Biomechanical Mechanism for Energy Harvesting from Gait for Rehabilitation Purposes

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***Abstract*—In this paper, a new method for biomedical energy harvesting system equipped in footwear has been proposed, which scavenges power from human gait motion, especially from the hell strike, by means of a power transmission system and a special generator. Once the electricity is generated, the equipped shoe can use the electrical power for rehabilitation purpose such as thermal and cold therapy. Two effective, automatically controlled heating and cooling instruments embedded in the shoe's sole maintain proper temperature and humidity within the normal or user selected range. In addition an alternative cooling system which is less expensive but effective has been proposed. Another useful system is obstacle detecting system for helping people with low-level vision. Few useful accessories including alarm system, distance estimation system have been discussed. Finally the experimental results confirmed the effectiveness of our proposed method.**

***Index Terms*— Footwear, human-walking, power-generation, thermal-therapy, ultrasonic.**

I. Introduction

TODAY's modern life is filled with frequent use of portable electronic devices like smart mobile phones, Tablets PCs and PDAs, and there is a huge demand for more efficient portable power sources as an alternative for conventional batteries with limited storage capacity. This demand has been partially responded by the development of biomedical energy harvesting devices, which benefits from negative muscle work done at different phases of daily activities with minimal metabolic cost and high efficiency to generate enough electricity for portable devices. Walking as a routine activity has great potentials for biomedical energy harvesting, namely heel strikes, center of mass motion, shoulder and elbow joint motion during arm swings, and leg motions, i.e., ankle, knee, and hip motions. There are many researches for harvesting the human motion energy [1] especially the heel strike collision energy, which is estimated to be up to 2 W [2], and convert it to electricity . Piezo-electric materials [3-6], magnetic rotary device [7], electro active polymers (EAPs) [8, 9], deployed for harvesting heel strike energy.

The present research propose a new method for harvesting heel strike's collision energy into the electricity based on an electrical magnetic generator and its application in empowering equipped shoes with intelligent thermal and cold therapy apparatus for special rehabilitation purposes. Foot has a very important role on human health due to the long period that a person wears shoes. Hence the functionality of shoe designs is so critical.

In this research first of all previous studies in shoes specifications have been reviewed and then a new technological solution namely intelligence shoe has been proposed. Foot like any other part of the body demands distinct temperature range to function properly. Any increase or decrease in the temperature of foot above the normal range may become hazardous for normal foot operation, especially for people living in cold climate regions, moreover in some disease such as diabetic foot; the foot temperature plays a vital rule either as a rehabilitation factor or as a damage preventing factor.

There are many different approaches to harvest power from ambient sources, based on solar, thermal and mechanical energy [10, 11]. Many researches highlight the vibration-based energy harvesting [12].

II. Materials and Methods

Our goal was equipping a pair of shoe with different apparatus that can provide the required therapy and comfort. Therefore many different components have been developed. Section A presents designed components for harvesting heel strike collision's energy and turning it to electricity. Section B deals with the heat generation component, followed by section C and D that air conditioning systems have been discussed. Sections E to G are pertaining to different supplements proposed for this shoe including LCD accessories, alarm system and distance estimation systems respectively. Finally section H is pertaining obstacle detection..

A. Electrical power generation

Beneath the sole of the Intelligence Shoe, there is an apparatus including a plate which is attached to the heel by means of a spring and a tiny shaft, and there are two curved

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teethed metal parts on the other side of the plate which functions as two sets of gears in combination of two other gears on the shaft of a generator located in the shoe according to Fig.1a.

1) Pinion gear
2) Generator
3) Batteries
4) Shoe Sole
5) Sensitive to shock
6) Spring
7) Crow
8) Airbag (detailed magnified in Fig 1c)
9) Curved teethed metal parts

As a person walks during specific phases of gait, due to the gravity, inertia and ground reaction force, the plate will rotate and causes two curved metal parts rotation and the transition of torque to the second pair of the gears, which will finally lead to electric power generation of the generator. For instance in the heel strike, considering a subject with 85 kg and 185 cm, the ankle joint torque will reach approximately at 1.25 nm/Kg [13], that can be utilized by Intelligent Shoes to produce electricity. Many vivid benefits are provided using Intelligent Shoe, including:

1) Reduction in stress and pressure imposed on the lower extremities limb's joints and muscles.
2) Decrease in the total power demand of the gait using spring embedded in the Intelligent Shoe, and so on

B. HEAT GENERATION

Using an air filter, fresh air can circulate in the shoes. Coil applied in the shoes functions as a heater if any increase in the shoe temperature is needed. In the middle of the shoe sole, a cooler has been located under a sheet of an alloy with high heat conductivity ratio that can transfer the heat to the ground Fig1d.

Both the cooler and heater system will be monitored using a temperature sensor and feedback will be processed by AVR microprocessor while the user can adjust the desired temperature by a keypad and LCD monitor indicating the real temperature. Having adjusted by the user, AVR will precisely maintain the desired internal temperature of the shoes, by switching the cooler or the heater on and off. It is important to notice that one can use TEC with transitory switch instead of heater, thereby the cooler can acts as a heater and generate heat by changing the TEC input current direction.(Fig 1b and Fig1d)

As mentioned earlier the temperature control system of these shoes benefits from an AVR microcontroller programmed by "for example C+". As an example the scripts pertaining to the temperature sensor and LCD will follow

```
#include <mega32.h>
# include <stdio.h>          #include <math.h>
# asm
equ __w1_port=0x15 ;PORTC .
equ __w1_bit=0.#endasm
  #include <1wire.h>
  #include <ds18b20.h>
float temp;
  #asm
equ __lcd_port=0x1B ;PORTA.
#endasm
#include <lcd.h>
void main(void)
{
charlcd_array[16];
lcd_init(16);
lcd_clear();
ds18b20_init(0,25,37,DS18B20_12BIT_RES);
while (1)
{
do{
```

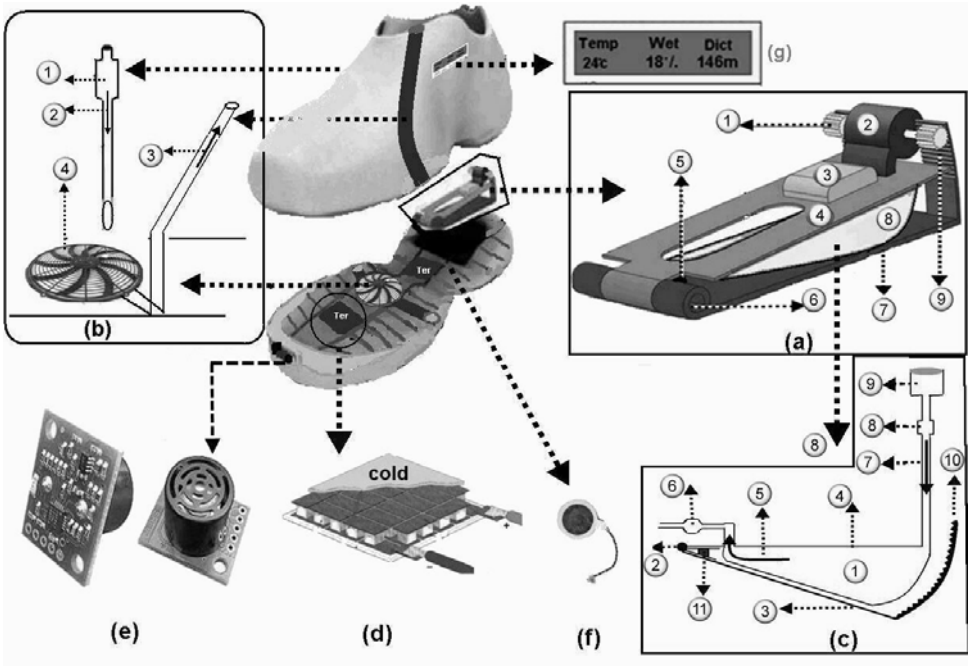

Fig. 1- Different component of intelligent shoe

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```
temp = ds18b20_temperature(0);
  }
  while (temp==-
9999)sprintf(lcd_array,"temp=%.2fC",temp);
  lcd_gotoxy(0,0);
  lcd_puts(lcd_array)
  }
  }
```

The AVR architecture pertaining to temperature monitoring system has been depicted in Fig. 2.

C. Air conditioning using fan

An automatic humidity controlling system benefits from a humidity sensor feedback to AVR controller to turn off/on a micro fan embedded in the shoe. As a result the air circulates and in this way it prevents from growth and expansion of skin fungus and bacteria. Fig 1b illustrates the component of this system.

1) Air filter
2) Air entrance tube
3) Air exit tube
4) Fan

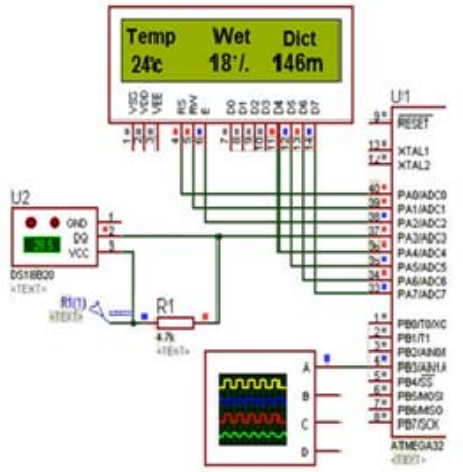

Fig. 2-AVR architecture for temperature monitoring system

D. Air conditioning using especial air bag

Instead of previous air conditioning systems, a different system can be used. An air bag under the sole of the foot will frequently be filled due to gait cycle and using one-way valve, then the trapped air in the air bag will flow into the shoe by tiny holes on it. This air circulation will refresh the skin and also prevent bacteria growth. Fig 1C is a schematic of the air bag system.

1) Air bag
2) Spring
3) Links
4) Shoe's sole
5) Air exit way
6) One-way valve no.1
7) Air entrance way
8) One-way valve no.2
9) Air filter
10) Curved teethed metal parts
11) Sensitive to sock

E. Accessories

Due to the electricity generation system numerous accessories can be used in these shoes. The three most important of them are LED light system, mobile battery charging apparatus and LCD monitor for temperature, moisture and distance indication. It is important to note that each of the features of intelligent shoes can be used independently (Fig 1g).

F. Alarm systems

Different alarm/ warning system can be added to the shoes according to the user characteristics, including sound/voice, light and impact alarms. For example, people who suffer from weakness in their peripheral neuron system in the foot area may use a voice alarm or an especial impact alarm system constituted of a small magnetic hammer under the toe that warns the wearer (Fig 1f).

G. Distance estimation

Force sensitive resistor sensor can be applied in the shoe to detect heel strike for each step. An AVR micro multiplies the number of pulses from senor to average length of cadence then after an exercise the person can be informed on a LCD screen about the approximate walking distance.

H. Obstacle detection system

The intelligent shoe has a warning system that prevents direct impact between foot's fingers and obstacle. Also ultrasonic sensors could inform the user about obstacles on its way through using mentioned alarm systems. This feature is very important for persons with low level vision because it enables them to walk easily and with more confidence. In Fig 1e the obstacle detection system has shown.

The Ultrasonic Transmitter is based on a 4011 quad 2-input NAND gate. Two gates namely IC1a and IC1b are used as a conventional CMOS Astable circuit whose oscillation frequency is set by capacitor C1, resistors R6 and R7, plus preset VR2, which adjusts the frequency.

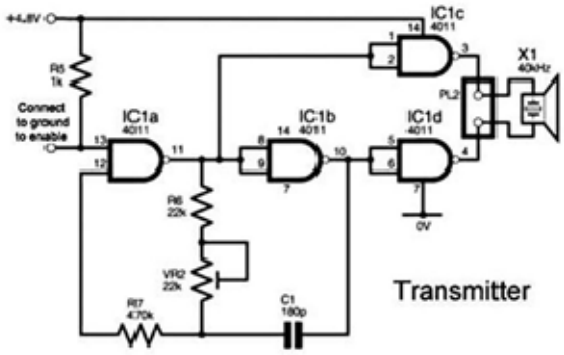

Fig. 3-Ultrasonic Transmitter circuit

Gates IC1c and IC1d buffer the outputs from IC1a and IC1b and drive the ultrasonic transmitter transducer, X1, in push-pull mode (Fig 3).

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In the receiver circuit, ultrasonic echo signal is received by transducer X2. It is first amplified by the two-stage amplifier based on transistors TR1 and TR2. The output from TR2 is rectified by diode D1 and smoothed by capacitor C4. The result is a voltage level at inverting terminal of IC2 which varies between 1·4V and 2·7V when X2 is not receiving ultrasound echoes, but falls to 1·2V when a strong enough echo is detected from an object. The rectified signal goes to op amp comparator IC2's inverting input, pin 2. The signal is compared with a reference voltage set by preset VR3, and applied to IC2's non-inverting input, pin 3. The output at IC2 pin 6 is low when there is no echo, but swings high when an obstacle is detected ahead of the system. The receiver circuit has shown in Fig 4.

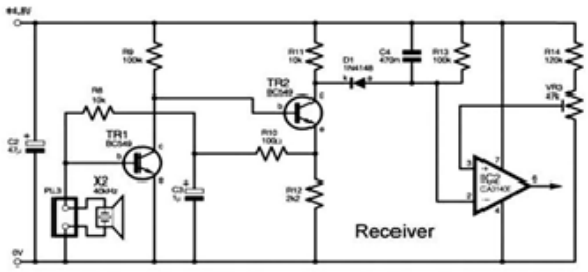

Fig. 4- Ultrasonic Receiver circuit

III. Results & Conclusion

A new biomedical energy harvesting system from human gait has been proposed and its application in empowering thermal and cold therapy instruments in footwear has been explained.

Firstly, a pair of shoe has been equipped with novel electrical power generation system which composed of torque transmission system and electricity generator. Secondly, embedded in the insole of the shoe, heater and cooler system was installed to control the inside shoe temperature and humidity by means of a close loop feedback controller system. As an alternative for air conditioning system special airbag has been introduced and finally an overview of useful accessories that can be attached on the shoe has been discussed. The main goal of this research was to combine and benefit from current technological solutions for maintaining proper conditions within a pair of shoe effectively.

Reducing the foot and ground contact forces by converting it to electricity could improve neurologic gait disorder. This shoe will prevent damages to the foot bones.

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