# Low-power Step Counting Paired with Electromagnetic Energy Harvesting for Wearables

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## ABSTRACT
Fitness related wearables have become ubiquitous in the recent past. Nevertheless, short battery life of these devices is still a pressing issue. Limited battery capacity in small form factor and power hungry continuous monitoring of accelerometer have been significant concerns in this regard. To address these issues we propose a novel low-power step counting solution based on an Electromagnetic energy harvesting mechanism. Extremely simple nature of the step counter removes the requirement of any step detection algorithm, thereby reducing the power consumption, while the energy harvester generates a portion of energy requirement prolonging the battery life.

## ACM Classification Keywords
C.5.3 Micrcomputers: portable devices; C.2.4 Distributed Systems: Distributed applications

## Author Keywords
Wearable Systems, Energy Harvesting, Step Counting

## INTRODUCTION
The number of smart wearable devices in possession of users is growing rapidly [6]. An incredible amount of computational power is compacted in smaller footprints, facilitating a variety of attractive services through these wearables such as precision health and fitness [6]. However, such applications have intensive power requirements. Frequent need to recharge multiple devices negatively impacts the quality of user experience and hence makes wearable device management increasingly difficult [6]. In this paper we propose a step counting methodology paired with Electromagnetic energy harvesting for better power efficiency. We choose Electromagnetic harvesting mechanism that rely on motion and impact of foot since it is proved to be generating considerably more power than other body energy harvesting mechanisms [7]. Moreover, we utilize the harvesting signal to estimate the step count, completely removing the requirement of accelerometer sampling which is shown to be energy intensive [2].

## BACKGROUND AND RELATED WORK
Mechanical vibrations have been investigated for motion based body energy harvesting through Electromagnetic and Piezoelectric methods. Piezoelectric material which are small in footprint harvest less energy in comparison to bulky Electromagnetic harvesters [3]. In [8], 4.3$mW$ is generated at a walking speed of $5km/h$ using an Electromagnetic harvester, on which our design is based.


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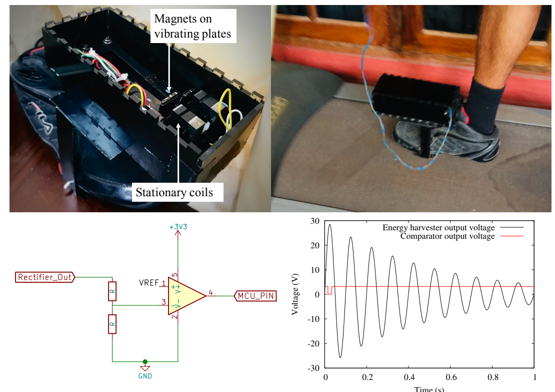
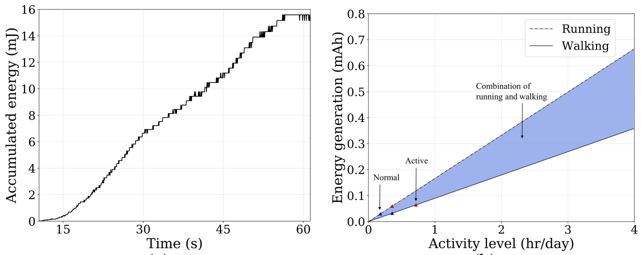


Figure 1. Top: Energy harvester design and experiment setup Bottom: Comparator and its input/output waveforms

Typically, step detection is done by processing accelerometer data which involves peak detection and adaptive thresholding. Adaptive-jerk-pace buffer (AJPB) [4] is a commonly used adaptive thresholding algorithm which we refer to as base algorithm hereafter, against which we compare our harvesting signal based method. Work in exploiting the potential of energy harvesting signal for other purposes is limited. An accuracy of 96% in step counting is achieved in [2], post-processing Piezoelectric energy harvester signal. In contrast, we propose a complete hardware solution, removing the requirement of energy consuming algorithms. We utilize periodic Electromagnetic harvesting signal and a properly tuned hardware comparator to detect steps and increase a counter in software.

## SYSTEM DESIGN
Our system design consists of three main components; energy harvester, energy converter and comparator circuit. Electromagnetic harvester generate energy using two sets of Neodymium magnets fixed on pivoted metal plates, which vibrate in close-proximity to inductor coils with laminated steel sheet cores as depicted in the top left figure of Fig.1. This is then mounted on a rigid bracket fixed to the sole of shoe, which transfers the impact force to initiate vibration. The converter circuit comprises of four Schottkey diodes, a filter and a buck-boost converter configured to output 3.3V. The decaying periodic output signal of the harvester is utilized by the comparator circuit for step detection, which shows a peak voltage oscillation at the impact generated upon a step. The comparator is tuned to flip its output state at this first peak of each period. Bottom row of Fig.1 shows the comparator circuit with its input output waveforms. High logic output




(a) (b)

Figure 2. (a) Energy accumulation (b) Energy generation with activity level

| Method | Power consumption ($mW$) | Number of instructions ($s^{-1}$) | Accuracy (%) |
|---|---|---|---|
| Base algorithm | – | 39,901,139 | 98.7 |
| Simplified algorithm | 41.6 | 5,473,264 | 98.7 |
| Harvester based method | 2.3 | 42 | 98.75 |

Table 1. Efficiency and accuracy of step counting methods

of the comparator goes low once every period, providing an interrupt that wakes the processor to count steps efficiently without running a step detection algorithm.

We implement a simplified algorithm based on AJPB for step counting using accelerometer, followed by the proposed step counting method using harvester signal. AJPB is developed for a step counting application that runs on a mobile phone, for which the accelerometer typically rests around the hip. But in our application scenario accelerometer is placed in shoe, which will give more distinctive patterns in accelerometer data. This facilitates the simplification of base algorithm to an Adaptive Magnitude Threshold (AMT),in which, magnitude acceleration is considered instead of jerk and pace data. Intention here is to reduce the number of instructions and memory requirement of the algorithm. We compare performance of proposed harvester based method against these algorithms.

## EVALUATION AND RESULTS

Performance of the proposed method is evaluated for its efficiency of power generation and step counting. Power generation for walking and running are separately measured in a treadmill based experiment as depicted in the top right figure of Fig.1. The converter circuit is connected to a $940\mu F$ super capacitor and accumulated energy in 1 minute time frame is evaluated at 100 steps for walking and 160 steps for running [1] as shown in Fig.2a. Average power generation is measured to be $0.499mW$ for running and $0.269mW$ for walking. Running will almost double the power generation compared to walking, as observed. Fig.2b shows energy generation at $3V$ for different activity levels of the user. Two lines corresponds to using the device while either running or walking. Each point in shaded area shows achievable energy generation for different activity levels. Marked points in red and blue shows considered running and walking activity levels recommended by WHO respectively for an active and a normal person [5].

Efficiency of step counting options is presented in Table 1. Power consumption is measured on an ARM Cortex M0+ processor which suits an actual deployment and number of instructions is evaluated on a STM32 Discovery evaluation platform, without affecting the comparison as both have ARM Cortex processors. A significant reduction in power consumption is observed for harvester based method. This is complemented by the reduction in number of instructions, in a scale of millions, which is a result of highly simplified nature of the proposed hardware solution rather than using step detection algorithms. It is worth noting that this remarkable efficiency is achieved without sacrificing the accuracy of step counting.

## DISCUSSION, CONCLUSION AND FUTURE WORK

Step counting using energy harvester signal proves to be highly efficient in terms of energy and number of clock cycles consumed. Instead of running step detection algorithms on harvester signal, we use a hardware based approach utilizing a comparator circuit. This method simplifies the algorithm to just incrementing a counter, thereby reducing the processing required. However, we need to tune the comparator to detect only a certain voltage threshold as a step. Since the impact force of foot with ground is different for each person, the maximum peak achieved in an oscillation differs. Therefore,some initial configuration setup for comparator has to be done for this to work on a new user.

In this paper, we proposed a simple but accurate step counting solution paired with an Electromagnetic energy harvester intended for fitness wearables. The proposed method results in highly satisfactory reduction in power consumption, although energy generation is not adequate. This is due to constraints in mechanical design. With availability of customizable components according to the requirement, we hope to design a miniature harvester with a better mechanical design that can be integrated to a wearable shoe without any practical concerns in the future. Furthermore, we aim to evaluate the validity of this proposed method with Piezoelectric harvesting technique which will avoid the bulky nature of the harvester.

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