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Transiently Powered Computers

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Abstract

Demand for compact, easily deployable, energy-efficient computers has driven the development of general-purpose transiently powered computers (TPCs) that lack both batteries and wired power, operating exclusively on energy harvested from their surroundings.

TPCs' dependence solely on transient, harvested power offers several important design-time benefits. For example, omitting batteries saves board space and weight while obviating the need to make devices physically accessible for maintenance. However, transient power may provide an unpredictable supply of energy that makes operation difficult. A predictable energy supply is a key abstraction underlying most electronic designs. TPCs discard this abstraction in favor of opportunistic computation that takes advantage of available resources. A crucial question is how should a software-controlled computing device operate if it depends completely on external entities for power and other resources? The question poses challenges for computation, communication, storage, and other aspects of TPC design.

The main idea of this work is that software techniques can make energy harvesting a practicable form of power supply for electronic devices. Its overarching goal is to facilitate the design and operation of usable TPCs.

This thesis poses a set of challenges that are fundamental to TPCs, then pairs these challenges with approaches that use software techniques to address them. To address the challenge of computing steadily on harvested power, it describes Mementos, an energy-aware state-checkpointing system for TPCs. To address the dependence of opportunistic RF-harvesting TPCs on potentially untrustworthy RFID readers, it describes CCCP, a protocol and system for safely outsourcing data storage to RFID readers that may attempt to tamper with data. Additionally, it describes a simulator that facilitates experimentation with the TPC model, and a prototype computational RFID that implements the TPC model.

To show that TPCs can improve existing electronic devices, this thesis describes applications of TPCs to implantable medical devices (IMDs), a challenging design space in which some battery-constrained devices completely lack protection against radio-based attacks. TPCs can provide security and privacy benefits to IMDs by, for instance, cryptographically authenticating other devices that want to communicate with the IMD before allowing the IMD to use any of its battery power. This thesis describes a simplified IMD that lacks its own radio, saving precious battery energy and therefore size. The simplified IMD instead depends on an RFID-scale TPC for all of its communication functions.

TPCs are a natural area of exploration for future electronic design, given the parallel trends of energy harvesting and miniaturization. This work aims to establish and evaluate basic principles by which TPCs can operate,