HAQSS: High-precision Adaptive Quantization Based on Sensor's Specification

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Variable quantization in embedded systems is an effective technique for enhancing the performance of floating-point computations by converting them to fixed-point representations, particularly on microcontroller units (MCUs) that lack a floating-point unit (FPU). However, the most straightforward and naive method - simply rounding floating-point values to a commonly used integer type (e.g., *i*32) - typically results in substantial precision loss.

Previous research has proposed specialized techniques that determine fixed-point bitwidths based on profiling the approximate range of specific variables. While this method can improve precision, it requires multiple redundant profiling runs and may fail when outliers exceed the profiled range. In distributed sensor network systems, studies [2] and [3] estimate bounds of signals through the network using historical transmission data to inform bitwidth selection. On standalone embedded devices, [1] gathers variable ranges by inserting profiling code and analyzing the LLVM intermediate representation (IR). However, these profiling-based approaches introduce practical limitations, including redundancy and potential inaccuracies caused by unanticipated outliers. CoSense [4] offers a more robust alternative by extracting precise and reliable range information directly from sensors' datasheets. Building on this idea, we developed a high-precision adaptive quantization method that eliminates the need for redundant profiling while achieving a superior balance between precision and performance.

In this paper, we present **HAQSS**, a novel system that performs lossless (or nearly lossless) quantization by leveraging sensor specifications - specifically the **RANGE** and **PRECISION** parameters - from datasheets. HAQSS significantly enhances execution speed and reduces energy consumption without compromising accuracy, which is particularly crucial in high-precision environments.

We evaluated HAQSS using the Madgwick Filter as a representative real-world application on a development board featuring a Cortex-M0+ MCU. Our results demonstrate up to **1.77× speedup** in end-to-end execution time and a **20.03% reduction** in energy consumption, with signal-to-quantization noise ratio (SQNR) reaching up to **70.39 dB**. We believe that HAQSS offers a promising direction for embedded system optimization and provides system designers and researchers with new methodologies for precision-aware performance tuning.

Additional Key Words and Phrases: Embedded Systems, Sensors, Quantization, Performance, Precision

References

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