Designing a General Purpose Development Platform for Energy-harvesting Applications

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ABSTRACT

Battery-less energy-harvesting systems have widened the landscape of Internet-of-Things (IoT) applications by taking computation to hard-to-reach places. Energy-harvesting sensors are perpetual, environment-friendly, cost-effective, and maintenance-free. Despite having such lucrative characteristics, battery-powered devices hold majority share of today's IoT market, since developing energy-harvesting applications require more expert knowledge, careful implementation, and rigorous debugging than applications with stable power. In this paper, we argue that development becomes easier, faster, efficient, and scalable with a standard, re-usable, general purpose platform that ensures the platform's versatility across various application with proper balance between abstraction and accessibility in hardware and software. Such platforms would provide flexibility across both hardware and software layers, at the same time, producing reliable performance. However, realizing this design point pose several research challenges that need to be identified and addressed. We identify the limitations in existing systems, articulate the challenges and provide guidelines for the community to work towards a general purpose platform that would enable new diversified battery-less applications in the future.

CCS CONCEPTS

• **Computer systems organization** → **Sensor networks**; **Embedded systems**.

KEYWORDS

Energy Harvesting Systems, Intermittent Computing, Development Platform

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1 INTRODUCTION

Devices that scavenge energy from environment and stores them momentarily in small capacitors has enabled zero-maintenance and life-long ubiquitous sensing [1, 2, 6]. From smart buildings to wearable health, from massive scale industry applications to academic research, such energy-harvesting devices have shown promising results in sensing, monitoring, and re-configuring, successfully replacing batteries and tethered power supplies. Looking back into the progress made in energy-harvesting systems over the last ten years, one can safely assume the trend will be only upward from now on.

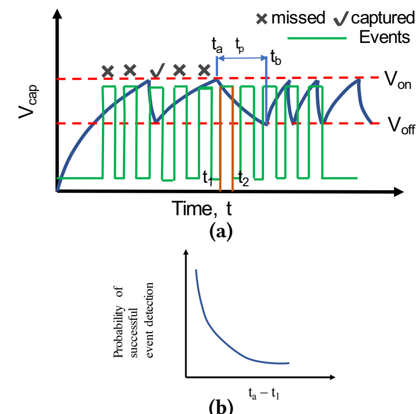

Figure 1: Uncertainty in successfully detecting an event in intermittently-powered systems. Intermittently-powered devices turn on once its capacitor reaches a minimum threshold and performs a routine task. Events that happen during recharging is missed compromising the resolution of the sensed data. (a) depicts a series of missed and captured events throughout capacitor life cycles. t_1, t_2 denote the start and end time of an event and t_p indicates the period of capacitor lifecycle. If energy availability and the event of interest does not coincide, the likelihood of detecting the event decreases as shown in (b).

However, developing applications without a stable power is more challenging than the ones with it. The energy-harvester's (e.g. light, kinetic, thermal, RFID) output power, optimum operating voltage varies depending on time, place, and the application's behaviour, which is difficult to characterize for all possible deployment scenarios. Without proper knowledge of the underlying energy dynamics of the system and how that impacts a sensor's working profile, developers end up designing systems that fail to achieve expected outcome. With unreliable power, programs are forced to restart in the middle of an execution, critical data are lost if not explicitly saved, interesting events are missed due to insufficient energy. All these factors make it difficult for an embedded developer to design hardwares and write codes for battery-free applications.

Analyzing the existing works in battery-less systems and from our own experience with developing energy-harvesting applications, we identify a polarizing gap between the extremities of two common design strategies. In one group of these design strategies [1, 3, 5, 9], systems are designed with a specific application

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