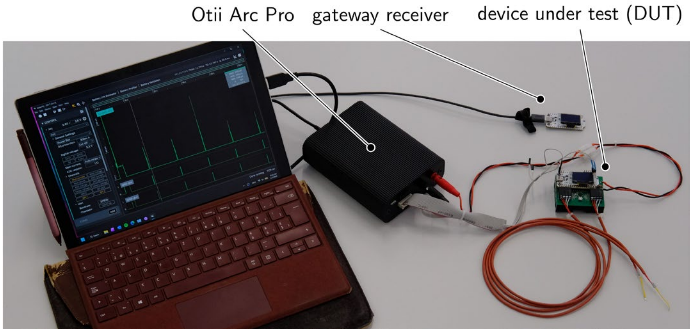
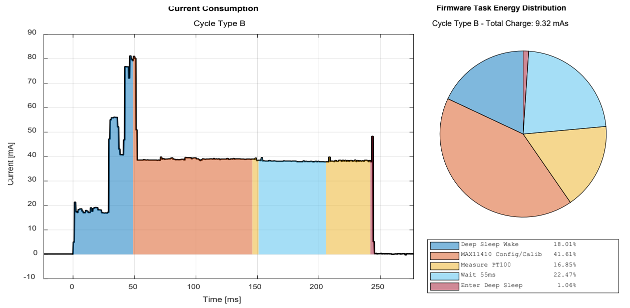
Master of Science in Engineering

Energy Consumption Optimization of a Battery-Powered Data Logger System



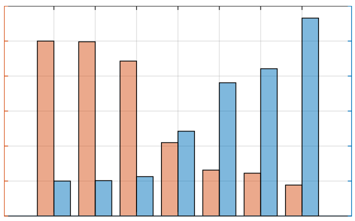
Current consumption of the data logger (DUT) was measured using the Otii Arc Pro power profiler. A dedicated ESP32-S3 was used as the receiver for ESP-NOW transmissions.



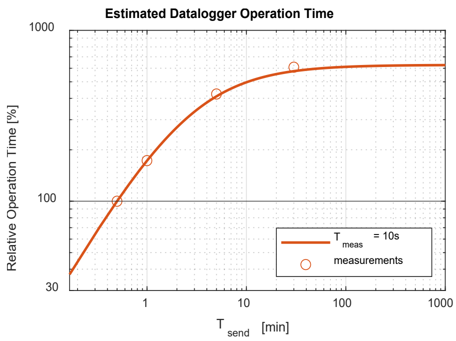
Power profile of a data logger wake cycle running the baseline firmware, with different colors indicating individual firmware segments. The extended plateau phase reflects prolonged busy-waiting and hardcoded delays, which were targeted for optimization in the low-power firmware variants.

	I_{avg} [µA]	E_{rel}[%]
Arduino (Baseline)	796	100.00
V0: SW Port	793	99.62
V1: SW Refactoring	705	88.57
V2: ADC Sequencer	334	41.96
V3: ULP	209	26.26
V4: ULP SW SPI	195	24.50
V5: FW Optimization	141	17.71

Summarized numerical results of the energy measurements across all variants. E_{rel} denotes the relative energy consumption compared to the currently deployed Arduino baseline variant.



Graphical representation of the results, including an illustration of the relative operation time compared to the baseline variant.



Theoretical logger operation time for modified send intervals, relative to the configuration with T_{send} = 30s.

Task Definitions

To simplify data acquisition for pinch analyses, the Institute of Mechanical Engineering and Energy Technology (IME) developed a portable measurement case equipped with sensor devices for temperature and volumetric flow rate measurements. The temperature data loggers are powered by NiMH rechargeable batteries and enable autonomous measurements at non-instrumented and hard-to-access locations. Wireless data transmission via the ESP-NOW protocol eliminates the need for cabling.

In the current system configuration, the temperature data loggers operate for up to 117 days before battery recharging or replacement is required.

To reduce maintenance effort and enable long-term measurements, this thesis focused on optimizing the energy consumption of the temperature data logger. The objective was to achieve a minimum operational lifetime of one year without compromising system functionality or modifying the power supply. In addition, the influence of the temperature measurement interval and the data transmission periodicity on overall energy consumption was investigated.

Methodology

Energy consumption was reduced through a comprehensive redesign of the ESP32-S3 firmware. Baseline energy measurements of the original firmware motivated the development of several iterative low-power variants. After porting the firmware to ESP-IDF and refactoring the software architecture, the ultra-low-power (ULP) core of the ESP32-S3 and the sequencing capabilities of the external MAX11410 analog-to-digital converter were successively integrated. This approach enabled autonomous measurements while offloading tasks from the main processor and significantly reducing active time.

Results

Energy consumption was reduced stepwise across the developed firmware variants. Under baseline measurement conditions, the final low-power variant achieved an average current consumption of 141 µA, corresponding to a 5.65-fold reduction compared to the original Arduino-based firmware. This resulted in a theoretical operating lifetime of over 1.8 years, exceeding the initial target of one year.

Further reductions were achieved by adjusting measurement and data transmission intervals. Increasing the transmission interval from 30 s to 5 min reduced energy consumption by more than 70 %. By combining the optimized firmware with longer transmission intervals, multi-year operating lifetimes become feasible. For example, with a measurement interval of 10 s and a transmission interval of 5 min, a theoretical operating lifetime of nearly six years can be achieved.

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