A MICROPROCESSOR-BASED DATA-ACQUISITION SYSTEM FOR MONITORING FOOT PRESSURES

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ABSTRACT

We have developed a portable, microprocessor-based data-acquisition system to measure the pressures between the foot and shoe from ambulatory subjects. We attached seven pressure sensors on the surface of each insole of a pair of extra-depth shoes. They were located under the center of the heel, the five metatarsal heads, and the big toe of each foot. This system continuously collects raw pressure data for 7 min at a 20-Hz sample frequency per channel. We then dump the data to an IBM PC for postprocessing and display.

INTRODUCTION

Patients with diabetic polyneuropathy often lose pain sensation in their feet. They receive inadequate information about pressures under the feet during walking or standing. Thus they can injure their feet accidentally without being aware of it. Painless trauma develops and results in ulceration. Infection frequently develops in these ulcers, which further may lead to gangrene and amputation [1].

With the advent of the Electrodynogram (EDG), physicians can quantify foot pressures at the interface of the foot and appropriate surfaces and make a diagnosis based on statistical data [2, 3]. To determine the role of pressures in causing damage to insensate diabetic feet, we built a portable, microprocessor-based data-acquisition system to monitor the pressure distribution under the bony prominences of the feet during normal walking in shoes. It consists of the Interlink pressure sensors, amplifiers, an analog-to-digital converter (ADC), a microprocessor, program and data memory, and an interface between the microprocessor and an IBM PC. We mounted the above components and batteries in a $20 \times 18 \times 7$ cm metal box. The subject carries the portable system in a backpack while he/she is walking. It can continuously collect data from 14 sensor channels for 7 min at a 20-Hz sample rate for each channel. The data are then transferred to the IBM PC through a parallel port for later analysis and display. The microprocessor-based data-acquisition system enables us to monitor the pressure distributions as a function of time.

DATA ACQUISITION, POSTPROCESSING, AND DISPLAY

We used resistive pressure sensors (Interlink Electronics, 535 E. Montecito St., Santa Barbara, CA 93105) 16 mm in diameter to measure foot pressures. We taped seven sensors on the surface of each insole of a pair of P. W. Minor Super X extra-depth shoes. They were located under the center of the heel, the five metatarsal heads, and the big toe of each foot since these bony prominences have higher pressures than other areas. We used the foot-print technique to locate the bony prominences. We calibrated all sensors before and after each test using a 440-N load cell as a reference. We fed the outputs from the sensor and the load cell into an IBM PC to generate a piece-wise linear lookup table. This compensated for the nonlinearity of the sensor.

The amplifiers yield outputs in the range of 0 to 3.5 V with the pressure in the range of 0 to 1.5 MPa. We used 14 of 16 channels of the ADC0816 integrated circuit to convert analog data to digital data. The amplitude resolution of the 8-bit ADC is 20 mV which results in 11-kPa pressure resolution with the pressure in the range of 500 to 700 kPa. We found that peak pressures at 20-Hz sample frequency were within 5% of those at 200-Hz sample frequency. Thus we chose 20 Hz as the sample frequency to increase recording time.

We use a HD64180 8-bit microprocessor which provides many on-chip functions to control data acquisition. It consumes 19 mW at a clock frequency of 6 MHz by providing a SLEEP mode and a SYSTEM STOP mode. We use an integrated Memory Management Unit (MMU) in the microprocessor to access a 120-kbyte physical space. A 3-V lithium battery provides back up for the RAMs. A memory-full indication circuit turns on a LED with a 5% duty cycle at 5 Hz when the memory is full.

We use two 8-bit parallel ports to transmit 120 kbyte of data from the microprocessor to the IBM PC. One port transmits 8-bit data. The other port, which has 4 input lines and 4 output lines, is used for handshaking signals between the two systems. It takes 60 s to transmit 120-kbytes of data to the IBM PC.

After transmitting data to the IBM PC, we translate the voltages into pressures by looking up prestored sensor calibration tables. We then display the recorded pressure versus time. We can display either one or multiple pressure channels and see time correlations between them. Figure 1 shows the pressure waveforms of seven sensors under the right foot when a subject walks normally.

We use six 1.5-V AA alkaline primary batteries as the power supply. To obtain a stable 5.0-V power supply, we use a LM340 voltage regulator. The regulator yields a stable output voltage as long as its input voltage is larger than 6.5 V. The portable system takes 30-mA current in the active mode. The 300-mAh capacity of the batteries allows the system to run continuously for 10 h.

TESTING RESULTS

We have tested a subject who has normal feet to determine peak pressures during walking. The subject walked for 7 min at a cadence of 60 steps/min. Figure 2 shows averaged peak

CH2566-8/88/0000--1599 $1.00

pressures for this normal subject. We found peak pressures that are consistent with those obtained by other researchers. Cavanagh and Michiyoshi found that the peak pressures could go up to 1000 kPa when the subject was wearing shoes [4]. Soames found peak pressures in the range of 600–900 kPa when the subject walked in shoes [5].

CONCLUSION

Our portable, microprocessor-based data-acquisition system for measuring foot pressures offers the advantage that it does not affect the subject's normal gait. Our results on a normal subject show consistency with other researchers. We plan to run tests on diabetic subjects and then compare their pressure data with those from normal subjects. We will try to discover the role of pressure in causing damage to the insensate diabetic foot. Then we will feed back the most important information to the patients through electrotactile stimulation to protect diabetic feet from tissue damage.

ACKNOWLEDGMENT

This investigation was supported by Contract Number 695-D75077 from the Rehabilitation Medicine Service, Veterans Administration Medical Center, Milwaukee, WI 53295.

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Locations	Right foot	Left foot
Center of heel	665	653
5th metatarsal	603	595
4th metatarsal	590	600
3rd metatarsal	610	617
2nd metatarsal	720	716
1st metatarsal	764	769
Great toe	595	600

Figure 2 Averaged peak pressures (kPa) for a normal subject.

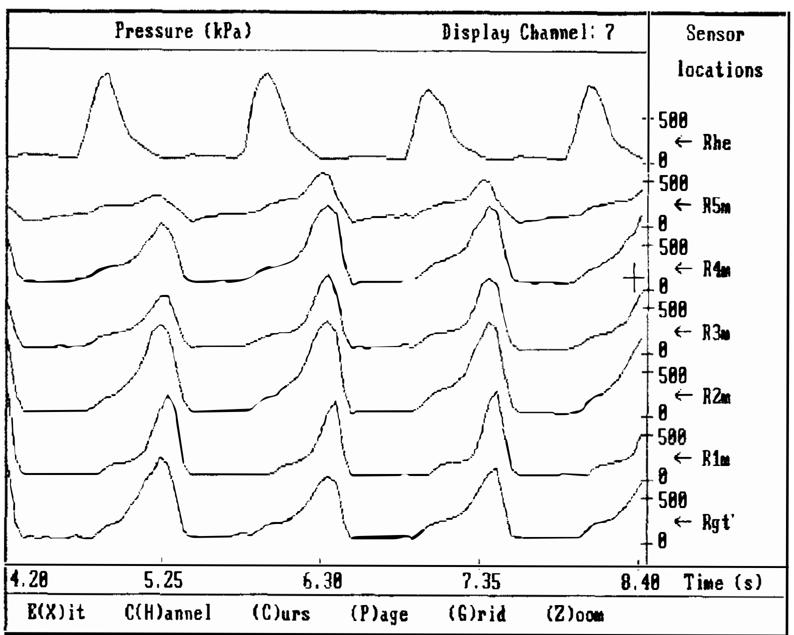

Figure 1 Pressures under seven right foot sites as a function of time.