Realization of Low Cost Footwear Integrated Step-Counting Device for Health Monitoring System

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Abstract. In this paper, a piezoelectric sensor is used to sense the pressure generated when steps are taken. The output voltage generated by the piezoelectric sensor is passed through a cascade combination of two voltage comparators, (LM 358 AND 741), the output of which is HIGH(5V) when a piezoelectric sensor is pressed and the voltage across the sensor goes above the threshold. The output of the comparators is then fed to the counter circuit (implemented using 4026 IC), which counts the number of times the output is high/steps are taken. Finally, the output is exhibited on a 7-segment display common cathode display.

Keywords: Foot-Step Counter, Piezoelectric Sensor, IC CD4026.

1. Introduction

Nowadays, step counting is the new strategy to demystify the complex health dynamics and data for people. With the offset of various sensor-based technologies, various models that track the steps taken by a person in a particular time frame, have flooded the market. The buzz about step tracking isn’t new as researchers have incorporated this methodology in laboratories for research purposes on health sciences for long, since the 1960s, and after 2011 the technology was made accessible for the common mass, which they welcomed with open arms. Step counting now is not merely a tool for health consciousness, but also a milestone to boast off. The craze encircling the phenomena has reached an all-time high, with more and more people growing enthusiastic about knowing their body functionalities through numbers. Something that has proved to have a direct correlation with a lot of health factors like decreased risk of chronic and heart disease, decrement in blood pressure, reduction of bone density diseases, increases in muscle strength and endurance, decreased cases of many kinds of cancer, reduction of symptoms of elevation of mood and depression, etc. [1,2].

Tracking Heartbeats, pulse rates, etc. being an added advantage to the step counting, the mechanism has opened doors for people to judge and improve their health conditions in a more informed way. Currently, in the market there are three types of pedometers available [3,4,5], first one is the general Spring-levered pedometers [6], which works on the mechanism of a spring-suspended horizontal lever arm, having up and down movements according to your hip movement (vertical accelerations) when you run or walk. The electric circuit is opened and closed during movement and a step is counted with the contact of lever arms. The second kind is available in wristbands format and is more famous among people, available in different styles and looks, they are extremely easy to wear and perform the complex exercise as well. They use accelerometers [7] to count the steps and translates them into digital measurements, along with steps their ability to measure distance traveled, calories burnt, and sleep quality makes these watches and wristbands more trendy. The third one is simply, our very own smartphones [8]; they can measure the steps taken to a certain level of accuracy, but the user always has to carry the smartphone with them while jogging, walking or intense exercises which sometimes pose a burden for the user. One major problem with wristbands, pedometers, and smartphones that use accelerometer technology to count the steps is that
they measure jerks involved, like the movement of an arm, jerks while riding the motorbike or simply waving the hands, as steps, hence give increased no. of steps, resulting in wrong data.

Piezoelectric effect [9] is the ability of some specific materials in which on the application of mechanical stress an electric charge is generated in them. Between two plates of metal, a non-conductive and piezoelectric ceramic or crystal (piezoceramic material) is placed. When these materials are applied upon with mechanical stress, electric charges are discharged. History has been a witness to various proposals of piezoelectric energy harvesters, in our proposition we are using that energy in the step-counting mechanism. With the offset of innovation in the footwear industry, brands are constantly coming up with new product innovations to sustain themselves in the highly competitive market. This proposal to make a step counter integrated with the shoes using the piezoelectric technology aids the process further. When a person walks, pressure is generated at the sole of a shoe, where a piezoelectric sensor placed produces an emf; each electrical output generated in one cycle of pressure and relaxation is counted as one step and simultaneously displayed on a small screen placed. Figure 1 shows the basic architecture of the proposed model.

There are several benefits in this model when compared to the existing ones. Saves the person, the effort, to carry any additional accessory to just measure their steps as shoes are sufficient in this case, as carrying smartphones during workouts, exercises, proves to be a difficult task. Unlike existing ones, our proposed model doesn’t count steps due to the jerk, like waving of hand or riding a bicycle on a rough road, hence the count is exactly the same as actual steps taken by them, hence, enhancing the accuracy.

The current proposition costs us around Rs.100 in making, that too, when the components were bought individually. Through our research, we’ve found that if mass-manufactured, this device can be chalked out at a mere cost of Rs.40. Hence this super cheap mechanism pre-integrated within shoes by the manufacturers serves the dual purpose of monitoring health as well as providing the ease of free movement.

The organization of this paper is as follows: The main components of the proposed model are described in section 2. The explanation of the proposed circuit is there in section 3. The experiments to reach the final circuit are explained in section 4. In Section 5, the advantages of the proposed model are there and finally, in section 6 the conclusion is drawn.

2. Electronic Components

2.1. Piezoelectric Sensor
A piezoelectric sensor as shown in figure 2 has the working principle that it converts mechanical energy(stress) into electrical energy(charge). Inside the sensor, To transfer the force applied to the piezoelectric element a thin membrane is placed on a massive base. When pressure is applied on the thin membrane, the piezoelectric material is loaded and the voltages are generated. As large as the pressure applied, as greater will be the voltage.

The internal circuit of the piezoelectric sensor is given in figure 3. The capacitance (Ce) is inversely proportional to the elastic power of the material of the sensor. The resistance shown in figure (Ri) is the insulator resistance or internal resistance. The inertia of the sensor results in inductance. To make the sensor response properly, the leakage and load resistance must be large so that low frequencies can be preserved. We can also define the sensor as a pressure transducer for the electrical signals. The output voltage of the piezoelectric sensor for normally applied pressures is of order 0.5 volts.

2.2. IC LM 741 (Operational Amplifier)
The 741 Op-Amp IC [10] contains a general-purpose operational amplifier as shown in figure 4. Having a large value of gain this is generally used as a voltage amplifier and voltage comparator. It only has a single op-amp inside. Pin 1 is for offset (offset null). Inverting input is at Pin 2. Pin 3 is for non-inverting
input. Pin 4 is the negative terminal of IC(Ground). Pin 5 is offset pin (offset null). Pin 6 is the output of the op-amp. Pin 7 is the positive terminal (VCC). Pin 8 has no connection.

2.3. LM358 Dual Op-Amp IC:
LM358 [11] is a dual op-amp IC having two operational amplifiers with a common voltage supply (figure 5). We can consider it as one half of Quad op-amp IC LM324 which has a similar pattern of 4 op-amps having a common voltage supply [12,13]. We can vary the input differential voltage to the range equal to that of the voltage of the power supply. It has a very low default offset value ranging around 2mV.

Its pin configuration is as follows: The output of the comparator is Pin-1 and Pin-8. Inverting inputs are Pin-2 and Pin-6. Non-inverting inputs are Pin-3 and Pin-5. Pin-4 is the GND terminal. Pin-8 is the VCC+ terminal.

2.4. CD 4016 IC
The IC CD4026 [14] is an IC that can be directly used with a seven-segment display because it includes a counter as well as a seven-segment Driver (figure 6). A single IC of this kind can count from zero(0) to nine(9) on the Common-Cathode type of display and this counts increases with the clock pulse at its clock input[15,16]. Also, more than 1 digit is counted by the cascade connection of these ICs.

3. Proposed Circuit
The proposed Piezoelectric sensor-based footstep counter is shown in (figure 7). Two op-amps LM741 (U4) and LM358(U3: A) have been used to realize the amplification part of the circuit. The potentiometers (RV1 AND RV2) are used to provide a reference voltage to the op-amps. With CD4026
counter ICs (U1 and U2) for the counting part of the circuit. A 7-Segment common cathode display is used for the purpose of displaying the counts.

![Figure 4. IC LM 741](image)

![Figure 5. IC LM 358](image)

![Figure 6. IC CD 4026](image)

Figure 7. IC Hardware photo

The Proteus schematic of the proposed model is shown in (figure 8). When a person walks, every time he stamps his foot on the ground a voltage is generated between the plates of the piezoelectric sensor. According to Iswanto et al. [21] the output voltage of a piezoelectric sensor for foot-step pressure is of very low range and on testing, it comes to be around 0.4-0.5 Volts. IC CD 4026 operates properly on an input of 5-9 volts. On the inputs below 4.5 volts, it does not work properly, either
the count or the output is not proper, hence the 7-segment display does not correspond to any number. So, the output of the piezoelectric sensor must be amplified to a range well within the range of 5-9 volts and must not be less than 4.5 volts and hence to amplify the input voltage signal an Op-amp can be used as a comparator.

Figure 8. Schematic of the proposed circuit

3.1. Function of OP-AMP as a positive voltage comparator
The basic configuration of the op-amp functioning as a positive voltage comparator is as shown in figure 9. This configuration is also called a non-inverting comparator and makes the $V_{OUT}$ HIGH when $V_{IN}$ is greater than $V_{REF}$ otherwise the $V_{OUT}$ is LOW.

4. Experiment
The piezoelectric sensor was experimented with an individual connection to common op-amp LM 358 and then with an individual connection to common op-amp LM 741 but in both cases, the op-amps were not able to amplify such a low input even if their inverting terminal was set to 0 volts. The cascade combination of both IC’s was used as another test. The combination of having a piezoelectric sensor connected to 741 IC and LM 358 to the output of 741 IC gave accurate results.

4.1. Cascading of IC LM741 and LM358
The non-inverting end of IC LM 358 is connected to the piezoelectric sensor with its Inverting end connected to Potentiometer to set a reference voltage. It amplifies the input voltage to a certain level. The output is fed to the non-inverting end of IC LM 358 with its inverting end also connected to the ground. Hence the output of the final circuit produces the desired results as shown in figure 11.

5. Advantages
Various piezoelectric energy harvesters [17,18,19,9,21] have been proposed in the literature history. J.G. Rocha et al. [6] have proposed a Model of energy harvesting using piezoelectric sensors. The model of the footstep counter can be used as an add-on to these circuits for counting the footsteps.

5.1. Accuracy
Unlike all other models [6,1,2,22, 23], this model is not affected by any jerk except the jerk provided by a foot-step. Hence the accuracy of the proposed model is several notches higher than the other proposed models.
Also pertaining to the same reason, this can be used to accurately count no. of stairs climbed, works in
every condition, irrespective of environmental and surface circumstances, be it normal walking at varied speed or a walk on the treadmill.

5.2. Cost
The overall cost of the proposed model is very less as compared to all other models. It costs around 100Rs when all the components are bought individually. With the application of mass manufacturing schemes, the cost reduces down to somewhere around Rs. 40 to 70% less, which is an affordable deal.

5.3. Shoe Integration
This model can be infused into the sports shoes of the athletes which eliminate their need to have an extra module/device for pedometer data [5,20,24,25]. The initial threshold value can be set at the first non-inverting input to avoid any kind of errors due to the piezoelectric sensor. The counter can be increased to count as many no. of steps as required, by adding the CD4026 IC and seven-segment display in a similar fashion. The chances of error in this device zeroes down to an absolute minimum, as the piezo sensor, cannot be triggered without a threshold amount of pressure.

6. Conclusion
Our proposed model, piezoelectric step counter aims to deal with the problems relevant to the existing models, innovatively. An accurate count of steps is churned out by our proposed model which was a flaw of the existing ones. Movements other than that of steps taken, sometimes get included in the previous models, resulting in wrong step counts. Our model sieves out this loophole, it registers a step only when a real one is taken. Employing an exterior device to keep track of steps can seem cumbersome at times, especially, when a walk on a treadmill or gym is considered. Our model eliminates the burden of carrying an exterior device. Our approach aims to build the mechanism in shoes itself, also the whole process being super cheap, the implementation becomes butter smooth.
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