technische universität dortmund

computer science 12

Master Thesis

FreeRTOS-Based Dynamic Energy-Aware Scheduling on Microcontroller Platforms

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In battery-powered or energy-harvesting embedded systems, the energy consumption of the software determines the lifetime of the device, while the system still has to meet its real-time requirements. Two mechanisms are commonly used to reduce the energy consumption. Dynamic Voltage and Frequency Scaling (DVFS) lowers the clock frequency and the supply voltage of the processor, which reduces the power draw but increases the execution times. Dynamic Power Management (DPM) switches the processor to a low-power state while it is idle. Many scheduling algorithms combine these mechanisms with timing guarantees, and Bambagini et al. give an overview of them [1]. Most of them are, however, only evaluated in simulation using simplified power models, and they require information that a real system first has to obtain, for example the power consumption of a single task. Suitable algorithms therefore have to be implemented and evaluated on real hardware, and adaptations that fit the concrete platform have to be developed.

For example, an ESP32-S3 offers several mechanisms for this purpose. It can run at 80, 160, or 240 MHz, gate the clocks of individual peripherals, and enter light or deep sleep. Each transition between these states costs time and energy, so a sleep state only saves energy if the idle interval is long enough, and lowering the frequency is not always better than finishing the work early and sleeping afterwards. FreeRTOS[1] provides the required functionality, such as tickless idle and the trace macros, but the application has to decide when to change the frequency or to enter a sleep state.

Preliminary work in our group has shown that the necessary information can be obtained on the platform itself (Figure 1). There, a current sensor board is read over I^2C and the measured values are mapped to the running task with the FreeRTOS trace macros, which allows the energy consumption of individual tasks to be computed at runtime.

In this thesis,[2] the student should implement and evaluate dynamic energy-aware scheduling that minimizes the energy consumption of an ESP32 microcontroller without violating the timing requirements of the task set. First, the student should get familiar with the platform, FreeRTOS, and the available power states, and set up a system that assigns the measured energy consumption to individual tasks at runtime. The hardware setup is not fixed, but the existing measurement setup can be reused.

Then, a selection of energy-aware scheduling algorithms should be adapted to the platform, i.e., to its discrete frequency levels, its sleep states, and its transition overheads, and implemented in FreeRTOS. Afterwards, the algorithms

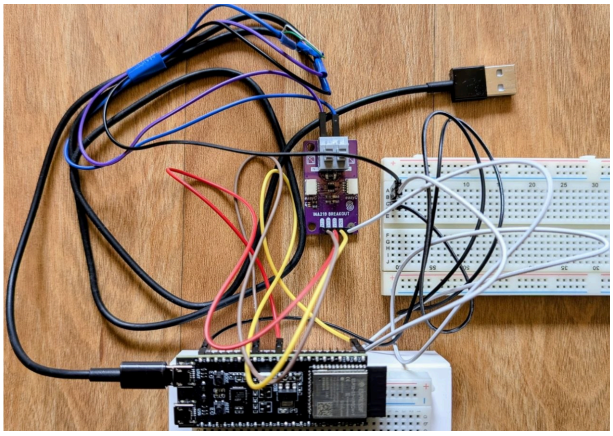

Figure 1: An example measurement setup used to determine the energy consumption of individual tasks.

should be optimized further, for example by using the measured energy consumption instead of worst-case assumptions. In addition, general optimizations such as tickless idle, clock gating, or moving periodic work to a low-power coprocessor, for example the one present in an ESP32-C6, should be examined.

Finally, the implemented approaches should be evaluated with an external high-precision DC power analyzer, both for the energy consumption and for the timing behavior. Optionally, the approaches can be ported to an MSP430, whose low-power modes differ from those of the ESP32, to determine which of the design decisions can be made platform-agnostic.

Required Skills:

- Knowledge of low-level C programming
- Knowledge of embedded systems

Acquired Skills after the thesis:

- Knowledge about firmware development for microcontrollers and internals of real-time operating systems.
- Knowledge about energy-aware scheduling and power management on real hardware.

References:

[1] M. Bambagini, M. Marinoni, H. Aydin, and G. C. Buttazzo, "Energy-aware scheduling for real-time systems: A survey," *ACM Trans. Embed. Comput. Syst.*, vol. 15, no. 1, pp. 7:1–7:34, 2016. [Online]. Available: https://doi.org/10.1145/2808231

[1] `https://www.freertos.org`

[2] Other suggestions and related topics are also welcome. Please do not hesitate to make an appointment.