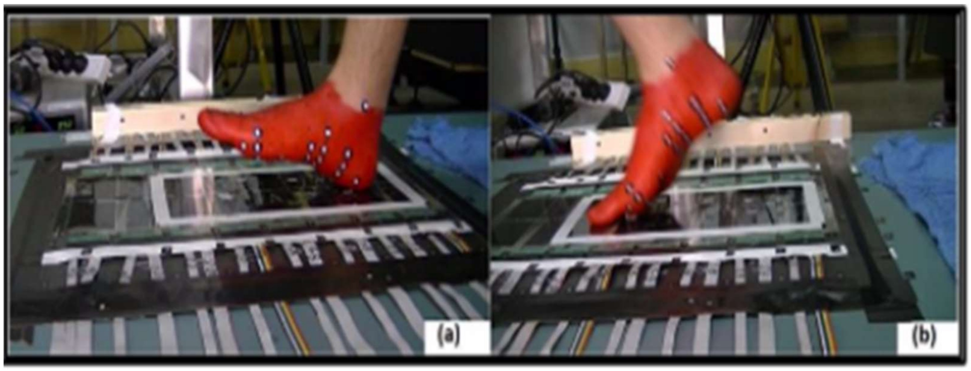

Figure 6 sensor arrays (AL-Baghdadi, K, & D., 2015)

3 CHAPTER 3: MARKET

Measurement of pressure under the foot is of particular interest to the clinician and researcher, particularly in the fields of diabetes, orthopaedics, sports science and rheumatology. The move to in-shoe measurement is an exciting prospect as this form of mechanical assessment can be applied to clinically relevant areas such as the study of activities of daily living and the evaluation of the effectiveness of in-shoe therapeutic devices. (Woodburn & Helliwell, 1996).

Generally, plantar load measuring systems can be classified into two main types:

1. Planter Pressure measuring systems.
2. Ground reaction force (GRF) measuring system.

A number of measuring system products are commercially available. For example, foot insole and pressure pad, Pedar and pressure platform systems have been designed to record Planer Pressure.

In addition, force plate and wearable force sensors (e.g. the flexi-tactile sensor system Nitta Corporation) are commonly utilized to measure GRF of the moving foot, these turn-key systems are expensive equipment.

Of course every foot-load measuring system used to measure plantar load or plantar pressure has some advantages and disadvantages.

3.1 F-Scan in-shoe pressure measuring system

The F-Scan system (Tekscan Inc.). The manufacturers claim that the system will allow accurate, reliable, and cost-effective measurement of in-shoe plantar pressures. The in-shoe advantages of F-Scan have been utilized by a number of workers who have conducted a series of useful clinical studies focused mainly on the evaluation of various therapeutic measures including footwear and in-shoe orthoses2-9. More recently the accuracy and reliability of the system has come under closer scrutiny, highlighting the need for further debate supported by experimental studies. (Woodburn & Helliwell, 1996)

3.1.1 Description of the F-Scan system

The F-Scan sensor is a matrix system utilizing ink-based force sensing resistors incorporated into a thin (0.15 mm) flexible polymer insole (Figure 7).

The total number of sensors per insole is 960, 4 cells/cm. Each cell acts as a force measuring device, the system software calculates the average pressure on each cell based on the measured vertical load and the cell area.

Figure 7: F-Scan system flexible polymer insole (Woodburn & Helliwell, 1996)

Signal processing units, attached at the ankle, umbilical cables and dedicated interface boards are used to acquire and transfer data to an IBM compatible PC. F-Scan software allows measurement of vertical ground reaction force, pressure, peak pressure, contact area, and gait cycle timings.

The initial inspection of the system identified several good features:

1. The sensor was thin and unobtrusive in the shoe.
2. Spatial resolution (5 mm) was good enough to identify small features in the foot such as individual metatarsal heads.
3. Sampling rate (1 -. 100 Hz) was adequate for most clinical applications.
4. The software was user-friendly.

Initial trials revealed a number of limitations which were attributed to the physical characteristics and capabilities of the sensor:

1. The thickness and use of a smooth polyester material in the design of the sensor did not lend to its durability. In use we frequently experienced creasing in the heel region with permanent damage to relay wires and ultimately sensor failure.
2. The sensor was found to be flexible in two directions but not at once and therefore did not adapt well to curved surfaces and protrusion inside a shoe nor to the curved surface of a foot orthotic.
3. The upper pressure range of the sensor (1250 kPa) may be inadequate for use in some patient groups who experience very high plantar pressures, particularly neuropathic diabetics with plantar ulceration. However, a systematic investigation of the attenuating effects of different shoe types on the ground reaction forces measured in-shoe is necessary to clarify this latter statement.

3.1.2 Calibration

The calibration of the F-Scan system uses total body mass applied directly over each sensor in a static manner. The procedure involves the patient standing on one foot, the calibration force being equivalent to the body mass. In our experience, using the system in a rheumatology clinic, this technique was unsuitable for unstable patients (unless supported) or those with lower limb pain. Evaluation of the calibration procedure consistently overestimated body mass across a normal range by 4%. with individual error as high as 14%, the greatest error being in the 75-90 kg range. (Woodburn & Helliwell, 1996)

3.1.3 Discussion

The performance of the F-Scan sensor is affected by a number of mechanical and electrical effects. The poor durability of the F-Scan sensor challenges the cost-effectiveness of the system. a matter which we have partially addressed by backing the underside of each sensor with very thin flexible EVA (expanded vinylacetate) material.

Measurements generated by F-Scan appear to be reasonably accurate when measured in the initial first few loading sequences; however, one should be aware of the potential for large differences both within and between sensors. The overall accuracy of the system is further hampered by inaccurate calibration, and poor hysteresis and creep properties. A dedicated calibration system is necessary to replace the current technique, which is not accurate. The large creep effect measured was due either to an alteration in the properties of the ink or plastic deformation of the polythene-base material, or a combination of these two factors.

Finally, accuracy may be further affected by a temperature drift in the sensors, and this requires proper evaluation. The F-Scan sensor does not yield repeatable measurements, and output is affected by cutting the sensor. It may therefore be unrealistic to compare clinical data from sensors of different sizes and periods of use. However, the nature of the relationship between the output force and the number of loading cycles was linear, suggesting that raw data could be converted if the number of steps per insole were known. Further work would be required to test sensors over a wider range of input forces over the range of modified sensor sizes. (Woodburn & Helliwell, 1996).

3.2 Pressure Profile Systems:

PPS's Foot Pressure Mapping System uses sensors to measure and analyze pressure distribution on a person's foot for research and product development applications.

The Foot Pressure Mapping System was designed for footwear or orthotic designers, researchers in gait analysis, diabetic foot complications, or other disciplines interested in the pressure distribution on the foot. The pressure sensor system can measure and analyze pressure distribution on between a person's foot and a shoe during any sort of stationary or ambulatory action in real-world conditions. PPS's Foot Pressure Mapping System captures and visualizes quantitative, sensitive pressure data in real time over a wireless interface for minimally-invasive measurements in real-world conditions. Flexible, sensitive sensor integrates easily with footwear and provides industry-leading, quantitative data with excellent repeatability and sensitivity.

The Foot Pressure Measurement System includes a pair of reversible sensors (Men Size 10) that can be used with either foot and a rechargeable electronics interface module with Bluetooth connectivity. The system connects to a computer and includes PPS's Chameleon image capture and analysis software. This industry-leading software is fully featured which means it can export replay, save test data, and perform analysis functions. Chameleon can also record and playback video with your data results for even greater insight and analysis.

3.2.1 Key system features and benefits:

- Highly sensitive and repeatable tactile sensors featuring 55 sensing elements to provide most sensitive and repeatable data available for accurate research and optimized product design.
- Flexible design integrates easily into footwear or existing insole material allowing data capture without artificially modifying the natural actions of the test subject.
- Compact wireless Bluetooth electronics provides simple and easy to use set up with minimal wires to encumber use.
- High performance capacitive sensing technology saves time and improves results by significantly reducing recalibration and repeated tests allowing developers to resolve problems and answer questions faster. Twice the repeatability, 5x better minimum pressure detection, and 50% better pressure sensing resolution compared to typical resistive tactile sensor technologies.
- Chameleon Visualization Software provides intuitive, easy to use, high-quality visualization, and easy access to data for analysis and export to other applications. The software is fully featured which means export, replay, save, and analysis functions are included with every system, unlike competitors who require a paid upgrade for these features. (Appendix A).

3.3 Trublu calibration device

All sensors of the pedar-x system are individually calibrated using constant air pressure.This procedure is computer-assisted and can be performed in a short time.

Calibration guarantees accurate and reproducible data. The calibration curves, one for each sensor can be checked by the user at any time. This method guarantees the accuracy of the absolute values measured, not only for the total force (dynamic body weight), but especially for the local load on each area of the foot. This allows the system to determine body weight (no need to be entered by the user!) and at the same time assess local pressure, which often proves to be the cause of disturbances.

Measurement is accurate and repeatable. The pedar-x system is delivered with calibrated measurement insoles. Calibration should be checked at least once a year.

The pedar-x is an accurate and reliable measurement system for monitoring local loads between the foot and the shoe. The system operates with a straight connection to the PC, but also via radio signal with its built-in Bluetooth telemetry system.

Pedar In addition, measurement data can be stored in built-in flash memory, to be downloaded to the computer at a later stage. It is also suitable to monitor loading through the ground reaction forces. For this purpose novel created the pedoport software, especially designed for long-term monitoring.

Due to its compact design and ergonomic shape, the pedar-x system can be used for many applications:

- The pedar-x system allows to measure local loading in real life situations during daily activities, such as while walking, running, climbing stairs, carrying loads or riding a bicycle. The pedar-x system connects to thin, elastic sensor insoles that cover the whole plantar surface of both feet, or to dorsal pads to measure the dorsal area of the foot.
- The pedar-x system can be synchronized with EMG and digital video sequences for motion analysis. The measurement can be triggered and controlled from the computer, via Bluetooth, or directly by the test person through switch control.

3.3.1 Pedar-x software:

Pedar-x software data acquisition software contains many helpful and user -friendly options for fast pressure data collection and analysis. Features of pedar individual sensor configuration online and offline modes synchronous digital video recording (up to 4 cameras) storage of pressure data and video as one combined file simultaneous display of 2D and 3D isobar display dynamic and frame by frame playback of the rollover process maximum pressure picture step selection force-time integrals comparison for pre/post difference picture averaged and individual gait lines ASCII output long-term load monitoring link with novel database link with pedoport –x software

Software pedar link with scientific novel analysis software synchronization with EMG and video based gait analysis systems (novel, 2008)

4 CHAPTER 4: PRACTICAL

4.1 Needs for Plantar Pressure Measurement

Plantar pressure distribution is commonly investigated by analyzing indicators such as peak values, pressure/time integrals, bi-dimensional maps of maximum or mean pressures under the foot sole. The analysis of this last parameter requires time-consuming and complex processing tools, and often leads to qualitative observations only. On the other hand, peak values are easily processed which only take into account instantaneous loading events. The shape of the peak pressure curve along the whole stance phase of gait, instead, might contain more information than instantaneous peak values, with reasonable processing complexity and time.

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 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. 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.

4.2 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:

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.

   In our model the sole of foot can be divided into 12 areas: heel (area 1–2), Midfoot (area 3–7), forefoot (area 8–10), and toe (area 11), as illustrated in Appendix B. These areas support most of the body weight and are adjusted by the body's balance; therefore, ideally the 12 sensors are necessary to cover most of the body weight changes based on the Appendix B.
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. (Razak, Zayegh, & Wahab, 2012)

4.3 Force Sensitive Resistors (FSRs):

4.3.1 Overview

FSRs are sensors that allow you to detect physical pressure, squeezing and weight. They are simple to use and low cost. This is a photo of an FSR, specifically the Interlink 402 model. The 1/2" diameter round part is the sensitive bit.

They have a number of things in common. First, they have a body consisting of an insulator and 2 conductors. In the case of the CUI sensor, this is a kapton strip with copper conductors, the same thing used for flexible circuit boards. For the remainder, they use a thin plastic with printed traces (usually Indium-Tin-Oxide (ITO) or silver ink). The next thing they have in common is a pair of electrodes. These can either be discs on either side of the FSR material, as shown on the FlexiForce FSR above, or with alternating traces on the same side, which the Interlink sensors use. The final piece is the FSR material itself, which is a resistive (Stephen R. Urry, 2005) polymer in most commercial sensors. A cross-sectional view of both of these styles is shown below.

The Interlink FSRs have a unique feature: their resistive polymer is attached with double sided tape on the edges (the glue/spacer shown in Figure 3). This means that the FSR material does not contact the electrodes when no force is applied, and therefore the resistance is infinite. This allows for easy contact/no-contact detection, and a consistent off-state.

It also lets you take the material off easily, if you want to make your own electrodes and custom FSRs. An exploded view of an Interlink FSR is shown in figure 8.

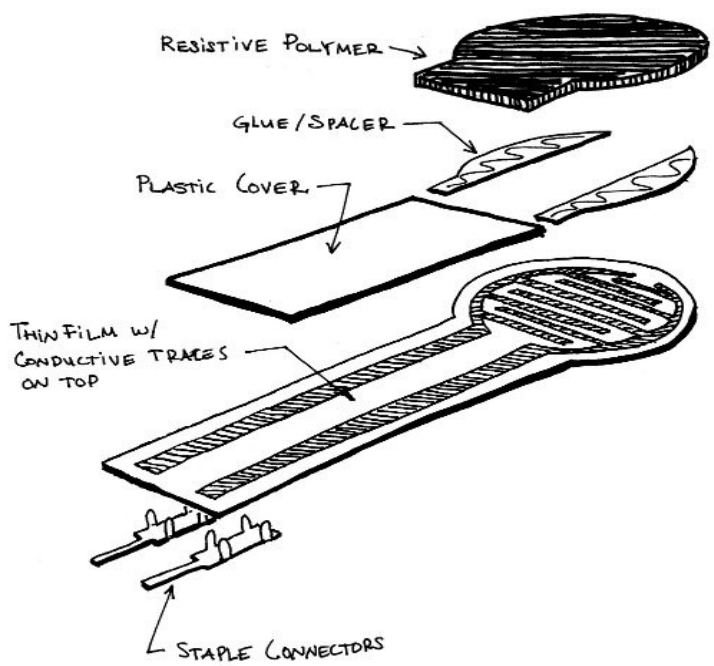

Figure 8 An exploded view of an Interlink FSR (Labs, 2015)

4.3.2 Some Basic Stats

These stats are specifically for the Interlink 402, but nearly all FSRs will be similar. Checking the datasheet will always illuminate any differences.

- Size: 1/2" (12.5mm) diameter active area by 0.02" thick (Interlink does have some that are as large as 1.5"x1.5")
- Price $7.00 from the Adafruit shop (http://adafru.it/166)
- Resistance range: Infinite/open circuit (no pressure), 100KΩ (light pressure) to 200Ω (max. pressure)
- Force range: 0 to 20 lb. (0 to 100 Newtons) applied evenly over the 0.125 sq in surface area
- Power supply: Any Uses less than 1mA of current (depends on any pullup/down resistors used and supply voltage).

Modern FSRs use a resistive polymer to obtain the same effect, but because of the small size of the "granules" in the polymer, they achieve a much more uniform resistance change with pressure. You can build your own FSR from conductive foam. The type that integrated circuits get shipped in for anti-static protection. A piece of this foam is shown below, and you can see all of the voids in the foam when it isn't compressed. If you place an electrode on either side (or two on one side), you can make the resistance drop by compressing all the voids out of the foam. With the foam shown below, the resistance went from infinite with no pressure, to 100kohms when pressed very hard.

FSRs are just resistors, so they are easy to work into circuits, and sometimes don't require any support circuitry. They are also relatively inexpensive and readily available, even Digikey has started carrying the Interlink FSRs. But, unfortunately, that is where the pro's end. The main drawback to FSRs is a result of its central component – the

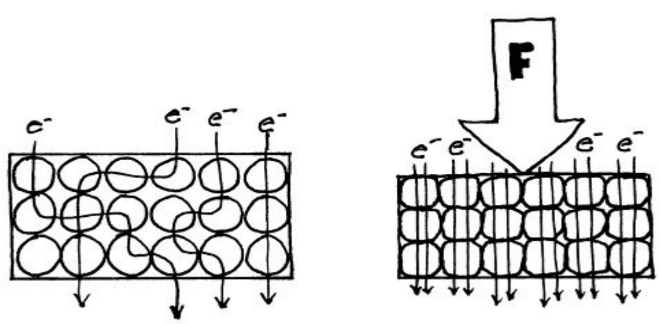

Figure 9 Force effect on fsr (Labs, 2015)

spongy resistive material in the middle. Just like a sponge, it takes a while to re-inflate after it has been compressed. And worse yet, this re-inflation time is a function of how long and how hard you pressed on it. After you release, the FSR value will come back to 95% of its initial value almost instantly, and then drift that final 5% over the next 10 seconds.

The inner material is also very sensitive to how it is pressed. It has a non-linear pressure response which varies with time, temperature, humidity, and even between parts of the same production batch. This makes the FSR a poor choice where accuracy and repeatability are a concern, especially across many units. Fortunately, a lot of musical applications have a human in the feedback loop who is able to just press harder or softer to get the desired effect, making this inaccuracy of less concern.

Finally, FSRs can also be very fragile. They are made of thin, laminated plastics, and are frequently placed under high forces. This usually results in them coming apart if they are not mounted correctly. Despite these drawbacks, with careful mounting, the FSR can be a very useful tool in creating expressive interfaces.

An FSR can easily replace almost any resistor in your circuit and give you instant external control. The resistance varies from several megohms with no pressure, down to a few hundred ohms under very heavy pressure. This is particularly useful for audio circuits, as you often want to modify a frequency or amplitude over large ranges.

If you want to create a control voltage with an FSR, or send its signal to the ADC on a microcontroller, there are a couple of options. The first is shown on the left of Figure 7 below. This is a standard voltage-divider configuration, with the FSR acting as one of the resistors. You can place the FSR on the top of the divider if you want the voltage to increase with pressure, or at the bottom if you want the voltage to decrease, which will

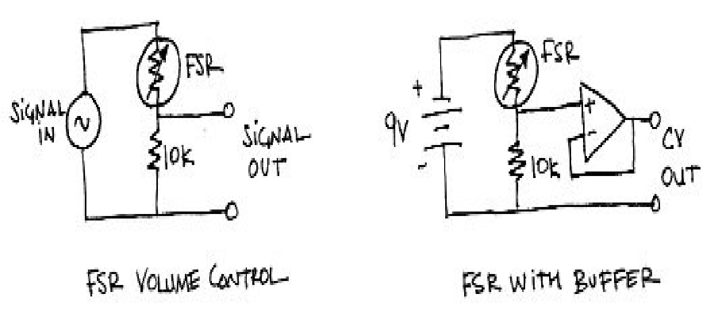

Figure 10 parts connected to FSR (Labs, 2015) keep the FSR output consistent and buffer the signal for driving smaller loads. You can also put gain in this op-amp if you want to increase the output swing of the FSR signal.

One of the characteristics of an FSR is that its resistance does not change linearly with applied force. The resistance will tend to drop quickly at first, and then more slowly as most of the spaces within the FSR material become compressed. This can be advantageous if you want to cover a large range of force values, as it essentially compresses the range, but it also makes the circuit very sensitive to the initial light touches on the FSR. To compensate for this, and linearize the FSR output, the circuit in Figure 8 can be used. As with the voltage divider circuit, you can get either positive or negative voltage swings by tying the FSR to either the positive or negative voltage supply and gain can also be used to increase the FSRs effective range.

With any of these circuits, it's important to remember to keep the current low through the FSR. The more current you send through them, the more they heat up, and the more the resistance changes. With too much current, the FSR material can even be damaged. It's best to keep the current under 1mA.

Although FSRs are relatively easy to use in a circuit, they can be a bit tricky to attach to things, both mechanically and electrically. Most FSRs use metal staples which pierce the plastic film and crimp on to the electrical conductors printed on top. The problem with these staples, is that it can be difficult to solder to them without melting the plastic and hurting the electrical contact within. If you do solder to the contacts, be sure to have the wire you are soldering to pre-tinned, and only heat long enough to melt the solder and make a good joint. Other options for connecting an FSR include screw terminals or SIP sockets. These have the advantage of making sensor replacement quick and easy at the expense of a less robust connection. Most FSRs also use .1″ spacing, so you can easily press them into a protoboard as well.

4.3.3 Analog Voltage Reading Method:

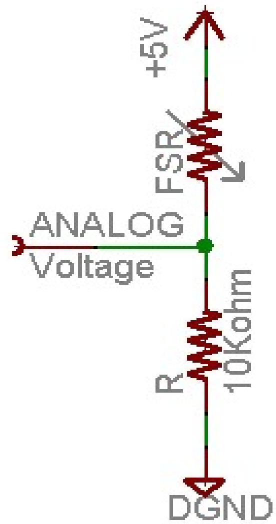

Figure 11: Voltage Reading (Fried, 2015)

The easiest way to measure a resistive sensor is to connect one end to Power and the other to a pull-down resistor to ground. Then the point between the fixed pull-down resistor and the variable FSR resistor is connected to the analog input of a microcontroller such as an Arduino. Note that our method takes the somewhat linear resistivity but does not provide linear voltage!

That's because the voltage equation is:

$$Vo = Vcc \left(R / (R + FSR) \right)$$

That is, the voltage is proportional to the inverse of the FSR resistance.

A good mechanical connection to your FSR is very important, and often over-looked. The mounting system should do two things – provide a stiff, flat surface for contact, and limit the amount of shear force on the sensor. One of the problems with FSRs is that they can give different readings under the same force conditions, depending upon how they are pushed. This is because the sensor averages out the pressure over the whole surface, and a poorly distributed load will apply a lot of pressure in one place, but not another. To counter this effect, always use a relatively stiff material on either side of the FSR, with a thin cushion between, in order distribute the load evenly.

Another drawback FSRs have, is that they easily split in half under sideways (shear) forces. They also only work under compression, and tear under tension. This is why you want to make sure that pressure can only go straight down onto the FSR (a delaminated FSR can be seen above). Depending upon how hard you expect to press on the sensor, this may not be an issue. But, if possible, have the actuator that presses against the sensor constrained to move only up and down. This can be accomplished with a small groove, or a cantilevered hinge. (Fried, 2015)

The main two manufacturers of FSR sensors are Interlink and FlexiForce. Interlink FSRs come in a wide range of shapes, are relatively inexpensive, and fairly robust. On the downside, they vary greatly between units, have a lot of resistance drift over time, and are a bit slow to respond. The FlexiForce sensors, on the other hand, tend to be more accurate and repeatable, but are more expensive and fragile.

4.4 Arduino Mega:

The Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila. (Appendix A).

The maximum length and width of the Mega 2560 PCB are 4 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

The Mega 2560 can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the GND and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may become unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive 20 mA as recommended operating condition and has an internal pull-up resistor (disconnected by default) of 20-50 k ohm. A maximum of 40mA is the value that must not be exceeded to avoid permanent damage to the microcontroller. (Massimo, 2005)

Refer to Appendix C for Code of Project Part I.

4.4.1 Mega specifications:

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
Length	101.52 mm
Width	53.3 mm
Weight	37 g

Table 1Mega properties (Massimo, 2005)

4.5 Matlab:

Millions of engineers and scientists worldwide use MATLAB to analyze and design the systems and products transforming our world. MATLAB is in automobile active safety systems, interplanetary spacecraft, health monitoring devices, smart power grids, and LTE cellular networks. It is used for machine learning, signal processing, image processing, computer vision, communications, computational finance, control design, robotics, and much more.

The MATLAB platform is optimized for solving engineering and scientific problems. The matrix-based MATLAB language is the world's most natural way to express computational mathematics. Built-in graphics make it easy to visualize and gain insights from data. A vast library of prebuilt toolboxes lets you get started right away with algorithms essential to your domain. The desktop environment invites experimentation, exploration, and discovery. These MATLAB tools and capabilities are all rigorously tested and designed to work together.

MATLAB helps you take your ideas beyond the desktop. You can run your analyses on larger data sets and scale up to clusters and clouds. MATLAB code can be integrated with other languages, enabling you to deploy algorithms and applications within web, enterprise, and production systems. (Mathwork, 2016)

4.5.1 Key Features

- High-level language for scientific and engineering computing
- Desktop environment tuned for iterative exploration, design, and problem-solving
- Graphics for visualizing data and tools for creating custom plots
- Apps for curve fitting, data classification, signal analysis, and many other domain-specific tasks
- Add-on toolboxes for a wide range of engineering and scientific applications
- Tools for building applications with custom user interfaces
- Interfaces to C/C++, Java, .NET, Python, SQL, Hadoop, and Microsoft Excel
- Royalty-free deployment options for sharing MATLAB programs with end users.

4.5.2 MATLAB Speaks Math

The matrix-based MATLAB language is the world's most natural way to express computational mathematics. Linear algebra in MATLAB looks like linear algebra in a textbook. This makes it straightforward to capture the mathematics behind your ideas, which means your code is easier to write, easier to read and understand, and easier to maintain.

You can trust the results of your computations. MATLAB, which has strong roots in the numerical analysis research community, is known for its impeccable numerics. A MathWorks team of 350 engineers continuously verifies quality by running millions of tests on the MATLAB code base every day. (Mathwork, 2016)

4.5.3 MATLAB Is Designed for Engineers and Scientists

MATLAB provides a desktop environment tuned for iterative engineering and scientific workflows. Integrated tools support simultaneous exploration of data and programs, letting you evaluate more ideas in less time.

- You can interactively preview, select, and preprocess the data you want to import.
- An extensive set of built-in math functions supports your engineering and scientific analysis.
- 2D and 3D plotting functions enable you to visualize and understand your data and communicate results.
- MATLAB apps allow you to perform common engineering tasks without having to program. Visualize how different algorithms work with your data, and iterate until you've got the results you want.
- The integrated editing and debugging tools let you quickly explore multiple options, refine your analysis, and iterate to an optimal solution.
- You can capture your work as sharable, interactive narratives.

Comprehensive, professional documentation written by engineers and scientists is always at your fingertips to keep you productive. Reliable, real-time technical support staff answers your questions quickly. And you can tap into the knowledge and experience of over 100,000 community members and MathWorks engineers on MATLAB Central, an open exchange for MATLAB and Simulink users.

MATLAB and add-on toolboxes are integrated with each other and designed to work together. They offer professionally developed, rigorously tested, field-hardened, and fully documented functionality specifically for scientific and engineering applications.

4.5.4 Arduino Support from MATLAB

With MATLAB® Support Package for Arduino® Hardware, you can use MATLAB to interactively communicate with an Arduino board over a USB cable. The package enables you to perform tasks such as:

- Acquire analog and digital sensor data from your Arduino board
- Control other devices with digital and PWM outputs
- Drive DC, servo, and stepper motors (also supports Adafruit Motor Shield)
- Access peripheral devices and sensors connected over I2C or SPI
- Build custom add-ons to interface with additional hardware and software libraries

Because MATLAB is a high level interpreted language, you can see results from I/O instructions immediately, without compiling. MATLAB includes thousands of built-in math, engineering, and plotting functions that you can use to quickly analyze and visualize data collected from your Arduino. (Mathwork, 2016)

5 CHAPTER 5: CONCLUSION

Barefoot load distribution characteristic differ from person to person due to a range of factors such as the variations in the walking speed, body weight, individual age, foot geometry and stride length. However, pacing velocity and the structural variations in the foot arch can have significant influences in changing the foot load distribution among people.

Foot function is assessed clinically by observation of the patient's gait and of the pattern of wear on the soles of the shoes. Callosities on the sole of the foot can also indicate areas of excessive loading. Instrumented forms of recording give an objective record from which certain aspects of foot function can be quantified.

To be suitable for routine clinical use the number of parameters measured should be kept to a minimum, and information should be displayed in a form which enables both minor and major changes in foot function to be readily assessed.

Flat feet are usually judged by a visually-based assessment of arch height during static standing, with some cut off point beyond which the foot is classified as flat (although arch height itself is a continuous variable). In addition, a functional test may be used, for example the heel raise test to determine if the arch reconstitutes. Flat feet may not necessarily exhibit any symptoms, either at the time of assessment or in the future. Most treatments intend to alleviate any symptoms and/or correct a symptomatic flatfoot to more closely resemble a neutral foot. Therefore there is a question as to whether current treatments actually target the cause of symptoms.

The distribution of load under the foot can be measured in one of two ways; either by the subject walking over a surface that is in some way pressure sensitive, or by introducing a thin transducer between the foot and the supporting surface.

The Proposed device is able to detect differences in pressure between different points and show the values on screen as first step for full pressure mapping system.

Depending on how much pressure is applied on inner-foot sensor a warning massage “Flat Feet Detected”.

6 CHAPTER 6: RESULTS AND FUTURE ASPECTS:

After buying and connecting all the parts, we chose a wooden plate to be the sensor holder, then we placed the sensors in the proposed points to achieve the best pressure mapping, for Project I stage the sensors were able to show readings change values between 0-1023, as the values closes to upper limit this means that some attention should be given to the point of interest.

For Project II, the Arduino-Mega chip was integrated successfully with MATLAB and the code which was written in MATLAB language was used to receive readings from Arduino, store them and display them on 3-D axis as force applied on test points.

FSRs can handle the weight of a person since according to (AL-Baghdadi, K, & D., 2015) the weight is almost divided equally on both feet, on each foot the contact area with the ground is relatively small compared to the surface area of the foot and each senor can withstand 100 N or 10 Kg.

The device was tested on 42 volunteers with different feet sizes, also, age, weight and height of each volunteers were recorded for further analysis.

The values recorded showed that, it is very important to carefully treat the sensors during installing on the wooden plate, sensors were very sensitive to how they were put under pressure and the number of surfaces separating them from the planter surface of the foot. Any change would affect the resolution of the measurement.

The project can be developed in order to become more suitable for clinical use:

- These improvements can be made in the plate and overall design, it can be developed into a wide pressure plate for subject to stand or walk over it.
- Increase number of used sensors to be able to capture pressure values from more points on the foot which will make a good and reliable device to be used in the field.
- Minimizing the circuitry and make the device mobile to provide best usage and cost efficiency.

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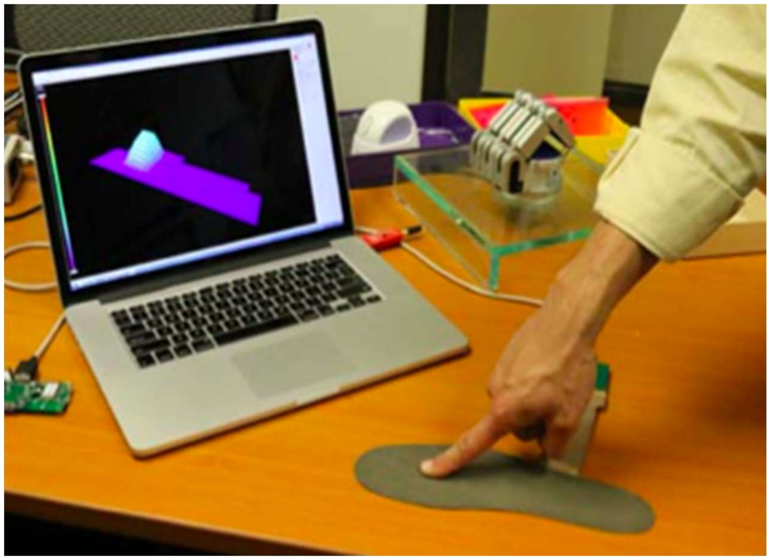
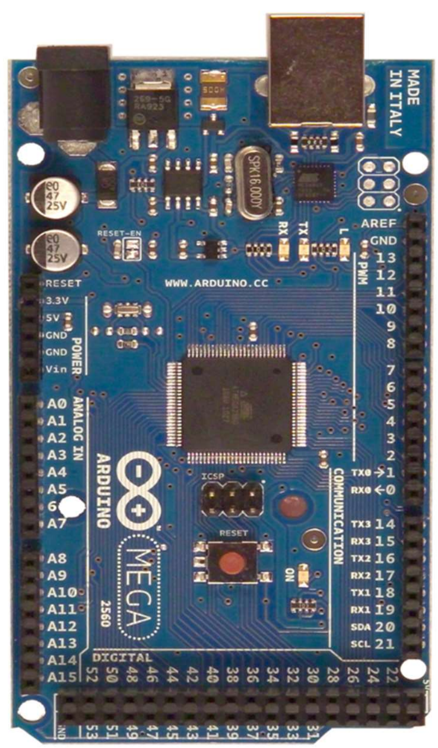
8 Appendices:

8.1 Appendix A:

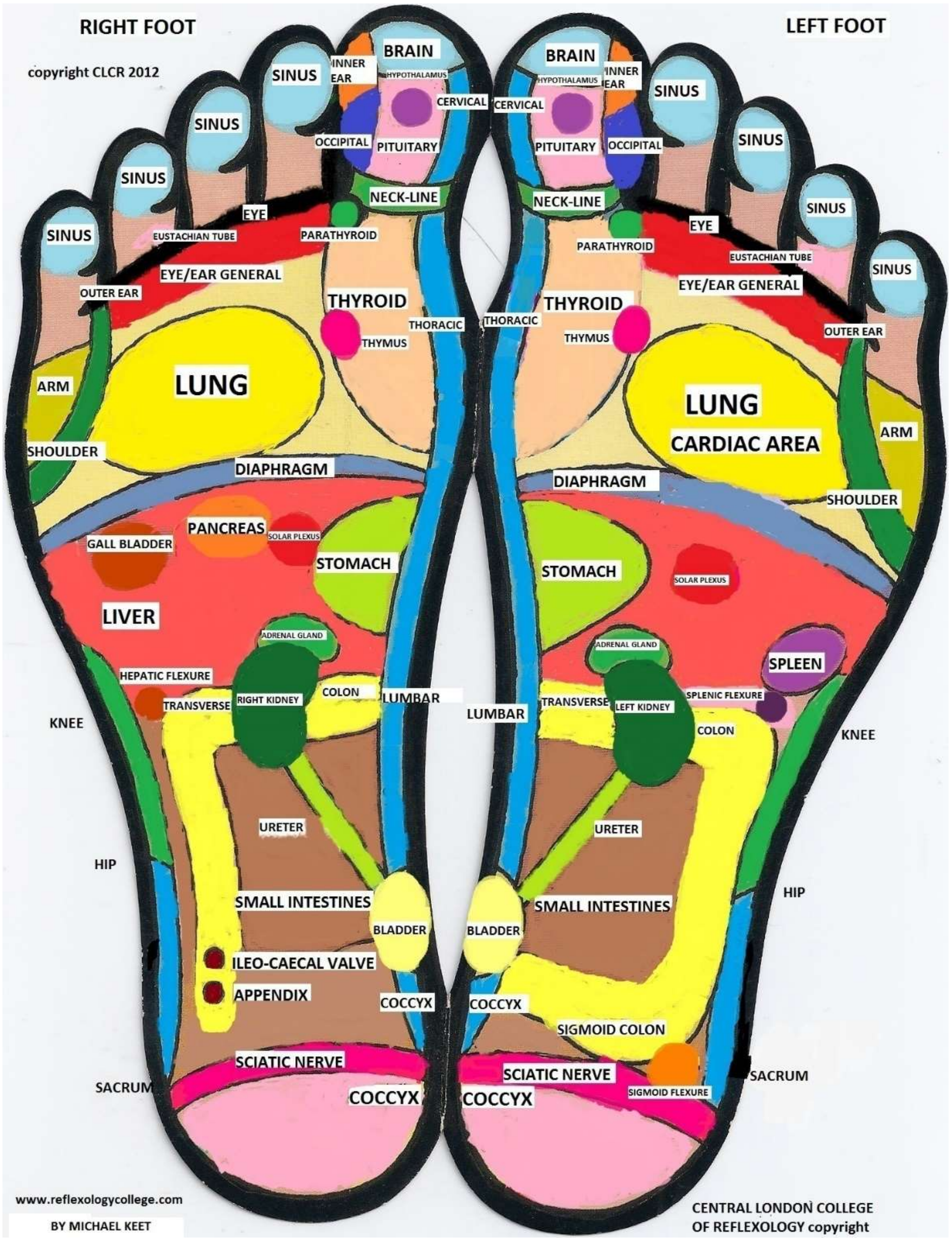
Chameleon Visualization Software:



Arduino Mega:

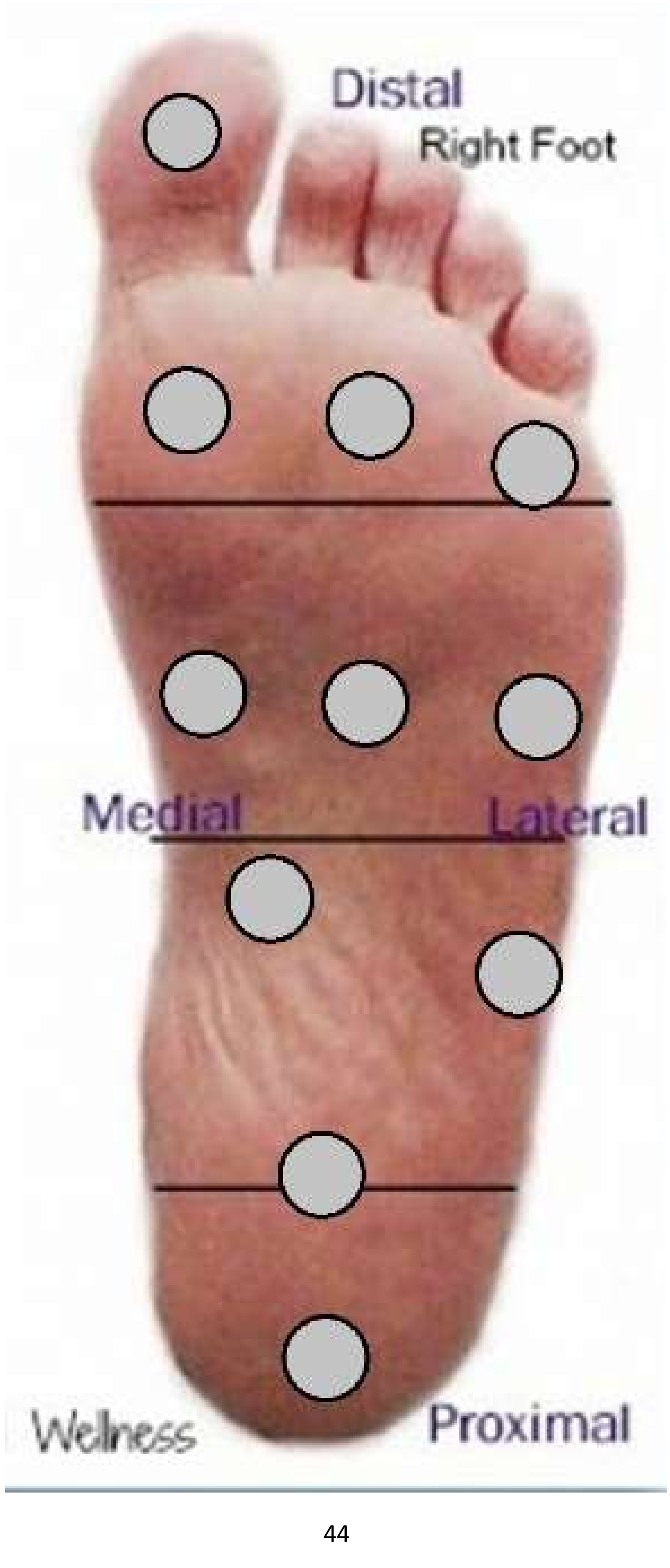


How is the feet connected to different parts of the body:



8.2 Appendix B

Sensors placement against planter surface of the right foot.



8.3 Appendix C

Arduino Program:

```
const int fsrin0 = A0; // FSR is connected to analog 0
const int fsrin1 = A2; // FSR is connected to analog 2
const int fsrin2 = A5; // FSR is connected to analog 5
const int fsrin3 = A7; // FSR is connected to analog 7
const int fsrin4 = A8; // FSR is connected to analog 8

int fsrrd0; // the analog reading from the FSR resistor dividers
int fsrrd1;
int fsrrd2;
int fsrrd3;
int fsrrd4;

void setup() {
  Serial.begin(9600);
  pinMode(fsrin0, INPUT); //identify pin mode
  pinMode(fsrin1, INPUT);
  pinMode(fsrin2, INPUT);
  pinMode(fsrin3, INPUT);
  pinMode(fsrin4, INPUT);

}

void loop() {
  fsrrd0=analogRead(fsrin0);
  fsrrd1=analogRead(fsrin1);
  fsrrd2=analogRead(fsrin2);
  fsrrd3=analogRead(fsrin3);
  fsrrd4=analogRead(fsrin4);
```

```
  Serial.print("Big Toe reading = ");
  Serial.println(fsrrd0);
  Serial.print("Small Toe reading = ");
  Serial.println(fsrrd1);
  Serial.print("Inner foot reading = ");
  Serial.println(fsrrd2);
        if (fsrrd2 != 0){Serial.println ("FLAT FEET DETECTED");delay(100);}
        //notification of flat foot
  Serial.print("Outer foot reading = ");
  Serial.println(fsrrd3);
  Serial.print("Heal reading = ");
  Serial.println(fsrrd4);
  delay(1000);
}
```

Matlab Code:

```
set(handles.t1,'string','Reading');
age=str2double(get(handles.ag,'String'));
wght=str2double(get(handles.wht,'String'));
tall=str2double(get(handles.tal,'String'));
rng=get(handles.rngg,'String');
set(handles.t1,'string','Reading');
ard=arduino('com3');
for i=0:11
configureAnalogPin(ard,i,'input');     //Prepare Pins
end
for k=0:0.5:2
   anr1=readVoltage(ard,2);            //Analog value read
   anr2=readVoltage(ard,3);
   anr3=readVoltage(ard,4);
   anr4=readVoltage(ard,5);
```

```
    anr5=readVoltage(ard,6);
    anr6=readVoltage(ard,7);
    anr7=readVoltage(ard,8);
    anr8=readVoltage(ard,9);
    anr9=readVoltage(ard,10);
    anr10=readVoltage(ard,11);
end
anrall=[anr1,anr2,anr3,anr4,anr5,anr6,anr7,anr8,anr9,anr10];
fsrvlt=mapp(anrall);                // Change values to mVolts
m=length(fsrvlt);
fsrForceall=zeros(1,11);
set(handles.t1,'string','Loading Data');
for j=1:m        //Changing voltage to force
    fsrR=(((5000-fsrvlt(j))*1000)/fsrvlt(j));
fsrC=(1000000/fsrR);
if fsrC<=1000
   fsrForceall(j)=fsrC/80;
else
   fsrForceall(j)=((fsrC-1000)/30);
end
end
xlswrite('test.xls',[age,wght,tall,fsrForceall],'NEU',rng);       //Store result
set(handles.t1,'string','Ready');
pause(2);
fsrFplot=zeros(19,9);
fsrFplot(3,3)=fsrForceall(10);fsrFplot(6,3)=fsrForceall(9);fsrFplot(6,5)=fsrForceall(8)
;fsrFplot(6,7)=fsrForceall(7);fsrFplot(9,3)=fsrForceall(6);fsrFplot(9,7)=fsrForceall(5);
fsrFplot(12,4)=fsrForceall(4);fsrFplot(12,7)=fsrForceall(3);fsrFplot(15,5)=fsrForceall
(2);fsrFplot(18,5)=fsrForceall(1);      //Reflect sensors' positions
bb=1:9;          // X-axis
tt=1:19;          // Y-axis
```

```
[b,t]=meshgrid(bb,tt);
        axes(handles.ax1);          // Prepare the Arises
        hold on
        title(handles.ax1,'Pressure Map');
        zlabel(handles.ax1,'Force');
surf(t,b,fsrFplot)      // Show results
```