Development of Planter Foot Pressure Distribution System Using Flexi Force Sensors

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Abstract: Diabetes brings with it neurovascular complications, which results in development of high pressure areas. Patients with diabetic polyneuropathy often lose pain and temperature sensations in their feet, resulting in inadequate information about pressure under the feet, during walking or standing. This may cause injury in the feet; at times accidentally, painless trauma develops and results in ulceration. Repetitive injury may also produce bone changes, causing the foot to become deformed. It is thus very important to locate such areas using pressure distribution measurement system. A detailed study of the pressure distribution on the sole of the foot in static position is carried out. In this paper the low cost planter foot pressure system is developed to measure foot pressures in normal subjects and diabetic patients. These pressure profiles i.e. pressure concentrations can assist in writing proper orthotic prescriptions. Pressure profile of 37 diabetic and 33 normal subjects is analyzed. The initial results indicate pressures in range of 50 to 400 KPa for normal subject, higher pressures i.e. above 600 KPa at metatarsal heads for diabetic patients. Copyright © 2009 IFSA.

Keywords: Diabetic neuropathy, Flexi force sensors, Pathological Gait

1. Introduction

Feet provide stability support while standing, walking and running. The foot has five main functions, it is the base support for the body, it can adapt to uneven ground, it acts as a shock absorber for the body during gate, it provides leverage for propulsion, and it absorbs transverse leg rotation. Loss of any one of these functions can be detrimental to the patient, and is often noticed in patients with diabetes.
The load distribution process at foot to ground is still the subject of advance research. The abnormal pressure gives rise to injuries at various parts of the foot leading to ulceration and if not taken care of, may cause gangrene of the foot and may require amputation of the gangrenous foot. This puts major burden on health care system. In case of diabetic patients, the problem of uneven foot pressure is more serious and leads to ulceration. As per world health organization (WHO) diabetic population in India is expected to reach 85 million by year 2020 [1]. Foot ulcers leads to majority (85%) of lower-extremity amputations in patients with diabetes. Foot ulceration develops in approximately 15% of diabetic patients. Prevention of ulceration has therefore emerged as a major goal in reducing the number of amputations and overall morbidity in these patients and lowering health costs related to treatment of diabetic foot complications. Foot pressure measurements and planter ulceration have been extensively [14] researched in insensitive foot.

The traditional orthotic insole (by taking ink impression) is not sufficient to correct the orthotic problems like misalignments and stability. Foot orthosis is used to alter foot biomechanics and associated dysfunction [7]. Planter foot pressure studies, in patients with diabetic neuropathy indicated relationship between excessive pressure and ulceration [8].

The Pedopowergraph is developed and patented [1], it measures planter pressure distribution instead of peak values. Camera based system [3] performs a unique and novel analysis of human foot movement. This information can be used to drive various interfaces, devices or displays, such as video games, virtual walkway displays and interactive dance floors. Rapid foot pressure measurement system [5] with a body weight spring scale and an image-based foot/ground contact pattern identification scanning mechanism is developed Scaphoid or longitudinal arch pads are frequently prescribed pedorthics for foot and ankle rehabilitation [9]. Appropriate color intensities are used to indicate different pressure distribution of foot [4].

In this paper a low cost planter foot pressure system is described. This system is used to collect data from 33 normal subject and 37 diabetic patients. The initial results are given in the preceding sections.

Factors influencing the pressure on the foot are shape of foot, arch of foot, supporting muscles of foot and shoe structure and interface betweenfoot and shoe. It is clear from looking at these factors that first three factors are ‘not modifiable’. The remaining are modifiable and underlines the importance of numerous innovations in the design and construction of foot wear to enhance the foot’s ability to withstand high pressure. In a normal foot the center of pressure progresses from planter surfaces of heel to midfoot. It goes from midfoot to forefoot. From fore foot it deviates medially onto the planter surface of great toe.

Diseases affecting foot and importance of foot pressure measurements.

The diseases affecting the foot are Diabetes Mellitus, Rheumatoid Arthritis and Leprosy.

Diabetes is Heterogeneous group of disorders characterized by a state of chronic hyperglycemias, resulting from diversity of etiologies environmental and genetic, acting jointly. Complications of diabetes such as Diabetic neuropathy (nerves) and Peripheral vascular disease affect the lower limb is known as diabetic foot. Diabetic foot characterized by abnormal foot biomechanics Diabetes Causes Disordered sensations from muscles and joints (proprioception). This disordered proprioception causes abnormal weight bearing while walking and subsequent formation of callus or ulceration.

Rheumatoid arthritis (RA) - It is a chronic inflammatory autoimmune joint disease with a multisystem involvement. The joint involvement is characterized by pain, swelling, tenderness and painful limitation of movements. It is typically symmetric polyarthritis. ‘Morning stiffness’ of the joints is characteristic and pain in RA is caused due to ‘sinovitis’ (inflammation of sinovium). This leads to
dislocation of metatarso phalangeal joints. It results in clawing of toes causing pain. This in turn leads to abnormal pressure and ultimately to deformity so foot pressure measurement is important in this disease.

Leprosy (Hansen’s disease): It is a chronic infectious disease caused by Mycobacterium leprae. It affects skin, peripheral nerves, muscles and bones. Numbness in fingers and toes leads to injury, which in turn leads to infection. Infection causes ulceration. Fingers and toes may be lost ultimately. There is also weakness and wasting of muscles. Measuring foot pressure and providing adequate footwear is important for prevention, treatment and rehabilitation of such patients.

2. System Instrumentation

2.1. Sensor

Different types of pressure sensors; such as strain gage, piezoelectric force sensor, optical force sensors and FSR are available. Strain gage are used in robotic applications. Piezoelectric sensors are used in dynamic forces. Optical sensors are used to measure intensity of light [11]. The ultra thin flexi force sensors [6] are used in this scheme for measurement of the foot pressure. The flexi force sensors are made up of two layers of substrate (polyester/polyimide) film. On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive link. Model A201 is used of range (0-100 lbs) and active sensing area of 0.375" diameter.

Flexi force sensor act as force sensing resister in an electrical circuit. When the force sensor is unloaded, its resistance is very high (around 5 mega ohm) and when a force is applied to the sensor, its resistance decreases with respect to applied force. This sensor can be used to measure force above 100 lbs by applying driving voltage and reducing feedback resistance. Sensitivity of sensor can be changed according to requirement of the system.

2.2. Characterization of Sensor

The selection of sensor and its characterization is the most important aspect of system design. The sensor is characterized on Universal Testing Machine (UTM) and is tested for 0-100 N i.e. 0-1000 kPa by applying force in steps of 10 N and constant speed of 0.1 mm/min. The characterization graph is shown in Fig. 1.

![Characterization of Flexi force sensor](chart.png)
Placement of sensor to measure the foot pressure distribution eight areas [10] is suggested. These eight areas are heel, metatarsal head 1, metatarsal head (all high pressure area) metatarsal head 5, toe and arch1 (all medium pressure areas), fing, arch2 (low pressure areas). We have identified four locations to give optimized pressure distribution and complexity of sensing system. Fig. 2 shows the layout of the sensors placement in order to measure the pressure distribution of the foot.

![Fig. 2. Pressure areas of foot.](image)

The block schematic of the planter foot pressure measurement system is shown in Fig. 3. The sensor assembly is made by applying color to foot sole on identified locations. Flexi force sensors are placed on specified locations and carefully inserted into the rubber sole. All sensors are connected to excitation circuit through a connector. Signal conditioning circuit is designed to convert signals to appropriate voltage. A PIC microcontroller with inbuilt ADC is used for further processing and the output is displayed on LCD.

![Fig. 3. Block Diagram of the system.](image)

Using this system, the foot pressure measurement is carried out on ‘70’ subjects (‘33’ normal subject and ‘37’ diabetic patients). According to the height and weight of all the subjects, the bone mass density was recorded. All the subjects were of body mass index (BMI) ‘18’ to ‘25’ with fasting plasma glucose concentration ≥ ‘120’mg/dl. The diabetic patients with glycoselated hemoglobin (HBA1C) greater than ‘7’ were selected for test.
3 Experimental Results

Table 1 shows pressures at different locations in kPa of ‘5’ normal male subjects. The results show that pressure at heel and toe is higher than metatarsal heads.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Toe</th>
<th>MT1</th>
<th>MT2</th>
<th>Heel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>190</td>
<td>100</td>
<td>80</td>
<td>285</td>
</tr>
<tr>
<td>2</td>
<td>220</td>
<td>120</td>
<td>92</td>
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<td>4</td>
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<td>40</td>
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<td>192</td>
</tr>
<tr>
<td>5</td>
<td>250</td>
<td>40</td>
<td>90</td>
<td>270</td>
</tr>
<tr>
<td>Average</td>
<td>216.4</td>
<td>104</td>
<td>66.4</td>
<td>250.4</td>
</tr>
</tbody>
</table>

The pressure mapping graph for normal subject is shown in Fig. 4. The graph shows pressure mapping of normal subject with standard output obtained from sensor. The dark area represents standard output of flexi force and light area represents output pressures in terms of voltage (V).

The graph in Fig. 5 shows pressure mapping of diabetic subject with standard output obtained from sensor. The dark area represents standard output of flexi force and light area represents output pressures in terms of voltage (V). The graph clearly indicates that pressure at metatarsal heads is more for diabetics in comparison to the normal subjects.
4 Conclusions

Quantitative Planter foot pressure measurement system using flexi force sensors is developed. This system can be used to measure pressures at heel, MT1, MT2 and toe. The result shows the comparisons of the planter foot pressure distribution behavior between normal subject and diabetic patients. Diabetic patients have higher pressures at their metatarsal heads compared to normal subjects. This system can aid in deciding suitable foot wear for diabetic patients. The planter pressure values of normal subject selected areas lies between 50 to 400 KPa. It is envisaged that the said technique, developed and tested is effective biomechanical tool to diagnose various disorders related to foot.

References

[1]. Prof. Saurin R. Shah and Dr. K. M. Patil, Processing of foot pressure images and display of an advanced clinical parameter PR in Diabetic Neuropathy, in Proc. of the 9th International Conference on Rehabilitation Robotics, June 28 2005.


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