Towards battery-free LPWAN wearables

Charalampos Orfanidis
KTH Royal Institute of Technology
Stockholm, Sweden
corf@kth.se

Konstantinos Dimitrakopoulos
Uppsala University
Uppsala, Sweden
kostas.droid@gmail.com

Xenofon Fafoutis
Technical University of Denmark
Copenhagen, Denmark
xefa@dtu.dk

Martin Jacobsson
KTH Royal Institute of Technology
Stockholm, Sweden
marjacob@kth.se

ABSTRACT

Low-Power Wide-Area Network (LPWAN) is an emerging technology in IoT which is utilized in use cases like smart cities and smart agriculture. LPWAN offers new features to wearable systems and therefore introduces new application scenarios. Long range communication is already used in application scenariosm such as elderly monitoring, localization, sportsm etc. We demonstrate how LPWAN wearables can operate by using energy-harvesting means and be battery-free. This preliminary study with real experiments illustrates how the LoRa radio is able to operate by a combination of solar and mechanical energy on a smart shoe prototype outdoors. The results indicate that the activity can influence the harvest rate.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**; *LPWAN*; Wearable; • **Energy generation and storage** → Renewable energy;

KEYWORDS

Wearable, Battery-free, LoRa, LPWAN

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1 INTRODUCTION

The increased popularity of Low-Power Wide-Area Networks (LPWAN) made them attractive to application scenarios like smart cities [1], smart agriculture [2] and many more. LPWANs offer long range communication with robustness and low energy consumption. For instance in [3], the authors evaluate the lifetime of LoRa [4], an emerging LPWAN and conclude that it can be from 1.37 to 4.6 years using a battery of 3.7 V and 2 A h, depending on the radio configuration but with possibility to extend lifetime with careful configuration. Therefore LPWANs have started attracting other application scenarios used in wearable systems.

Using LPWAN for wearable applications is an ongoing research topic. The drawback is that the traffic requirements might be increased in comparison with smart city or other more common LPWAN use cases. This will affect the lifetime of the node. A more frequent battery replacement in cases like healthcare monitoring or elderly monitoring might be impractical.

In this work, we demonstrate a battery-free smart-shoe wearable based on LoRa [4] by only using low-cost commercial hardware. The smart-shoe harvests mechanical and solar energy to provide it to the LoRa radio. We carry out a preliminary study of the introduced system evaluating it under different experimental scenarios. The smart-shoe wearable can be used in numerous application scenarios such as localization, sports, healthcare and more.

One more advantage of using such a system is that there is no infrastructure requirement. In most of the use cases, the common wearable systems communicate through Bluetooth to a mobile phone. Given the fact that there are already 7458 LoRa gateways in 140 different countries documented at the The Things Network (TTN) [5], it is very likely that the proposed system can use the already deployed LoRa gateways. In that sense wearables which were designed for sports or elderly individuals, might not require the presence of a mobile phone to function. In that case we have to mention that the security and privacy of these personal data are of high importance.

The contribution of this demonstration is to open a new path to long range communication wearables and explore if an LPWAN wearable can operate under energy-harvesting means by quantifying the performance metrics that will ensure a sustainable operation. Furthermore we investigate how different activities, may affect the harvesting performance.

2 SYSTEM DESIGN

The system we propose can be described in three main parts, the radio part, the harvester circuit and the harvesting modules. Figure 1 illustrates the schematics of the system. The energy harvester has two sources to harvest energy. The first comes from the solar panel. We use four solar panels in our prototype as Figure 2 illustrates, which are connected in series. Moreover we use six piezoelectric modules in total, divided in two groups, placed to the back and front part of the sole. The piezoelectric modules are connected to a step-down module to convert the voltage to the desired output. The

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harvester stores the energy by using 2 super-capacitors. Finally, the stored energy is driven to a LoRa module. In order to check if the stored energy is enough to transmit a packet, we read the current voltage level from Vbat pin.

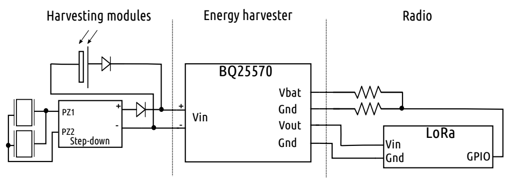

Figure 1: Schematics of the system

The system operation is based on a finite state machine approach and starts in the *initialization* state where the main configuration is established. Then it proceeds to the *measure* state which is reading the output voltage level from the capacitors and if it is above 3.5 V (3.3 V is the MCU minimum voltage input plus some power for transmitting a packet and operate through the state machine) it proceeds to the *transmission* state where the radio transmits a packet. If the energy level is lower than the threshold it goes to the *sleep* state for 4 sec and it goes again to the *measure* state when the time interval is passed. Table 1 lists the power consumption of the system states.

Sleep state	0.42 mW
Initialization/Measure state	1.18 mW
Transmission state 14 dBm	128 mW

Table 1: Feather 32u4 with LoRa. Power usage measured for the different states

One of the the goals of the system is to keep the cost low by using off-the-shelf hardware. To this end, we use a BQ25570 thermal/solar energy harvester with 2 super-capacitors with capacitance 10 F in total, for storing the harvested energy. We use an LTC3588-1 step-down module to convert the voltage coming from the piezoelectric elements from AC to DC. The piezoelectric elements are low cost acoustic discs with 27 mm diameter. The solar panel size is 114 mm × 36.8 mm from Powerfilm and the LoRa module is an Adafruit Feather 32u4 with semtech SX1276 using a 50 Ω sma RF antenna. For the prototype we used a New Balance commercial shoe which is depicted in Figure 2. The LoRa gateway is an iC880A-SPI concentrator board attached on a Raspberry Pi 3 which is connected to wifi and the TTN [5] cloud service.

3 PRELIMINARY RESULTS

We check how the harvest rate varies throughout different activities and under direct sunlight. To get the harvest rate we were moving at a certain pace and measuring the voltage with a multimeter. The pace was mandated by a metronome and we used 60, 120, 150 BPM (per foot) to imitate activities of slow walking, normal walking and jogging.

Figure 3 shows the time it takes to harvest 0.2 V, from 3.1 V to 3.3 V under direct sunlight, which can be described as the best case scenario. These experiments were repeated 3 times and we plot the

Figure 2: The smart-shoe prototype designed based on a regular shoe

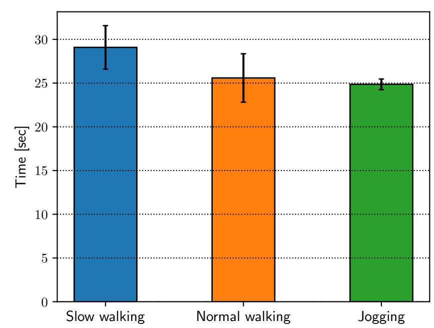

Figure 3: Energy harvest rates for different activities

mean values and the standard deviation with errorbars. It is clear that during jogging, the time to harvest the energy was less than during slow walk slowly and slightly less then during normal walk due to the piezoelectric elements.

With the presented harvest rates we can achieve the maximum throughput allowed by LoRaWAN regulations. Indeed, at 3.1 V and 3.3 V the capacitors hold 48.05 J and 54.45 J respectively (assuming 10 F capacitance). Hence, 6.4 J are harvested in 28 sec or less; this corresponds to a harvesting power of 228.6 mW. The consumed power at 1% duty cycle is less 5 mW. Thus, the proposed system is able to operate without any battery at the maximum duty cycle allowed by the regulations.

4 DEMO

We will demonstrate a hybrid energy-harvesting wearable prototype based on a LoRa radio that is able to operate without any battery outdoor under direct sunlight. We will also demonstrate preliminary results which outline the use-cases the proposed system is designed for.

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