Energy harvesting devices (EHDs) are replacing battery-powered IoT devices due to their infinite lifespan and low power consumption. However, harnessing ambient energy is challenging due to its intermittent and unpredictable nature. To efficiently use resource-constrained EHDs, it is crucial to characterize their architecture and functionality, addressing hardware and software limitations. This thesis explores EHD limitations and proposes architectural solutions.

Fluctuations in ambient energy can lead to state loss in EHDs. Checkpointing is commonly employed to address this issue. We proposed a SW+HW approach that uses ambient energy forecasts for checkpointing decisions, achieving near-optimal performance. We also surveyed the existing checkpointing techniques and developed a recommendation system.

The limited memory (2–8 KB SRAM and 64KB FRAM) and computational capability are other significant limitations of an EHD. Additionally, EHD applications frequently deal with enormous amounts of streaming data. To effectively utilize existing memory, we propose two solutions.

The first solution leverages the tolerance for slight inaccuracies in many EHD applications. We propose an approximate computing-based method that provides quick answers with significantly lower memory consumption. We propose to use sketching algorithms and present a generic hardware architecture that can be instantiated with several sketching implementations that can outperform state-of-the-art software implementations in terms of energy and time.

In contrast, our second solution preserves data in a lossless yet compressed form by using compact data structures. They reduced applications' memory footprint by up to 3.5x without significantly increasing energy or time overheads. Additionally, we introduce a novel hardware template that can be used to realize a wide range of data structures frequently employed in EHD applications.

In distributed settings, EHDs periodically sense their surroundings and relay data to a distant sink node for snapshot creation. However, messages from different nodes do not reach the sink simultaneously due to network congestion and different node-distances from the sink. Furthermore, it is difficult to synchronize all the nodes because they have different duty cycles due to variable ambient energy. To achieve an effective sink snapshot, we propose a distributed algorithm in which nodes adapt their sensing periods based on physical positions, ambient energy profiles, and network dynamics.

In this thesis, we propose a systematic and holistic approach to address the drawbacks of EHDs operating in standalone and distributed modes. We provide a combination of hardware and software solutions that help create a fast, energy-efficient, memory-efficient, and reliable EHD system.