Demo: Battery-free TinyML Made Easy with Riotee*

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ABSTRACT

This demo uses a machine-learning-based hot word detection application to showcase the capabilities of Riotee, an open-source and commercially available hardware-software platform for the battery-free Internet of Things. We describe the Riotee hardware consisting of a base module, a debug probe for easy firmware updates, and several expansion boards that enhance functionality without the need for custom-designed printed circuit boards (PCBs). The demo features the classification of live audio recordings using TinyML deep neural network inference aboard a Riotee device. The Riotee device transmits the classification results via Bluetooth Low Energy (BLE) to a smartphone given to visitors. Visitors can also observe how the Riotee software checkpoints and restores critical state in case of power failures via the visualization of logic analyzer traces.

CCS CONCEPTS

• **Hardware** → **Sensor devices and platforms**; • **Computer systems organization** → **Embedded software**.

KEYWORDS

Battery-free systems, intermittent computing, hardware and software platform, open source, embedded machine learning, TinyML

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1 INTRODUCTION

New programming abstractions [5], along with solutions for peripheral state retention [6] and wireless networking [2], are expanding the capabilities of battery-free devices. Most existing approaches either use development boards without energy harvesting or design custom battery-free hardware tailored to specific project needs. The few general-purpose platforms available today (e.g., [1, 4]) are suitable for prototyping but tend to compromise on size for flexibility and can be challenging for beginners to set up.

With the open-source and commercially available Riotee, we create a well-documented and unified platform for prototyping and real deployments [3]. The Riotee Board and its selection of stacking boards (Figure 1) simplify the creation of battery-free prototypes. The accompanying open-source software, easily installed with just a few clicks, supports intermittent computing and basic networking. After prototyping, the same module used on the Riotee Board can be soldered onto a custom PCB along with sensors and peripherals, enabling the development of compact, production-ready devices.

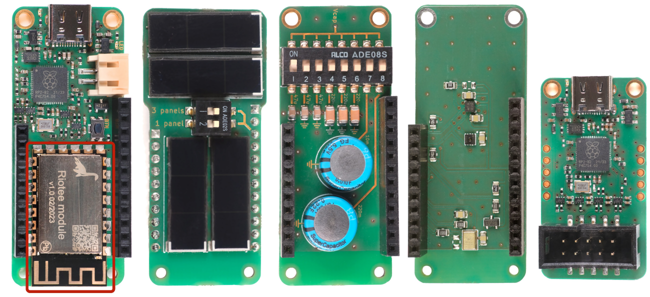

Figure 1: Riotee hardware consisting of stamp-sized reflow-solderable module, a user-friendly dev board, 3 expansion shields, and probe for in-circuit programming & debugging.

2 HARDWARE AND SOFTWARE

Riotee Module. The block diagram of the Riotee Module is shown in Figure 2. It includes a boost charger with maximum power point tracking, which transfers energy from an attached harvester to an on-board capacitor. Two comparators monitor the capacitor voltage against software-defined thresholds and alert the system of an impending power failure. The module is equipped with two fully programmable microcontrollers connected via a 4-wire SPI bus, both sharing access to the system's components: the Nordic Semiconductor nRF52833, which features a 64 MHz Cortex-M4 CPU with a floating point unit and a low-power 2.4 GHz wireless radio, and the TI MSP430FR5962, which has 128 kB of non-volatile FRAM to retain state during power failures. Application and networking code can run on the powerful nRF52 while the MSP430 handles non-volatile memory, or alternatively, the MSP430 can run application code while using the nRF52 as a wireless co-processor. When idling with timekeeping and capacitor voltage monitoring, the module consumes 4 µA. In deep-sleep mode, it draws less than 0.1 µA.

Riotee Probe. The Riotee Probe enables programming the device while preventing interference from leakage through the programming pins during battery-free operation. The probe is a programming dongle that connects to the Riotee Module via analog switches. During programming, the switches close to supply the module with a constant voltage. Once programming is complete, the connections are cut, allowing the device to operate using harvested energy.

*See https://riotee.nessie-circuits.de for hardware designs, code, and documentation.
†Work performed while at Networked Embedded Systems Lab, cfaed, TU Dresden.

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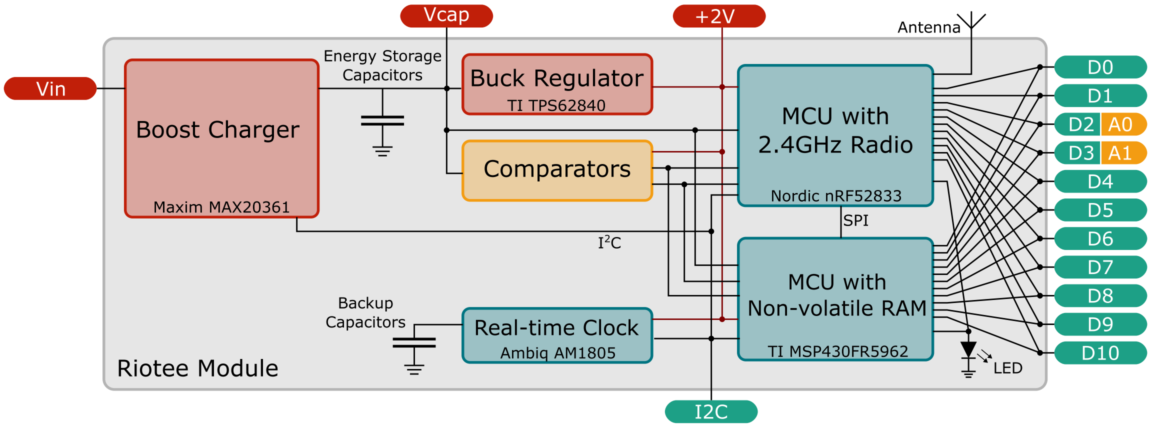

Figure 2: The Riotee module integrates energy harvesting, energy storage, power management, non-volatile memory, a powerful Cortex-M4 processor, and a 2.4 GHz BLE-compatible radio into a tiny module with the footprint of a stamp.

Riotee Board. The Riotee Board is a compact, user-friendly development board. It integrates the Riotee Module, the Riotee Probe circuitry, a push button, and an LED into a single PCB.

Expansion Shields. Three expansion shields enhance the capabilities of the Riotee Board. The Solar Shield adds four small solar panels for energy harvesting. The Capacitor Shield increases the on-board capacitance. The Sensor Shield features a microphone, a temperature sensor, a humidity sensor, and an accelerometer.

Battery-free Runtime. The open-source Riotee runtime executes user code as a FreeRTOS task on the nRF52. When the Riotee Module's comparator detects low capacitor voltage, a high-priority system task preempts the user task, triggering a context switch. FreeRTOS stores all registers on the user stack, and the system task transfers the stack, and global and static variables to the MSP430's non-volatile memory over SPI before entering low-power mode. Once the capacitor voltage exceeds a set threshold, the system resumes the user task and continues execution. Even after power interruptions, the application state is restored once energy returns.

3 DEMO SETUP

Visitors will see a Riotee Board outfitted with all three expansion shields along with a smartphone, a logic analyzer, and a laptop (see Figure 3). The Riotee device operates in low-power mode, listening to the Sensor Shield's microphone. When a sound is detected, the device wakes up and records a 1-second audio sample. After extracting features from the audio sample, the data is processed by a TinyML model that distinguishes between two predefined keywords: "yes" and "no." The classification result is transmitted to a smartphone via BLE, where an app displays the outcome.

Visitors will be invited to cover the solar panels with their hands to drain the capacitor and trigger a power failure. Visitors can observe the power failure on a live plot of the logic analyzer on the laptop. Once the panels are uncovered, the device automatically restores the application state from non-volatile memory. Visitors can then verify on the smartphone that the correct result is displayed after the inference completes, despite the power interruption.

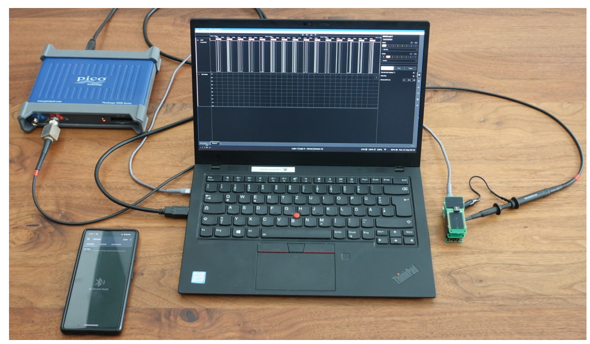

Figure 3: Our demo showcases machine-learning based hotword detection including checkpointing and networking.

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