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Low-Cost Gait Trainer

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ABSTRACT

Analysis of the foot is very important as the inside of the foot consists of valuable connections to every organ of the body. So every wrong posture of the foot affects or will affect that particular organ sooner or later. There are many people suffering from foot disorders which include changing the person's normal gait cycle (walking period). After getting affected with diseases like polio or temporary paralysis, their normal gait cycle changes and patients tend to walk in the wrong posture even after they are cured from the disease. Walking abnormally will cause serious health issues during the long run. This emphasizes on the need for monitoring the functioning of the foot and bringing back the normal gait cycle. "Low-cost gait trainer" is a handy product which can be used by patients and monitor their gait cycle. They can train their walking posture and monitor their improvements towards the normal gait cycle. The pressure distribution of the foot is measured using foil type strain gauges. The change in resistance of the strain gauges is converted to proportional voltages using a Wheatstone bridge. Instrumentation amplifiers are used as difference amplifiers as they are very precise, provide high gain and avoid impedance mismatch. The pressure points in the forefoot, the mid foot and the hind foot are then compared in the mid stance position.

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INTRODUCTION

About 37-69% of women wear high heels daily according to the survey (The Gallup Organization, Women's Attitudes and Usage of High Heel Shoes, 1986). Another study says that wearing high-heels modifies the normal gait kinetics and kinematics (Esenyel et al., 2003; Snow et al., 1992; Mandato and Nester, 1999; Voloshin and Loy, 1994; Kerrigan et al., 1998). Diseases like polio or temporary paralysis can also cause changes in the normal walking posture. Walking in a different posture is dangerous as it can create serious health issues. There are professionals who can train the patients and help them walk in the normal posture. However, after a period of training, the user can train himself at his home without visiting the hospital by using the gait trainer. This comforts the patients as well as the doctors.

The gait trainer is to be designed specifically for a unique person as the design specifications will differ based on the requirement of the user. The gait trainer is basically a footwear which has pressure sensors (strain gauges) in the inner sole. The pressure distribution on the foot is sensed by the sensors and the necessary signal conditioning is done. Using this data we can intimate if the person is walking in the correct posture or not and how correctly or wrongly he or she is walking.

Biomechanics Of The Feet:

A major part of foot bio mechanics involves the study of the GAIT CYCLE. One gait cycle is counted from that instant when the foot strikes the ground till the same foot strikes the ground again. A single walking cycle consists of 60% stance phase and 40% swing phase. At the beginning and end of each cycle, there is some time when both feet are flat on the ground. One particular phase, the MID-STANCE phase, is the one that is to be monitored primarily. This is because during this phase, the whole weight of the body is borne by the foot and this phase determines the proper gait cycle of a person.

Distribution Of Pressure And Weight:

The distribution of pressure for a normal mid stance phase is as follows. From the Fig 1, we can see the pressures denoted by letters A, B and C. Scientifically, the pressure in the region A and B should be equal to

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satisfy the condition for a normal gait cycle. The second condition is that the pressure in the region C should be less than either A or B (since they are found to be equal in the normal case).

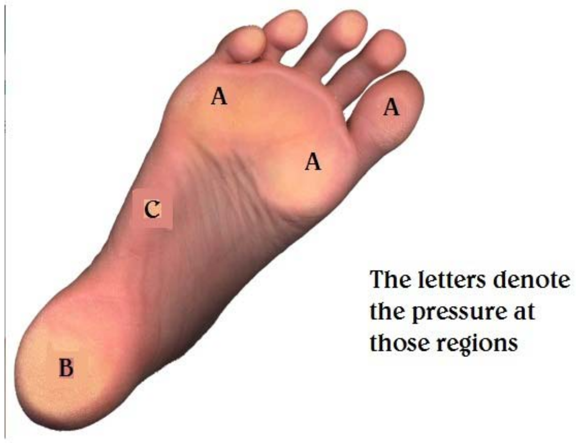

Fig. 1: Distribution of pressure on the foot

The distribution of weight is as follows. The front portion of the foot and the back portion of the foot bear equal weights. Whereas the side portion of the foot bears minimal weight (I.A.Kapandji**,** Physiology of Joints). For example, if the total weight put on the foot is 6 kg (for simplicity), 3 kg is distributed to the heel and 3 kg is distributed in the front as in 2 kg towards the toe region and 1 kg towards the small toe region. This also justifies the distribution of pressure discussed earlier.

Disorders:

The function of the foot is essentially mechanical. Given the appropriate neuromuscular control and aided by suitable footwear, the human foot is remarkable in the way it has adapted to function on such diverse terrain. The disorders in the foot are caused due to either improper footwear, disorders due to health issues or simply asking the foot to function in a way that it is not yet adapted to. Majority of the cases are due to improper shoes. The problem is that the design of shoes is focused to suit fashion rather than function.

A number of diseases affect the function of the foot by altering the physical posture. Polio and paralysis are two important diseases that affect the normal gait cycle largely. People affected by such diseases are given gait training which is often carried out in a kinesthetic studio. It is a specialized room where the floor consists of a mat embedded with pressure sensors on which the patient is allowed to walk. The physiotherapist then analyses the digital data and advises the patient accordingly. This sort of analysis is very important as the inner sole of the foot consists of valuable connections to every organ of the body. So every wrong posture of the foot affects or will affect that particular organ sooner or later. This emphasizes on the need for monitoring the function of the foot and bringing back the normal gait cycle.

Implementation:

The prototype is designed as shown in Figures 2 and 3. The pressures in the major parts of the foot have to be measured and analyzed. Strain gauges are used to sense the pressure. As we know, the output of the strain gauge is in terms of resistance. The strain gauges are fixed on the inner surface of the metallic strips as shown in Fig 3. When the pressure is applied, the strain gauges deform due the compression force on the top and thus due to the deformation of the metallic strips the change in resistance occurs. The change in resistance is measured using the Wheatstone bridge which converts the resistance to voltage. The output of the Wheatstone bridge will be of the order of mill volts and hence it requires amplification. We also have to find the exact voltage output without any impedance mismatches. Thus we make use of the instrumentation amplifiers here.

Fig. 2: Top View

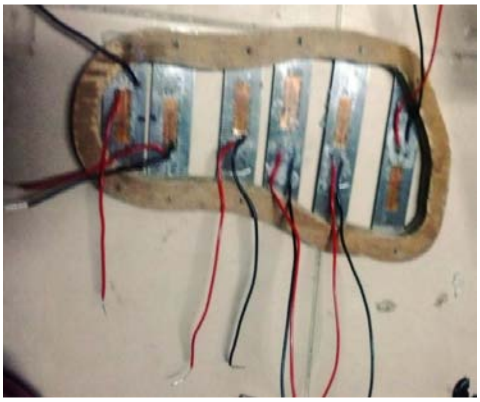

Fig. 3: Bottom View

The instrumentation amplifier (AD620AN) has three OP-AMPS within it and the impedance mismatch is greatly reduced. It will also act as a difference amplifier with the gain of up to 1000 precisely. Thus we need three instrumentation amplifiers to get the outputs of three Wheatstone bridges as shown in Fig 4. Now in order to compare the pressure applied on A, B & C positions, we use two more instrumentation amplifiers.

Comparing A & B - The output from A and B is given to an AD620AN and the output from this instrumentation amplifier is used to determine the correctness of the posture i.e. if the output (A-B) is positive, then the posture is correct else it is wrong and the user will be prompted about the wrong posture. Similarly, the circuit works for A & C also.

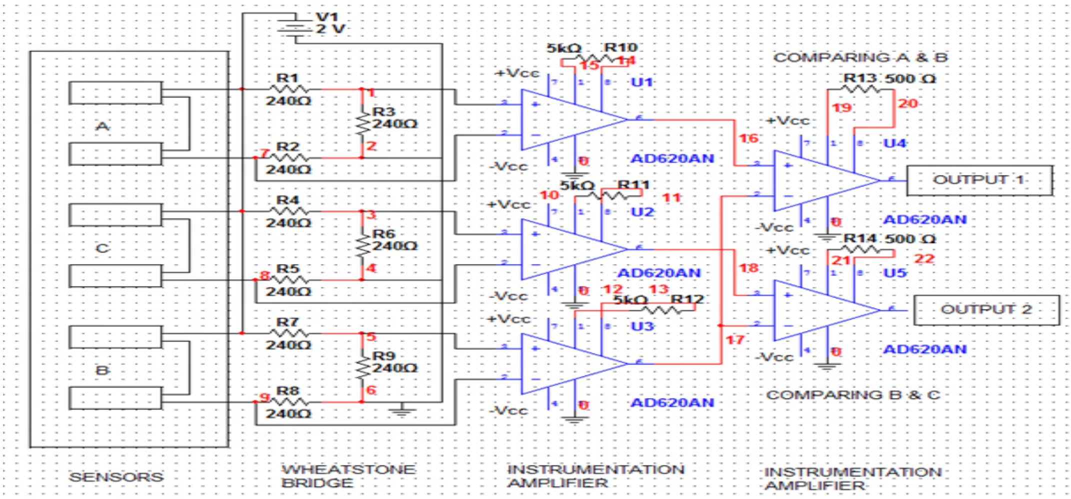

Fig. 4: Circuit diagram

Results:

Fig. 5: Experimental setup

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Voltage In Normal Position:

When the foot is in the mid stance position, the voltage output is 0.06V. The voltage from the difference amplifier after A and the voltage from the difference amplifier after B are found to be equal which shows that the pressure in the regions A & B is equal. This indicates the normal posture.

Fig. 6: Normal Posture

Voltage From Forefoot Region:

When a disordered person with their foot affected such that the forefoot is stressed most, the output is found to be negative. Fig 7 demonstrates this posture. In this case, the user will have to increase the pressure given on the hind foot which will balance the negative voltage and hence bring back the normal position.

Fig. 7: Pressure concentrated in the forefoot region

Voltage From Midfoot Region:

When a disordered person with their foot affected such that the mid foot is stressed most, the output is found to be of an average around 2.06V. Fig 8 demonstrates this posture. In this case, the user will have to balance the pressure on the fore and hind foot to hence bring back the normal position. This type of pressure distribution is usually found with people who are developing their flatfoots. People who tend to stand for long periods develop flatfoots.

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Fig. 8: Pressure concentrated in the mid foot region

Voltage From Hindfoot Region:

When a disordered person with their foot affected such that the hind foot is stressed most, the output is found to be highly positive. Fig 9 demonstrates this posture. In this case, the user will have to increase the pressure put on the forefoot which will balance the positive voltage and hence bring back the normal position.

Fig. 9: Pressure concentrated in hind foot region

Thus, from the above observations, the results can be tabulated as in Table 1 and 2.

Table 1: Readings for the normal posture

Wheatstone Bridge			Instrumentation Amplifier Output			Difference Amplifier Output	
Forefoot	Midfoot	Hindfoot	Forefoot	Midfoot	Hindfoot	A-B	A-C
25mV	24mV	25mV	2.51V	2.40V	2.51V	0V	0.11V

Table 2: Comparing different postures

Position	A-B	A-C
Normal	0.06V	0.11V
Forefoot	-0.62V	-
Midfoot	-	2.09V
Hindfoot	2.66V	-

Conclusion:

From the results we conclude that the voltage differs across the range -0.62V to 2.66V. To be specific, when the voltage is negative, the forefoot is stressed. Similarly, when the voltage is in the high positive region (around 2.66V), the hind foot is stressed. Finally, when the voltage is around 2V, the mid foot is stressed. These observations lead to a conclusion that the foot is in the normal posture only when the voltage is at 0V.

The prototype of this gait trainer was developed by using a simple wooden frame, low cost force sensors (strain gauges) and the results were shown to the user using a microcontroller. The sensors were placed on metallic strips and were arranged in the front, the middle and the back part of the footwear.

The pressure on the sensors gave the corresponding output as a change in resistance. This change in resistance is converted to proportional voltage using a Wheatstone bridge and fed to instrumentation amplifiers to amplify the voltage to the standard output levels i.e. 0 to 5 volts. After signal conditioning, the output is fed to the microcontroller and the algorithm is written in such a way that the results are user friendly i.e. using LEDs, buzzer and LCD screen. The advantage of this gait trainer is that is of low cost.

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